

Proceedings of the International Conference on Innovation - driven Knowledge Economies and Transformation in the Global South

Proceedings of the International Conference on Innovation - driven Knowledge Economies and Transformation in the Global South

Volume IV

The Green Economy and Financing Innovation: Low Carbon Innovations, Environmental technologies and Renewable Energy

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Preface / A word of welcome and thanks

It is a matter of great pride that the 20th-anniversary Globelics International Conference is being held in Thiruvananthapuram. This conference deliberates on an issue of much contemporary relevance – Innovation-driven Knowledge Economies and Transformation in the Global South, which is at the centre stage of development strategy both at the national and that of the government of Kerala. In 2006, when inclusive development was a major issue of global concern, Globelics conference was held in Trivandrum and deliberated on Innovation Systems for International Competitiveness and Shared Prosperity.

This Conference intends to bring together scholars across disciplines from over 50 countries to pool together experiences and expertise to reflect on varied issues involved in the process of transforming developing economies into sustainable, resilient, and inclusive innovation-driven knowledge economies.

In the conference, to be inaugurated by Shri Pinarayi Vijayan, the Hon'ble Chief Minister of Kerala, scholars of eminence will join as keynote speakers and panelists in plenary sessions and special sessions. The conference, organized in nine parallel tracks, will also have book presentations, excursions, and cultural events. As part of the conference, about 20 leading scholars from Globelics will visit different universities and colleges in Kerala to deliver lectures and interact with faculty and students, which is facilitated by Kerala Higher Education Council and Kerala Economic Association.

We welcome with great appreciation the Honourable Chief Minister Shri Pinarayi Vijayan and all the dignitaries who joined us for the inaugural address and eminent scholars delivering keynotes and addressing in different plenary sessions, special sessions, and parallel sessions. While the invisible hand of our honourable Chief Minister is there in all the important initiatives of GIFT, this program has been ably guided and steered by our Chairperson Shri K N Balagopal, Hon'ble Finance Minister of Kerala.

This important event is the outcome of the collective effort of all those involved, especially the Co-organising institutions: RIS, New Delhi, who inter alia managed the political clearance from the Ministry of External Affairs, IIM Bangalore, K DISC and the Digital University of Kerala. Our partnering institutions, ICSSR, Kerala State Higher Education Council, Centre for Development Studies, Kerala Economic Association, and the Centre for Latin American Studies also have been helpful in organising this conference.

With much appreciation for all of you for being with us, we welcome you

K J Joseph

For the local organising Committee

About the 20th Anniversary Conference

The central theme of the 20th Anniversary Globelics International conference is Innovation-driven Knowledge Economies and Transformation in the Global South.

This conference intends to bring together scholars across disciplines from over 50 countries to pool together experiences and expertise to reflect on varied issues involved in the process of transforming developing economies into sustainable, resilient, and inclusive innovation-driven knowledge economies. Episodes of development in economic history highlight the successful experience of countries that have managed to harness Learning, Innovation and Competence-building Systems at the global, national, subnational and sectoral levels in order to transform their social and economic structures for achieving prosperity. In the current times, the constellation of innovations driven by rapid advances in digital technologies has given rise to a new technological revolution, commonly referred to as the fourth industrial revolution, or Industry 4.0, with profound impacts on all sectors of the economies and sections of societies. New and persisting developmental challenges have driven a renewed interest in different types of innovations that highlight their impact on society and the natural environment, such as inclusive innovation, responsible innovation, transformative innovation, grassroots innovation and Jugaad. At the core of all these approaches is how knowledge, both science-based and experience-based, is harnessed for addressing development challenges, the basic premise being “the knowledge divide is at the root of the development divide”

At the current juncture, wherein globalization is at the crossroads, the economies across the world, ravaged by the once-in-a-century pandemic and external shocks, consider strengthening the innovation system as a strategic approach towards building resilience. Evidently, there is an across-the-board drive among developing countries to transform their economies into innovation-driven knowledge economies. Such a transformation is often viewed as capable of building resilience by addressing many of the downsides of globalization-induced high growth, like excessive exploitation of exhaustible resources and accentuated divides within and between countries. Such

initiatives in India are manifested, among others, in Atal Innovation Mission (AIM), Digital India, Skill India, and Make in India and other concerted efforts to transform India into an innovation-driven knowledge economy. It is also in sync with the national agenda of harnessing Science, Technology, and Innovation (STI) to achieve sustainable development. The choice of the location of the conference is inspired by Kerala's strategy towards transforming the state into a knowledge economy, as explicitly stated in the budgets starting with 2020-2021 and the subsequent concerted efforts that followed. It is in this background that Globelics revisits India for the 20th Globelics International conference with the chosen central theme: 'Innovation-Driven Knowledge-Economies and Transformation in the Global South'.

The 20th Anniversary Globelics is also an occasion to celebrate the journey of Globelics from Brazil 2003 to India 2023 and its varied achievements. At the same time, it is also a forum for critically reflecting on our perspective and the approaches *inter alia* in terms of its achievements and limits. This is especially important at the current juncture wherein there is growing disenchantment with the development experience under globalisation on the one hand and the need on the other hand, for reimagining innovation systems in the COVID and Post COVID world towards building the much needed resilience in the South.

Globelics-India 2023 coincides with India's Presidency of G-20 that *inter alia* aims at influencing the development dynamics of Global South and it is an appropriate time for translating the insights of the conference with respect to strengthening Learning, Innovation and Competence-building Systems (LICS) into policy action. For the past two decades, we have observed an increasing influence of Global South in shaping the paradigms and trajectories of the global development agenda—sustainability, climate change, pandemic, and energy security issues—with India playing a key role; all being closely linked to the research domains of the Globelics.

World-leading scholars are set to give this year's keynote address on innovation and development. It is planned that the conference will be inaugurated by the Chief Minister of Kerala and there will be a special keynote on the conference theme along with a Globelics Lecture and Freeman Lecture. The conference will combine plenary sessions, presentations of research papers in parallel tracks, thematic panel sessions or special sessions, poster presentations, book presentation sessions, excursions, and cultural events.

Conference Tracks

While submissions on the central theme of the conference have been especially encouraged, submissions on all the issues conventionally deliberated in the Globelics international conferences are also included. Submissions have been organized around the following themes:

1. Science, technology, innovation: Theory and policy for a knowledge economy
2. Transformative innovation, responsible innovation and mission-oriented innovation
3. Knowledge-driven development of national, regional, local and sectoral innovation systems, including Agricultural innovation systems and rural development
4. Measurement of the knowledge economy: Indicators, data requirements, different approaches and methodologies
5. Skilling for the knowledge economy: Industry-academy interaction, Intellectual property rights, open innovation and development
6. Industry 4.0 and development: Digitalization and automatization, productivity and employment implications, gig economy and quality of employment
7. Economic and social upgrading for sustainable Catch-up: trade policies, FDI, value chains and innovation networks in a knowledge-driven economy
8. Innovation for inclusive development: Indigenous knowledge, Grassroot innovations, Jugaad, informal economy, micro and small enterprises
9. Entrepreneurship, employability and gender dimension in innovation and development
10. The green economy and financing innovation: Low carbon innovations, environmental technologies and renewable energy

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Effect of irrigation with indirectly recharged groundwater using recycled water on soil and crop in semi-arid areas

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Abstract

The reuse of wastewater for irrigation has been considered as an alternative to alleviate the pressure on freshwater resources in arid and semi-arid regions. Poor water quality of wastewater can carry the risk of soil salinity, accumulation of heavy metals, emerging and persistent inorganic pollutants, and microbial contamination limiting its agricultural reuse. To address these issues the present study introduces the use of indirectly recharged groundwater (GW) using municipal secondary treated wastewater (STW) for irrigation. The main aim of the study was to assess the quality of indirectly recharged GW and its impact of irrigation on soil properties as well as on the crops in impacted areas receiving recycled water in comparison with non-impacted areas (not receiving recycled water). Physicochemical and microbiological properties were monitored in STW, indirectly recharged GW and soil. The presence of water-borne pathogenic species such as *Shigella* and *Klebsiella* was also monitored along with total coliform and *E.coli* (as indicator organisms) in a few of the harvested crops using standard culture methods. The quality of indirectly recharged GW in impacted areas significantly improved when compared to the quality before the recycling as hard water turned into soft water as a factor of dilution. Significant differences were not observed with respect to the physicochemical and microbiological properties of the soils irrigated with indirectly recharged GW in comparison with soils irrigated with non-impacted GW, except for electrical conductivity (EC) and sodium adsorption ratio (SAR), which were reduced by 50% and 50% in soil irrigated using indirectly recharged GW. None of the

harvested crops recorded the presence of pathogenic bacteria. The parameters analyzed indicated that indirectly recharged GW using STW was a better and safe alternative source for irrigation compared to using direct treated wastewater drawn from deep aquifers.

Key Words: Crops, Freshwater scarcity, indirect groundwater recharge, Recycled water, Soil Aquifer Treatment

1. Introduction

Groundwater (GW) depletion is a new global issue as its demand is higher than its natural replacement which has resulted in a major threat to drinking water supplies and irrigated agriculture (Dangar et al., 2021; Dalin et al., 2017). It is estimated that by 2050 the demand for GW would reach 1180 billion cubic meters (Veeranna and Jeet, 2020). Thus, effective long-term management strategies in order to prevent future depletion and deterioration are being explored. Emphasis has been placed on the use of non-conventional water sources. The reuse of wastewater for irrigation purposes reduces the amount of water that needs to be extracted from other freshwater resources (Grinshpan et al., 2021; Bedbabis et al., 2014; Singh et al., 2012). It also reduces pressure on wastewater management, as it utilizes a huge volume of wastewater produced in cities. Wastewater commonly contains a high amount of plant nutrients and thus reduces the need for costly inorganic fertilizers and enhances soil fertility and crop production which has been explored by many researchers (Zolti et al., 2019; Farhadkhani et al., 2018; Goldstein et al., 2014; Assouline and Narkis, 2013). Table 1 represents a list of studies reporting the reuse of wastewater, its potential advantages, disadvantages, and knowledge gaps.

Table 1. Indirect reuse of wastewater for irrigation and its impact on soil and Crop

S. No.	Type of wastewater	Location	Duration (years)	Impact on Soil and Crop Properties	Remark	References
1.	Untreated wastewater (Domestic+Industrial)	Egypt	30	- Raw wastewater used for irrigation had higher heavy metal concentrations compared to freshwater but were within permissible limits with the exception of Cd concentration. - Soils irrigated with wastewater over the long term contained significantly higher concentrations of heavy metals (Cd & Pb) compared with freshwater but were within the permissible limits.	Need for the development of a strategy for the use of wastewater in irrigation for sustainable agricultural management.	Alnaimy, et al., 2021
2.	Untreated wastewater (Domestic+Industrial)	India	10	Pseudomonas resistance against amoxicillin.	An alternative source for freshwater with proper monitoring as there is a risk of antimicrobial resistance.	Shafiani and Malik, 2003

3.	Untreated wastewater (Domestic+Industrial)	Iran	20	• 20–30% increase in organic matter content of the soil. • Increase in pH by 2–3 units. • Accumulation of heavy metals (Pb and Ni) in topsoil • Contamination of some vegetables (spinach and lettuce) with Cd. • Accumulation of Ni and Pb in wheat crop.	Strict protection measures, stringent guidelines, and an integrated system for the treatment and recycling of wastewater is needed.	Qishlaqi, et al., 2008
4.	Untreated wastewater (Municipal)	Mexico	6-8	• Reported antimicrobial resistance for sulphonamide and fluoroquinolone.	Need for precautionary actions for farmers and consumers.	Dalkmann et al., 2012
5.	Secondary treated wastewater (Industrial)	Switzerland	0.6	• Treated wastewater quality was inadequate with high sodic and alkaline values. • Resulted in structural changes in soil with collapsed pore network. • Soil became sodic with an accumulation of high sodium and bicarbonates.	Careful examination of water quality before irrigation is important to reduce soil quality degradation and health hazards.	Sou et al., 2013

6.	Secondary treated wastewater (Municipal+Industrial)	Italy	1.5	• Significant increase in NH₄-N, Na⁺, SAR, and EC in soil irrigated with STW. • No significant effect on the qualitative traits of the crop - except for Na⁺ and NO₃. • High levels of E.coli were observed in STW but E.coli was not identified in soil and crop	The reuse of treated industrial wastewater for irrigation can be considered an effective way to cope with agricultural water shortage.	Libutti et al., 2018
7.	Secondary treated wastewater (Municipal+Industrial)	Iran	10	• Wastewater used for irrigation had Cd and Cu concentrations above tolerable limits. • Soils showed a high load of Zn, Cd, Cu, and Ni following irrigation with wastewater. • Cd was detected as the element of the highest risk in the soil-wheat system in the area. • The bio concentration and translocation factors of wheat showed that heavy metals quantitatively accumulated in the roots and	Specific attention should be directed towards continuous monitoring and development of appropriate strategies to reduce heavy metal-induced health risks by treated wastewater irrigation.	Rezapour et al., 2019

				were poorly translocate to the grains • Except Cd, mean values of hazard quotient (HQ) were within the safe limit (b1). • The HQ value of Cd exceeded 1 for both children and adults, indicating a high health hazard for the whole exposed population by this metal.		
8.	Secondary Treated wastewater	US A	10	• Marginal high sodium adsorption ratio (SAR) and EC in soil irrigated with STW when compared to control (soil irrigated with freshwater) but the tested soils were in good health as all the values (pH, SAR, and EC) were within the permissible range indicating low sodicity and salinity of the soil.	Treated wastewater is a viable substitute for freshwater irrigation in semiarid and arid regions.	Tahtouh, et al., 2019
9.	Secondary Treated wastewater	Iran	1	• STW has a high concentration of E.coli as per WHO recommendation for the reuse of	Secondarily treated wastewater can safely be used as	Farhad khani, et al., 2018

				treated wastewater. • No significant effects on other physicochemical properties of the soil except for increased EC and SAR of soil. • None of the studied pathogens (<i>E. coli</i> O157, <i>Salmonella</i>, and <i>Shigella</i>) were detected in soil and harvested crops.	an alternative source for irrigation.	
10.	Secondary Treated wastewater	Egypt	Not specified	• Improvement in the physicochemical properties of the soil, crop yield along with nutrient status.	Proper management and use of domestic wastewater for agricultural purposes is a viable option.	Abdel-Aziz, et al., 2015
11.	Secondary Treated wastewater	Tunisia	4	• Significant increase in OM, SAR, and EC were observed in the soil as STW has a high level of salinity and chloride (above than threshold).	STW is a reliable water and nutrient source for crops.	Bedbabis, et al., 2014
12.	Secondary treated wastewater	India	1	• No significant effects apart from, slight changes in salt solubility and alkalinity.	The use of treated wastewater could increase water	Singh, et al., 2012

					resources for irrigation which may prove to be beneficial for agricultural production.	
13.	Secondary treated wastewater	Italy	1	• No impact of heavy metals on soil and the harvested crop. • No E.coli was found on the studied crops.	The results are promising for the use of STW, especially for drip-irrigated crops.	Perulli et al., 2021

The studies discussed in Table 1 suggest that the direct use of untreated or secondary treated wastewater (mixed with industrial effluent) used for irrigation can be a viable option for conserving freshwater resources (Alnaimy, et al., 2021; Shafiani and Malik, 2013; Dalkmann et al., 2012; Qishlaqi, et al., 2008). However, the use of poorly treated wastewater for irrigation can lead to the accumulation of a wide range of contaminants such as heavy metals, pathogens, and other organic compounds, which can adversely affect soil properties and crop growth. The analysis of the literature reported above revealed that poorly treated wastewater resulted in high SAR, EC, and soil salinity due to the accumulation of salts in the soil as water containing high salts evaporates and deposits in the soil (Rezapour et al., 2019; Tahtouh et al., 2019; Libutti et al., 2018; Bedbabis et al., 2015; Sou et al., 2013). There is also a growing risk and concern regarding pathogen contamination of soil irrigated with poorly treated or raw wastewater (Shafiani and Malik, 2013). These accumulated contaminants may lead to GW contamination, can translocate to crops, and may affect the crop quality and potentially harm the health of those consuming it (Khan et al., 2015).

Studies have also reported unpleasant odors which have negative effects on local communities and tourism (Jeong et al., 2016; Keraita et al., 2008). Therefore, it is essential to control the mixing of industrial effluent with municipal wastewater through updated wastewater management techniques and also to use wastewater after proper treatment for irrigation purposes. Table 1 also reports a few studies where adequately treated wastewater has no adverse impact on soil and crop quality and has confirmed that treated wastewater sources can be safely used as an alternative source of freshwater for irrigation under sustainable agricultural management in semi-arid regions (Perulli et al., 2021; Tahtoh et al., 2019; Farhadkhani et al., 2018; Abdel-Aziz et al., 2015; Bedbasis et al., 2014). These practices still require strict precautionary actions and regular monitoring. In summary, to avoid these negative impacts the present study provides an alternative by indirectly recharging GW (IRGW) using STW and using this recharged GW for irrigation.

Indirectly recharged GW refers to the process of replenishing GW by allowing surface water/treated wastewater to infiltrate into the ground, where it can percolate downward and recharge the underlying aquifers (Alam et al., 2021). Indirectly recharged GW using treated wastewater however is a promising method for improving water availability in water-stressed and drought-prone areas (Gharoon and Pagilla, 2023). The benefits associated with this method include reducing wastewater discharge into natural water bodies, replenishing the depleted aquifers along with higher availability of water for irrigation (Levantesi et al., 2010).

Such an indirect GW recharge scheme using recycled water was initiated in March 2018 at Kolar district of Karnataka, India which is a semi-arid and drought-prone area. The GW recharge project is based on the concept of soil aquifer treatment (SAT) technology which is one of the artificial GW recharge methods under managed aquifer recharge (MAR) which aims to intentionally infiltrate, and recharge aquifers (Manisha et al., 2023). MAR is a dynamic approach that can utilize different water sources in order to sustain the recharge system. Soil aquifer treatment (SAT) is a unique MAR technology that utilizes treated wastewater (TWW) as source water (Alam et al., 2021; Grinshpan et al., 2021; Yaraghi et al., 2019). During this process, SAT upgrades the quality of wastewater when it passes through soil. As wastewater percolates through the vadose zone while being subjected to various physicochemical and microbiological contaminant removals mechanisms, such as physical filtration, biodegradation, adsorption, chemical precipitation, ion exchange, and dilution (Grinshpan et al., 2021). SAT is a globally practiced and adopted technique that has been successfully implemented in the USA (Sharma and Kennedy., 2017); Australia (Dillon et al., 2016); South Africa (Tredoux et al., 2012); Spain (Escalante et al., 2009); and Israel (Icekson-Tal et al., 2003). The performance of SAT system is site-specific and is dependent on wastewater quality, soil type,

and hydrogeology hence a preliminary study is required to bring out reproducible results (Idelovitch et al., 2003).

As per the authors' knowledge, there are very few full-fledged studies available that provide an understanding of the impacts of indirectly recharged GW using treated wastewater on soil properties in a semi-arid region. Thus, the focus of this study is to quantify the impact of large-scale recycling of STW for indirect GW recharge on soil properties, with specific objectives:

i) to determine the impact on GW level and quality ii) to determine the impact on physicochemical properties, and microbial load of soil and iii) to determine the microbial load on root crop (beetroot), vegetable crop (tomato as a seasonal crop), and as high-risk leafy vegetable (spinach) in a semi-arid area. The impacts were quantified by comparing the changes in the impacted locations (i.e., regions influenced by STW) with that of the non-impacted locations (i.e., regions not influenced by STW) of Kolar, and a comparative study was also carried out between pre-and post-recycling period of the impacted areas.

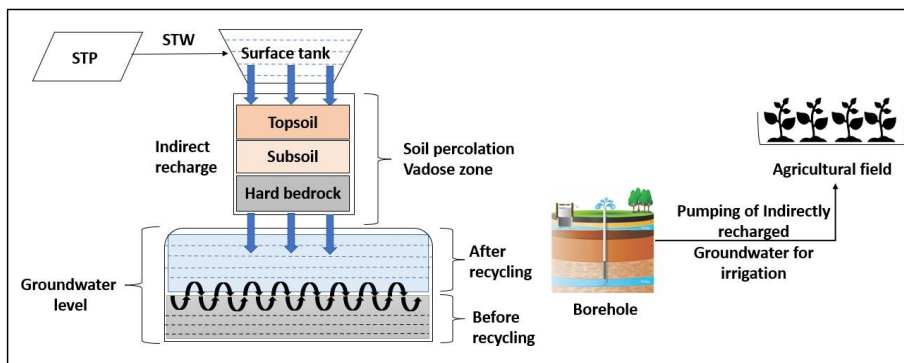


Fig 1. Indirect recharge of groundwater using secondary treated wastewater and its use in irrigation

2. Materials and Methods

2.1 Study area

Kolar district is located in the southeastern state of Karnataka, India, approximately 70 km east of Bengaluru (Fig 2). The hydrogeological area of the district is classified as hard rock terrain with crystalline bedrock consisting of granite, gneisses, and schists (CGWB, 2020; GoK, 2016). The study was conducted in Kolar district (13.1367°N: 78.1292°E), which is situated at an elevation of approximately 900 meters above sea level and characterized by hot and semi-arid climatic conditions (CGWB, 2020; DEIAA, 2019). The average annual temperature is 24°C with an annual average precipitation of 650 mm.

The district is characterized by red loamy soil to red sandy and lateritic soil (CGWB, 2020; 2012). Kolar district was known for its ancient surface water reservoirs, commonly known as tanks which were the major source of water for irrigation (Manisha et al., 2023). Kolar district experienced severe water shortages due to continuous drought, declining rainfall, over-exploitation of GW, and inadequate water supply infrastructure during the last few decades. The surface tanks that store water were also deepened in order to address the water scarcity of the dryland areas with direct impact on agricultural productivity.

To overcome the issue of continued drought, the Govt. of Karnataka along with the Minor Irrigation Department and BWSSB initiated Koramangala and Challaghatta (K&C) valley project, a large-scale indirect GW recharge project (Manisha et al., 2023). The project aimed to fill existing surface tanks (137) using STW coming from the two sets of STPs located in Bengaluru. The water from rejuvenated tanks is allowed to percolate into the soil through recharge wells and trenches, where it has replenished the GW table from 2018 (Manisha et al., 2023).

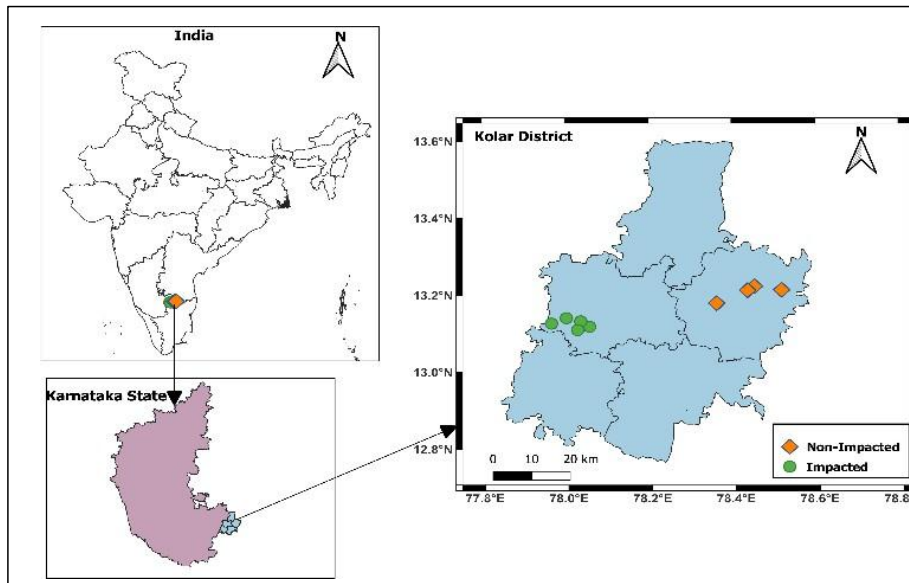


Fig 2. Study area to assess the impact of indirectly recharged GW on soil properties

2.2.1 Site Specifications

To study the impact of STW recycling on GW recharge, water quality, soil properties, and microbial distribution of harvested crops four different sites were identified from impacted and non-impacted areas. Table 2 provides details of all eight sites selected for GW, soil, and crop sample collection. The impacted sites were within the range of 10 km from the discharge point (DC) which is the receiving point for secondary treated wastewater pumped from STP. STW is pumped to all 137 surface tanks from the DC point. The

nonimpacted areas are comparatively far away (40 to 60 Km) from the DC point and have only rain-fed water as the only source of recharging GW. The radial distance of the eight sites is almost the same from their nearby tanks in impacted and non-impacted areas to maintain uniformity.

Table 2. Groundwater and soil sampling locations

Sample ID	Sample name	Location		Radial Distance from DC point (km)	Radial Distance from nearest lake(km)	Water Levels (mbgl)
Impacted						
1.	A	13°07'26.7"N	77°57'46.7"E	0.2	0.2	19.4
2.	B	13°08'16.4"N	77°59'55.8"E	4.3	0.1	19.1
3.	C	13°07'45.3"N	78°01'59.3"E	7.7	0.5	25.6
4.	D	13°06'54.3"N	78°03'15.1"E	10.1	0.05	25.4
Non-impacted						
5.	E	13°10'20.8"N	78°21'32.4"E	43.4	0.4	58.1
6.	F	13°12'18.6"N	78°26'00.6"E	51.9	0.2	86.8
7.	G	13°12'55.2"N	78°27'00.1"E	53.9	0.1	87.4
8.	H	13°12'18.8"N	78°30'54.0"E	60.6	0.05	53.8

(Note: mbgl: meters below ground level)

2.3 Sampling and data collection

2.3.1 Characterization of secondary treated wastewater and surface tank water
The STW samples from STP and water samples from surface tanks receiving STW were collected and analyzed following the standard methods (APHA, 2005). Water quality parameters were compiled with the most stringent surface water discharge standards as prescribed by India's Hon'ble National Green Tribunal (NGT, 2019). All the eight water quality parameters as per the Hon'ble NGT standard namely pH, biological oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), and ammonical nitrogen (NH₄-N), phosphate phosphorus (PO₄-P) and fecal coliform were determined. In addition to these specific parameters, the STW and surface water quality were also tested for other water quality parameters including heavy metals using ICPMS (Quadrupole ICPM- Thermo X series II) and total coliform count. The presence of total and fecal coliform was determined using the spread plate technique as described in standard methods (APHA, 2013). All the water samples were tested in triplicates and average values along with standard deviation are presented as avg.±std. dev.

2.3.2 Groundwater level and quality

Historical data on GW levels (2013 to 2022) and water quality (2015 to 2022) of all the selected sites (impacted as well as non-impacted) were obtained from the Karnataka Ground Water Authority (KGWA) and precipitation data were obtained from the Karnataka State Natural Disaster Monitoring Centre

(KSNDMC). The parameters studied for GW quality analysis were pH, EC, hardness, total dissolved solids (TDS), sodium adsorption ratio (SAR), chloride (Cl⁻), fluoride (F⁻), nitrate (NO₃⁻), potassium (K⁺), calcium (Ca⁺), magnesium (Mg⁺) and sodium (Na⁺). For total, and fecal coliform analysis GW samples were collected from the selected sites of impacted and non-impacted areas in triplicates and were tested using specific agar media following spread plate methods as per Standard Methods (APHA, 2013).

2.3.3 Characterization of Soil

The composite surface soil samples (0-30 cm) were collected from the identified impacted and non-impacted sites. Samples were collected, air-dried ground to pass through 2 mm sieve, and stored in plastic bags before analysis. The samples were analyzed for different physical, and chemical properties such as soil texture, pH, EC, organic carbon, available nitrogen, available potassium, available phosphorus, sodium adsorption ratio, and other micronutrients as per the standard procedure (Abegunrin et al., 2016; Pansu and Gautheyrou, 2006).

The microbiological analysis of the soil samples is important to understand the diversity of soil microbial communities and their role in supporting plant growth and health along with potential public health risks (Mohan et al., 2021). The samples were sent to Eurofins Scientific Co. Ltd. (Bangalore, India) for DNA extraction, PCR amplification, and cluster generation and sequencing. The metagenomic DNA was isolated from the samples using the Nucleospin kit (BIOKE, Netherlands), and the quality of the isolated metagenomic DNA samples was analyzed using Nanodrop 2000 UV-vis spectrophotometer (Thermo Scientific, Wilmington, USA). The amplicon libraries were prepared using the Nextera XT index kit (Illumina Inc.) as per the 16S metagenomic sequencing library preparation protocol (Part #15044223 Rev.B). The primers used in the study were (synthesized at Eurofins Genomics) 16S rRNA F (GCCTACGGGNGGCWGCAG) and 16S rRNA R (ACTACHVGGGTATCTAATCC). The amplicon library was purified by AMPure XP beads and quantified using a Qubit fluorometer. The data analysis was conducted using the QIIME software platform provided by Eurofins Scientific Co. Ltd. (Bangalore, India).

The soil samples were also tested for the presence of other specific microbes such as *Escherichia coli* (E.coli), total coliform, and fecal coliform as indicator organisms and *Shigella*, and *Klebsiella* as pathogenic bacteria. The concentration of studied microorganisms was determined by the spread plate technique as described in Standard Methods (APAH, 2013).

The selective and differential media used and the appearance of tested bacterial colonies is listed in Table 3.

2.3.4 Microbiological analysis of harvested crops

To assess the impact of irrigation with indirectly recharged GW using recycled water, harvested crops like beetroot (root crop), tomato (seasonal crop), and one leafy vegetable (spinach) were selected which were irrigated with drip irrigation from both impacted and non-impacted GW. At least five plants were randomly selected and aseptically picked using disposable gloves. All samples were collected in sterile glasses or bags and immediately transferred to the laboratory for chemical and microbiological tests. For each crop, the edible parts of fresh plant samples were washed with tap water and the surface swab was taken for culturing in sterile distilled water (Pansu and Gautheryrou, 2006). Total coliforms and E.coli were monitored as indicator bacteria and a few common pathogens such as Shigella and Klebsiella (Water born bacteria) were monitored using the spread plate technique with specific differential media listed below in Table 3.

Table 3. Specific media for pathogen identification

Sl.No.	Specific differential media	Pathogen	Appearance (USEPA, 2002)
1.	Eosin methylene blue agar	E.coli, and total coliform	Green metallic sheen and Purple colored
2.	MacConkey agar	Klebsiella, Shigella	Mucoid dark pink and Light pink and translucent

(Note: Results reported based on the most probable number (MPN) of detected microorganisms per 100ml or 100 g of sample).

2.4 Data analysis

To understand the impact of indirect GW recharge on GW levels business as usual /linear forecast statistical method was used to predict the future value of GW levels as a dependent variable based on its relationship with independent variables (historical yearly GW level data). It assumes a linear relationship exists between the independent variable(s) and the dependent variable. The formula for linear interpolation is given by:

$$y = y_1 + (x - x_1) * (y_2 - y_1) / (x_2 - x_1) \quad \text{Eq. 1}$$

where y is the estimated value, x is the value being estimated, x1 and y1 are the coordinates of the first known data point, x2 and y2 are the coordinates of the second known data point. The formula for linear extrapolation (Mühlbach et al., 1987; Liu, 2006) is given below where y is the predicted value, x is the value being predicted, m is the slope of the line, and b is the y- intercept.

$$y = mx + b \quad \text{Eq. 2}$$

An independent student's t-test was also performed for GW and soil samples to verify the statistical significance difference in obtained data between impacted and non-impacted areas. The results are represented as follows: (a) NS (not significant) for $p > 0.05$, (b) significant for $*p < 0.05$, (c) and $**p < 0.01$ (Manisha et al., 2023). The percentage of change was determined to present the differences between pre-and post-recycling data of Kolar district by taking an average of 3 years for every group.

3. Result and discussion

3.1 Characteristics of secondary treated wastewater and surface tank water

The results of physicochemical and microbial quality testing of STW and surface tank water are presented in Table 4. It can be observed from Table 4 that STW and surface tank water meet the standards of NGT (except for fecal and total coliform) for disposal of the water into water bodies and for land disposal/applications (NGT, 2019). Given the risks of heavy metals on human health, heavy metals were also monitored regularly in the two types of water samples and it can be observed that the STW and surface tank water quality meets the existing drinking water standards BIS 10500 for heavy metals.

Table 4. Quality of secondary treated wastewater and surface tank water

S.No.	Parameters	NGT (2019)	STW	First surface tank water
1	pH	6.5-9.0	7.6 ± 0.8	7.6 ± 0.8
2	Temperature (°C)	NS	24 ± 2	26 ± 2
3	EC (dS m ⁻¹)	NS	2.4 ± 0.6	1.8 ± 0.2
4	Alkanity	NS	236 ± 12	158 ± 8
5	TSS	10	8 ± 1.5	6.8 ± 2
6	TDS	NS	1358 ± 36	880 ± 30
7	TOC	NS	285 ± 3	92 ± 1.6
8	Hardness	NS	450 ± 28	390 ± 15
9	HCO ₃	NS	290 ± 10	208 ± 6

S.No.	Parameters	NGT (2019)	STW	First surface tank water
10	BOD5 (@20°C)	10	8 ± 1.5	6.4 ± 0.6
11	COD	50	46 ± 2	42 ± 4
12	NH4-N	5	4.2 ± 0.4	2.8 ± 0.8
13	TN	10	7.4 ± 0.2	5.2 ± 0.4
14	SO4	NS	220 ± 15	107 ± 10
15	PO4-P	1	0.6 ± 0.1	0.4 ± 0.15
16	SAR (mEq/L)	NS	4.5 ± 0.4	4.2 ± 0.2
17	Ca	NS	108 ± 16	88 ± 15
18	Mg	NS	43 ± 8	21 ± 5
19	Na	NS	136 ± 19	82 ± 10
20	K	NS	25 ± 4	12 ± 1.8
21	Cl	NS	455 ± 18	207 ± 11
22	Fe	NS	0.3 ± 0	0.001 ± 0
23	Mn	NS	0.01 ± 0	BDL
24	Zn	NS	0.01 ± 0	BDL
25	Cu	NS	0.02 ± 0	BDL
26	Hg	NS	BDL	BDL
27	B	NS	0.017 ± 0	BDL
28	Fecal Coliform (CFU/100 mL)	<230	280 ± 25	240 ± 18
29	Total Coliform (CFU/100 mL)	NS	1430 ± 22	280 ± 14

(Note: All values are represented in mg/L except for pH, temperature, EC, SAR, and coliform NS: Not stated in the NGT (2019) recommended guidelines)

It may be concluded from the water quality analysis of STW that treatment systems are functioning to their near-ideal levels as the effluent quality meets the prescribed norms. Marginal significant improvement in surface tank (first tank to receive STW) water quality can be observed in terms of EC, alkalinity, dissolved solids, organic content, nitrogen species, and total coliforms as a function of natural filtration it has traveled a distance of 53 km through pipes with nearly residence time of 22 hours as well as accommodates natural variability from various causes. Common natural chemical reactions that can improve the quality of flowing water include oxidation/reduction reactions to remove organic pollutants, precipitation reactions for heavy metals (if any) and

phosphorous removal, neutralization reactions to reduce toxicity by maintaining pH, and a series of microbial actions which break down and remove pollutants from the water through a variety of chemical reactions. Results of Manisha et al., 2023; Rao et al., 2020; Mahmoodi et al., 2017 also demonstrated similar outcomes where a significant reduction in water quality such as EC, TDS, SAR, and SO₄ was observed in flowing water.

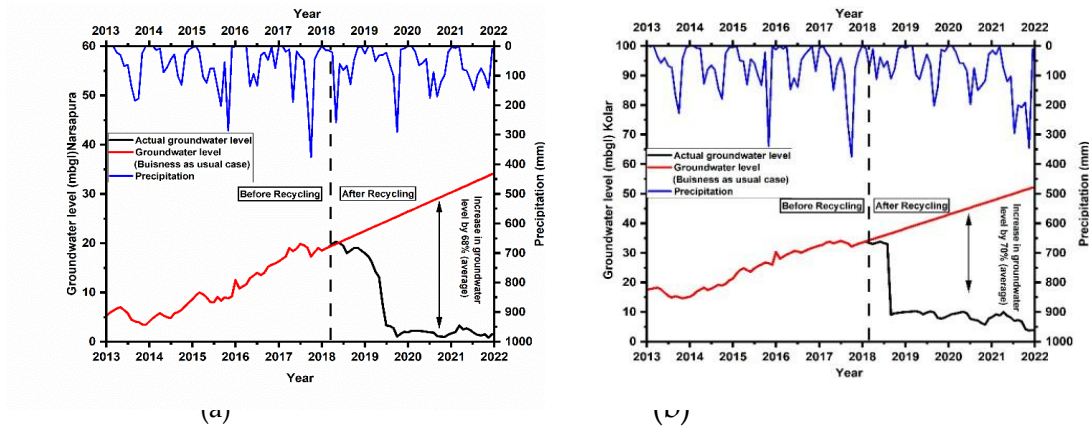
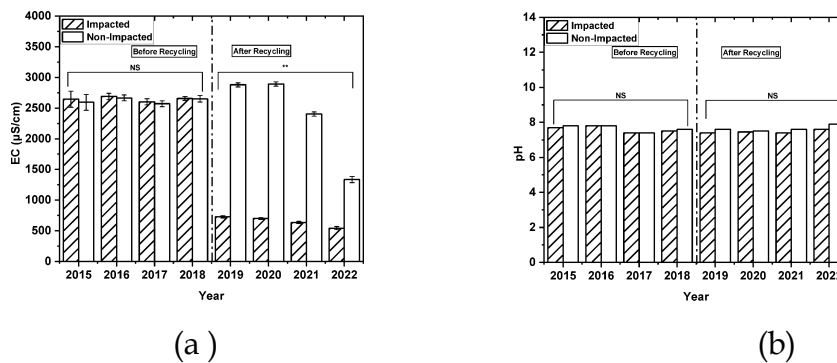
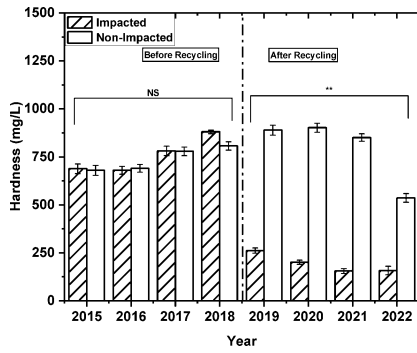


Fig 3. Impact of indirect groundwater recharge on groundwater level (Source: Precipitation data from KSNDMC and GW water level from KGWA and CGWB)

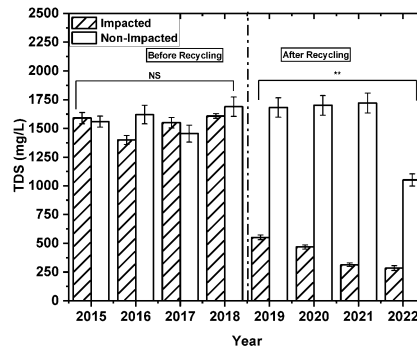
3.3 Impact of indirect groundwater recharge on groundwater quality

In order to ensure the safety and purity of GW and to prevent contamination, it is crucial to comprehensively assess and analyze the quality of indirectly recharged GW using STW. The changes in the quality of recharged GW in areas that have been impacted, as compared to non-impacted areas, are depicted in Fig. 4, 5, and 6. These figures demonstrate that there was no significant difference ($p > 0.05$) in the GW quality between impacted and non-impacted areas before the commencement of the recycling project (Before 2018). It is important to consider these findings when evaluating the efficacy of indirect GW recharge projects using recycled water





(c)



(d)

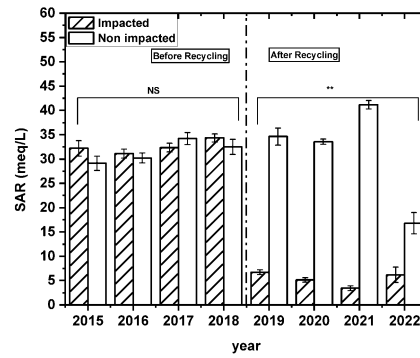
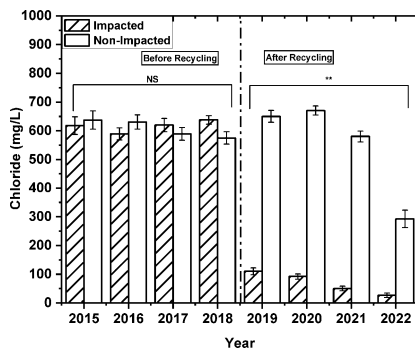
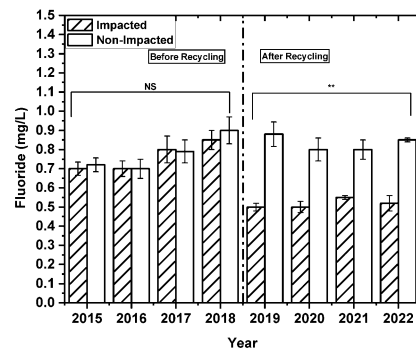


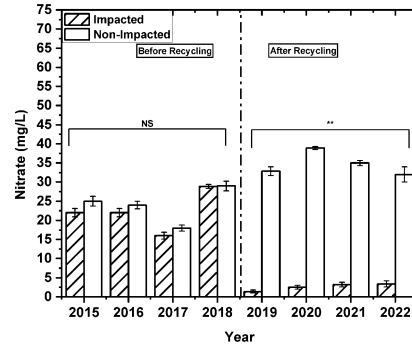
Fig 4. Impact of indirect groundwater recharge on groundwater Indirect groundwater recharge on quality (Physicochemical) (Note: Student's t-test value; (a)Before recycling (0.98),After recycling (4.69); (b)Before recycling (0.37), After recycling (1.89); (c)Before Recycling (0.37), After Recycling (6.64); (d)Before Recycling (0.64), After recycling (6.50); (e) Before recycling (0.74), After recycling (4.99), -NS- not significant for $p > 0.05$, $*p < 0.05$, $**p < 0.01$)



(a)



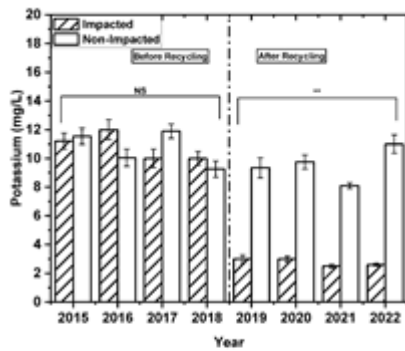
(b)



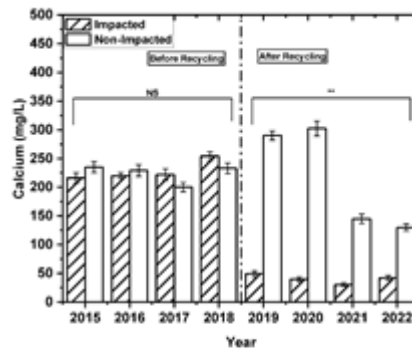
(c)

Fig 5. Impact of indirect groundwater recharge on groundwater quality (Anions)

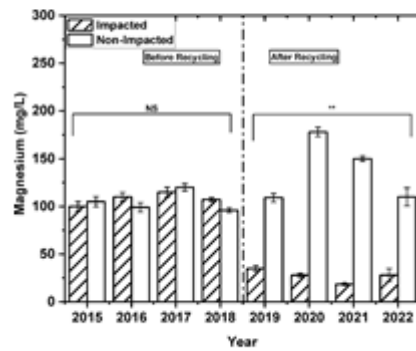
(Note: Student's t-test value: (a)Before recycling (0.46), After recycling (5.35); (b)Before recycling (0.16), After recycling (2.188); (c)Before recycling (0.50), After recycling (2.10); NS- not significant for $p > 0.05$, $*p < 0.05$, $**p < 0.01$)



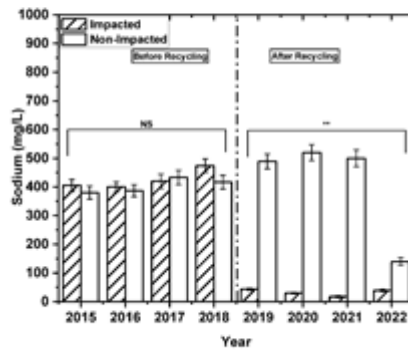
(a)



(b)



(c)



(d)

Fig 6. Impact of indirect groundwater recharge on groundwater quality (Cations)

(Note: Student's t-test value (a)Before recycling (0.14), After recycling (11.07); (b)Before recycling (0.31), After recycling (3.82); (c)Before recycling (1.032), After recycling (6.08); (d)Before recycling (0.97), After recycling (4.16), NS- not significant for $p > 0.05$, $*p < 0.05$, $**p < 0.01$)

It can be observed from Fig. 4 (physicochemical parameters), there is no significant change ($p > 0.05$) in pH of the GW when compared between impacted and non-impacted areas after the commencement of the recycling project. However, there was a significant reduction ($**p < 0.01$) in EC (97%), hardness (72%), TDS (68%) and SAR (84%) values. Additionally, Fig 5. represents a reduction in anion concentrations present in GW, with a significant decrease in chlorides (84%), nitrates (73%), and fluoride (41%). Fig 6. shows a reduction in cation concentrations, with a significant decrease in potassium (66%), calcium (82%), magnesium (75%), and sodium (93%). These results indicate that the recycled water from the surface tank, which infiltrated into the soil and percolated down to the underlying aquifer, diluted the hard water and improved its quality. Whereas it can also be observed from Fig 4, 5, and 6, that the GW of the non-impacted areas still remains hard with higher values of EC, hardness, TDS, SAR, and chlorides. Overall, a high degree of improvement in GW quality was achieved by allowing STW to infiltrate into the soil through the "vadose" zone which also acts as a natural filter. It can be attributed that there is no risk of GW contamination when recycled water is mixed with it whereas due to the dilution factor the GW quality has improved and softer freshwater is available for irrigation. El Arabi et al., (2012) supported the presented results by reporting the removal of essentially all suspended solids, nitrogen, potassium, and biodegradable materials. Wei et al., (2015) and Aharoni et al., (2011) also reported the efficient removal of organics, heavy metals, and other physicochemical parameters through the vadose zone during artificial GW recharge using SAT technique. Ickson-Tal et al., (2003) reported high quality of recharged effluent through the indirect (SAT) method which can remove most of the suspended solids, organic matter, nitrogen content, and other pollutants with great efficiency.

3.4 Impact of indirect groundwater recharge on soil properties

The soil textural properties (Table 5) indicates that the selected impacted and non-impacted sites have the same soil type and properties ranging from red sandy loamy soil to red sandy clay loamy (CGWB, 2020). Though it can be concluded from section 3.3 that the GW quality in the impacted areas had improved post-recycling project and the hard water had turned soft whereas the non-impacted areas still have GW with high salinity and TDS. However, it is important to study the impact of indirectly recharged GW using STW on soil

properties during irrigation to evaluate safety and risk of contamination in soil and crop as well.

Table 5. Soil textural properties

S.No.	Soil component	Sand	Silt	Clay
1.	Impacted area	71 ± 5.1	8.1 ± 1.5	22 ± 1.1
2.	Non-impacted area	74 ± 2.2	6.05 ± 2.9	19 ± 4.2

The impact of indirectly recharged GW on soil properties when used for irrigation is presented in Fig 7,8 and 9. It can be observed from Fig 7 that there was no significant change (> 0.05) in the soil pH after the recycling project (after 2018). The pH of the soil was around 6.5 to 7.5 which is ideal for most of the crops. Soil pH affects nutrient availability in the soil as when the soil pH is too low or too high, some nutrients become less available to plants. Similarly, a significant impact ($**p<0.01$) can be seen in the EC of impacted areas soil where after recycling the EC reduced to 50% when compared with before recycling whereas in non- impacted areas the soil was still saline with high EC. The reduction in the salinity of impacted soil can be clearly correlated to the improved water quality of indirectly recharged GW used for irrigation. High levels of EC in non-impacted soil is mainly attributed to the original high levels of soluble salts in the water which can lead to soil salinization and can limit crop growth and yield by impacting soil fertility (Manisha et al., 2023; Abdel-Aziz, 2015). It can also be concluded from Fig 8 and 9 that there is no significant change in the soil properties like organic matter, available nitrogen, available phosphorous, and available potassium where the indirectly recharged GW was used for irrigation.

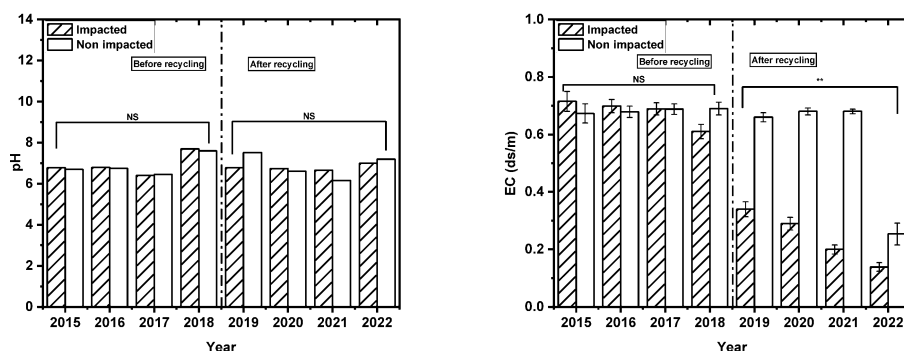


Fig 7. Impact on pH and EC of soil

(Note: Student's t-test value: (a) Before recycling (0.11), After recycling (0.25); (b) Before recycling (0.17), After recycling (11.19), -NS- not significant for $p > 0.05$, $*p < 0.05$, $**p < 0.01$)

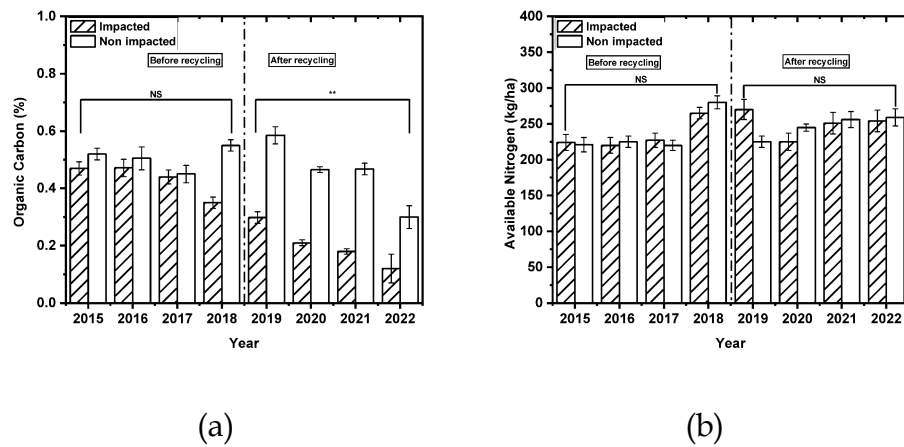


Fig 8. Impact on organic carbon and available nitrogen of soil
(Note: Student's t-test value: (a)Before recycling (2.07), After recycling (3.63);
(b)Before recycling (1.22), After recycling (0.70), NS- not significant for $p > 0.05$,
* $p < 0.05$,

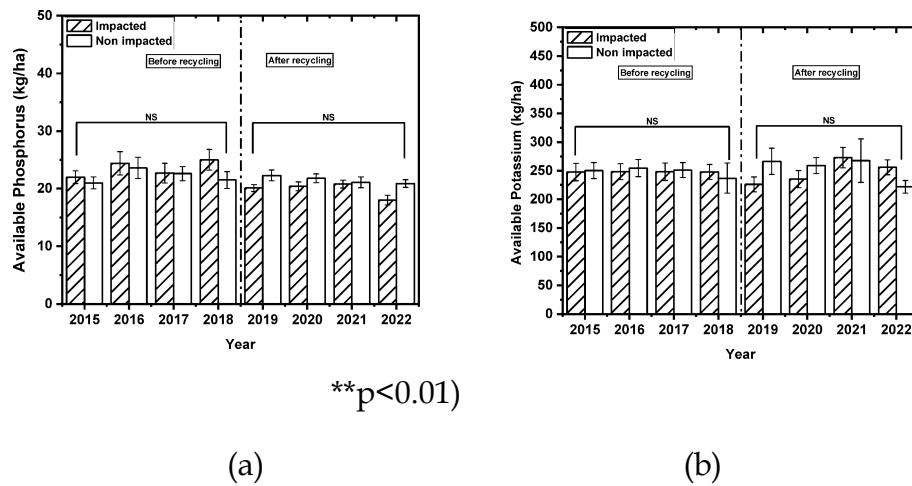


Fig 9. Impact on available potassium and phosphorus of soil

(Note: Student's t-test value: (a)Before recycling (1.47), After recycling (2.42);
(b)Before recycling (0.07), After recycling (0.40) -NS- not significant for $p > 0.05$,
* $p < 0.05$, ** $p < 0.01$)

Table 6 represents a comparative study on the impact of using indirectly recharged GW on soil micronutrients and sodium adsorption ratio (SAR). It can be observed that there is a significant improvement in the fertility status of soil in impacted areas as the salt deposition in the soil was less (SAR) which is attributed to the use of indirectly recharged GW which was soft in nature compared to the hard water from the deeper layer of the soil before the recycling project was initiated. A minor variation in other micronutrient concentrations can be observed as a result of dilution in impacted areas. Thus, it

can be concluded that there is no negative impact of using the indirectly recharged GW on soil properties when compared to the risk (like nutrient imbalance, heavy metal toxicity, soil salinization, microbial contamination, and reduced fertility) associated when treated wastewater is used directly for irrigation. The above results are in agreement with the results of Alnaimy et al., 2021 and Prasad et al., 2020.

Table 6. Impact on micronutrient content and SAR of soils

S.No.	Parameters (mg kg ⁻¹)	Impacted Area		Non-impacted Area	
		Before Recycling (2016-2018)	After Recycling (2019-2022)	Before Recycling (2016-2018)	After Recycling (2019-2022)
1.	Zinc	1.87 ± 0.09	1.05 ± 0.01	1.57 ± 0.2	1.77 ± 0.08
2.	Boron	1.59 ± 0.1	0.57 ± 0.06	1.82 ± 0.1	1.69 ± 0.2
3.	Iron	23.84 ± 1.2	11.62 ± 1.2	28.04 ± 2.2	24.55 ± 3.4
4.	Manganese	25.05 ± 1.6	18.68 ± 1.5	22.22 ± 1.8	25.01 ± 2.2
5.	Copper	1.4 ± 0.3	0.83 ± 0.01	1.9 ± 0.4	1.4 ± 0.01
6.	SAR (mEq/L)	5.7 ± 1.1	3.5 ± 0.9	5.5 ± 1.5	6.1 ± 1.8

3.5 Soil health card of the experimental site

The health of the soil based on the parameters prescribed by the Indian Council of Agriculture Research (ICAR) and the Indian Institute of Soil Science (IISS) is represented in Table 7. It can be observed that most of the parameters such as organic carbon, available N, and available P fall under the medium category whereas available K falls under the higher category. Hence, it can be concluded that there was no significant difference in the soil health of the impacted and non-impacted areas confirming that there is no negative impact of irrigating agricultural fields with indirectly recharged GW and can be considered as a safe alternative for irrigation instead of using treated wastewater directly.

Table 7. Soil health (GoI, 2017) based on parameters prescribed by ICAR and IISS

Sl.No.	Parameters	Impacted	Non-impacted
1.	Organic Carbon (Low: <0.5%; Medium: 0.5-0.75%; High:>0.75%)	Medium	Medium
2.	Available Nitrogen (Low: <240 kg/ha; Medium: 240-480 kg/ha; High:>480 kg/ha)	Medium	Medium

3.	Available Phosphorus (Low: <11 kg/ha; Medium: 11-22 kg/ha; High:>22 kg/ha)	Medium	Medium
4	Available Potassium(Low: <110 kg/ha; Medium: 110-280 kg/ha; High:>280 kg/ha)	High	High

3.6 *Bacterial diversity in soil*

The dominant phylogenetic bacterial diversity and their specific role in the two soil samples (impacted and non-impacted) are presented in Table 8. A total of 14 bacterial phyla in common were observed in the two soil samples. Proteobacteria was the most abundant community (28– 30%), followed by Bacteroidetes (10–15%), firmicutes (13–15%), Acidobacteria (12–15%), Actinobacteria (6–8%), Planctomycetes (6–7%), Chlorofexi (6–7%), Verrucomicrobia (2–3.5%), Gemmatimonadetes (1– 4.5%), Nitrospirae (1.5–2%) and few were the other groups. As seen from Table 8, there was no significant difference in the bacterial community concentration when compared in the two samples except for Gemmatimonadetes which are high in non- impacted soil as these are more prevalent in dry soils (DeBruyn et al., 2011). This gives a clear indication that the use of indirectly recharged GW for irrigation in impacted areas has no impact on bacterial diversity. It can be observed from the role of the dominant phyla represented in Table 8 that most of them are plant growth promoters, few are major members in the nitrogen fixation cycle, few of them facilitate phosphorus and other micro-nutrient solubilization, few are majorly involved in energy production and C metabolism, few of them secrete biofumigants and are associated in disease suppression by targeting pathogens (Malisorn et al., 2020; Li et al., 2020; Sharma and Salwan, 2018; Bruto et al., 2014). The outcomes of our study are in agreement with other studies (Ibekwe et al., 2018; Broszat et al., 2014) that have reported no significant impact on the overall diversity and richness of bacteria (depending on the quality of the treated wastewater) between soil irrigated with treated wastewater and synthetic freshwater. Table 8 also represents the comparison of phylogenetic bacterial diversity in soil when direct STW is used for irrigation.

Table 8. Phylogenetic bacterial diversity in impacted and non-impacted soil

Sl.No.	Phylum	Impacted soil	Non impacted soil	Secondary treated Wastewater (Ibekwe et al., 2018)	Role	Reference
1	Proteobacteria	30.60%	28.20%	32.1%	• Plant growth-promoting rhizobacteria • Nitrogen fixation • Helps in phosphate and zinc solubilization • Indole-3-acetic acid production	• Malisorn et al., 2020
2	Bacteroidetes	14.70%	11.60%	1.62%	• Secrete diverse arrays of carbohydrates active enzymes • Participate in energy production and conversion	• Lidbury et al., 2021
3	Firmicutes	14.20%	13.00%	26.5%	• Involved in cell wall biosynthesis • They are important chitinolytic bacteria • Play role in bio-control of plant pathogens in the phytoremediation of heavy metals	• Sharma and Salwan, 2018
4	Acidobacteria	14.30%	12.00%	3.15%	• Growth-promoting bacteria • Produce	• Kiela et al., 2016

					exopolysaccharides and modulate plant hormone level • Facilitate nitrogen, phosphorous, and iron acquisition	
5	Actinobacteria	7.50%	6.30%	14.3	• Helps to solubilize phosphorus and potassium • Involved in nutrient cycling, soil quality, and crop production • Ability to increase growth yield of staple crops like tomato • Potential destroyer of fungi and other bacteria that cause damage to plants • Associated with disease suppression • Produce volatile biofumigants	• Li et al., 2020
6	Planctomycetes	6.70%	7.10%	0.86	• Major role in the nitrogen cycle as can oxidize ammonia to dinitrogen	• Fuerst and Sagulenko, 2011

					without oxygen.	
7	Chloroflexi	6.20%	7.00%	-	•Filamentous bacteria •Ferment carbohydrates and degrade other complex organic compounds	•Lidbury et al., 2021
8	Verrucomicrobia	3.40%	2.20%	0.19	•Role in lipopolysaccharide biosynthesis and C metabolism	• Li et al., 2020
9	Gemmatimonadetes	1.00%	4.20%	0.07	•Important role in the cycling of organic C due to their metabolic strategies •These are more prevalent in drier soils	•Kiela et al., 2016
10	Nitrospirae	1.90%	1.60%	-	•Plays important role in nitrification as a nitrite-oxidizing bacteria •Also provide ammoniac oxidizers	•Fuerst and Sagulenko, 2011
11	Armatimonadetes	1.70%	1.40%	-	•No major role	•Lidbury et al., 2021
12	Crenarchaeota	0.10%	1.60%	-	•Involved in nitrogen cycle for ammonia oxidation	----

13	OD1	0.20%	1.20%	-	•No major role	----
14	WS3	0.10%	1.10%	-	•No major role	----

The pathogenic microorganisms in impacted and non-impacted soil samples are presented in Table 9. There was no considerable difference in the mean concentration of total coliform and E.coli in both impacted and non-impacted soil samples. Whereas it can be observed that non- impacted soil has a slightly higher number of total coliform and E.coli in soil when compared with impacted soil. This indicates that there is no significant impact of using indirectly recharged GW with STW on the microbial properties of soil. Since E.coli is one of the most important microbial indicators of fecal contamination, its presence in soil irrigated with non- impacted water could be due to any external environmental source of fecal contamination such as bird dropping, domestic animals, and open defecation (Edge and Hill, 2007). No pathogens studied (Shigella, Klebsiella,) were detected in soil samples. Farhadkhani et al., 2018 reported nondetectable pathogens in the soil whereas their concentration was high in treated wastewater used for soil irrigation. This concludes that the irrigation water source cannot be the only source of contamination in soil. Many studies have also reported E.coli contamination in soil irrigated with direct treated wastewater and tap water as well (Orlofskey et al., 2016, Gatta et al., 2016, Forslund et al., 2013).

Table 9. Microbiological load in soil

Sl.No.	Parameters	Total coliform (MPN/g)	E.coli (MPN/g)	Shigella (MPN/g)	Klebsiella (MPN/g)
1.	Impacted Soil	1208 ± 20	30 ± 5	ND	ND
2.	Non-impacted soil	1330 ± 42	44 ± 8	ND	ND

(Note: ND- Not detectable)

3.7 Microbial load on crop

Foodborne diseases associated with the consumption of contaminated produce are a main concern when wastewater is used for irrigation. The indirect recharge of GW using STW was a concern for the contamination of crops. The microbial load of crops irrigated with indirectly recharged GW and non-impacted GW is represented in Table 10. It can be observed that none of the studied crop samples (except for spinach) contained detectable Total coliform, E.coli (an indicator of fecal contamination), and pathogens (Shigella, and Klebsiella,) suggesting no risk of infection on consuming these crops. It can be observed that a few total coliforms were detected on spinach (leafy vegetables)

in both impacted and non-impacted areas. Hence, it is always recommended to wash and cook green leafy vegetables before direct consumption as they are most susceptible to bacterial contamination (Sinha et al., 2010). Consistent with our results, Orlofsky et al. 2016 showed no significant difference in the detection of fecal indicator bacteria on tomatoes irrigated with treated wastewater as compared with tomatoes irrigated with potable water. Farhadkhani et al. 2018, also detected a few of the selected pathogens in SWW and irrigated soils, but none of the tested plant samples were positive for the studied pathogens. Similar results were reported with regard to the microbial quality of eggplant and tomatoes drip irrigated with treated wastewater (Cirelli et al., 2012).

Table 10. Microbiological load on crops

Sl. No.	Crop type	Total coliform (MPN/100 mL)		E.Coli (MPN/100 mL)		Shigilla (MPN/100 mL)		Klebsiella (MPN/100 mL)	
		IRGW	NIGW	IRGW	NIGW	IRGW	NIGW	IRGW	NIGW
1.	Beetroot	ND	ND	ND	ND	ND	ND	ND	ND
2.	Tomato	ND	ND	ND	ND	ND	ND	ND	ND
3.	Spinach	200	480	ND	ND	ND	ND	ND	ND

(Note: ND- Not detectable)

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Conclusion

The present study introduces a sustainable and safe source of water (replacing direct use of wastewater) for irrigation by using indirectly recharged GW through STW. This study quantifies the positive impacts of indirect GW recharge on groundwater levels and groundwater

Sustainable Biofuels In India_Through Responsible Innovation

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Abstract

India is extending its renewable energy capacity by amplifying biofuels research and development programs by making an eager contribution toward energy security, climate change, and rural poverty. The new blending target with 20% ethanol is set to be achieved by 2025-2026 to expedite the process, a recent amendment from the National Policy on Biofuels (2018). Apart from such ambitious blending targets, using first-generation ethanol with (surplus) sugarcane as a feedstock raises questions on its long-term sustainability. Moreover, emerging technologies which show promise in addressing present needs of the society are often associated with ethical, social, economic and environmental concerns. Therefore it requires a greater understanding of the risks and benefits linked with the development and advancement of biofuels innovation in India. While avoiding the undesired impacts and complexities of first-generation biofuels, it is critical to explore the scope of second and third-generation biofuels, which are known as advanced biofuels. The second and third-generation biofuel technologies emerged as a new frontier where advanced biotechnology is deployed to cultivate crops with higher productivity and biomass growing on marginal lands; using agricultural residues as feedstock for producing bioethanol; and cyanobacteria/algae for producing biodiesel. Therefore, our first research question intends to explore the opportunities and challenges of using advanced biofuels.

Although biofuels have long remained in heated academic debates ever since it was introduced as an alternative energy source, advanced biofuels are currently expected to win over the fossil fuel game. Since we have few choices, we still have a chance to make it more sustainable, unlike fossil fuels with which irreversible damages have occurred. It is therefore unbearable for both developed and

developing economies to accept the inevitable price of progress due to the many local, regional and global repercussions we face today concerning pollution (air/water/land), global warming and climate change.

Gauging the impacts in a shorter period may not be possible or realised later after the (negative) consequences will have happened. In such a scenario, Responsible Innovation (RI) strives to align research and innovation to society's values, needs and expectations by deploying the five dimensions: anticipation, reflexivity, responsiveness, deliberation, and participation. The values reflected in the innovation are crucial for sustainable biofuel production and have not yet been fully explored in the Indian context. Therefore, the second research question addressed is how to produce advanced biofuels responsibly in India. This paper's key aspect is to analyse the RI framework's process-driven approach. The accountability and responsibility in the biofuels innovation can be embedded with] specific values which are relevant and significantly contribute to/shape the underlined cultural values of Indian society. The values that cater to these sustainability aspects have been identified and anticipated using qualitative and quantitative approaches. Deploying the RI approach, the values are embedded in the innovation to achieve the desired outcome of - socially, environmentally and economically sustainable biofuels

Key Words: Second and Third generation biofuel, Sustainability, Responsible Innovation, Values, Participation

Introduction

The global goals for sustainable development strive to ensure access to affordable, reliable, sustainable and modern energy for all (UNDP 2015), the developing countries like India are pushed to match the pace of low carbon futures with the developed nations. The fossil fuels being carbon-intensive energy systems and the primary culprit for global carbon emissions, achieving the goals require a global transition towards low carbon configurations (Rogge, Kern, and Howlett 2017). To accomplish this, new ways to explore our resources or create resources with new perceptions, consciousness, and social vision are being sought (Merchant 2012). Moreover, responsibly generated and sustainable sources for society and the environment are the need of the hour and are immensely advocated these days. The major challenge of the energy crisis and more extensive dependence on energy imports in India are amply strong reasons to explore biofuels as alternatives in which the country could perform better. By integrating multidisciplinary knowledge, including systems biology, biorefining, genetic engineering, synthetic biology and others (Gong and Jiang 2011).; not only that we will be able to reduce our ecological footprint of energy by following the multifaceted approaches (Koh and Ghazoul 2008; Patil, Tran, and Gislerød 2008) but also be not dependent on any one mode of energy generation. The alternatives in renewable energy offer various perceived advantages over fossil fuels, such as fuel switching, distributed availability of renewable sources, access to enabling technologies and their modularity, and forming new and potential forms of ownership (Burke and Stephens 2018).

The studies discussed in Table 1 suggest that the direct use of untreated or secondary treated wastewater (mixed with industrial effluent) used for irrigation can be a viable option for conserving freshwater resources (Alnaimy, et al., 2021; Shafiani and Malik, 2013; Dalkmann et al., 2012; Qishlaqi, et al., 2008). However, the use of poorly treated wastewater for irrigation can lead to the accumulation of a wide range of contaminants such as heavy metals, pathogens, and other organic compounds, which can adversely affect soil properties and crop growth. The analysis of the literature reported above revealed that poorly treated wastewater resulted in high SAR, EC, and soil salinity due to the accumulation of salts in the soil as water containing high salts evaporates and deposits in the soil (Rezapour et al., 2019; Tahtouh et al., 2019; Libutti et al., 2018; Bedbabis et al., 2015; Sou et al., 2013). There is also a growing risk and concern regarding pathogen contamination of soil irrigated with poorly treated or raw wastewater (Shafiani and Malik, 2013). These accumulated contaminants may lead to GW contamination, can translocate to crops, and may affect the crop quality and potentially harm the health of those consuming it (Khan et al., 2015).

1.1 What are advanced biofuels: A brief

The first-generation biofuels have failed due to their unviability and unsustainability in India (Naik et al. 2010). The unsustainability and non-viability in the sense that it caused issues regarding land acquisition (dedicated lands for fuel crops), food security (land use pressure and raised food prices) and water consumption (water supply for fuel crops as opposed to food crops). It could not address critique on the questions of food versus fuel and water & energy security challenges. Also, its linkages to high carbon emissions are the reasons for its criticism. The technology could assist the societal development and society could facilitate the technology to function in a desirable manner while avoiding negative impacts. The production and use of liquid biofuels are encouraged due to the new policies and expanding biofuel market globally (Hunsberger and Ponte 2014). As the central thrust area of research and development is also being directed towards bio-energy in India.

The sources considered for 'second generation' biofuel include lignocellulosic (non-food) materials such as sugarcane bagasse, forest and crop residues, vegetable grass, short rotation crops and municipal solid wastes (Sharma et al. 2011). Earlier the research into biofuel technologies was concentrated mainly in agriculture, automotive and chemical engineering (Kovarik 2013), which has expanded to other sources like microalgae as a sustainable and profitable mode of production (Patil, Tran, and Gislerød 2008). The recent biofuel feedstocks are microalgae and cyanobacteria, considered as 'third-generation' biofuel that can grow in water and hence restrain competition with land-based food crops (Chisti, 2008; Moody, McGinty, & Quinn, 2014; Parmar, Singh, Pandey, Gnansounou, & Madamwar, 2011; Raja, Hemaiswarya, Kumar, Sridhar, & Rengasamy, 2008; Satyanarayana, Mariano, & Vargas, 2010; Scott et al., 2010). Among other productions of biofuels, microalgae are considered as potential sources (Chisti 2008; Jena et al. 2012). Many countries are expanding its Research and Development (R&D) as an alternative renewable energy source. Using potential renewable biomass to produce biofuels is a sustainable way of CO₂-neutral energy production (Patil et. al, 2008).

Third generation biofuels with microalgae has inherent advantages in producing high lipid yields and utilising wastewater and abandoned land, representing a potential alternative feedstock. The focus areas like processing steps in bioconversion pathways to produce biofuel are rigorously explored to enhance the commercial feasibility of algal biofuel (Quinn and Davis 2015). The productivity potential of algae is orders of magnitude higher than the terrestrial feedstock. Its dynamic growth model further allows for improving the assessment of algae to biofuel processes while making seasonal and geographic variability apprehensions (Quinn and Davis 2015). The factors such as the viable source of water with most negligible environmental impact and CO₂ emission are required to be considered in scaling up the biofuel production; to ensure sustainable production, the integrated phyco-remediation coupled

biofuel technology is approachable (Rawat et al. 2013). The evaluation of alternative processing technologies is leveraged through the deployment of critical drivers in achieving commercial viability and social adoptability as discussed in section 3. As we realise a comprehensive analysis is required to explore the universe of the study, the following section discusses how we evolved to deploy Responsible Innovation as an analytical framework through various literature/research papers about innovations.

The ongoing research on advanced biofuels needs critical attention on issues of biofuel production with excess food grains, agricultural wastes and growing algae in water bodies in closed and open water systems in India. However, there are many significant problems regarding advanced biofuel technologies and their adaptability in the society. The unintended risks may be vital in anticipating and addressing at the research level to prevent any unintended risks. If scientists, innovators and companies do not discuss unintended negative consequences, then who should be held accountable for the adverse effects? Such a condition demands greater accountability from innovators and technology developers for advanced biofuels. As a result, the research questions pondered through this study are: How to responsibly produce advanced biofuels in India? And what are the opportunities and challenges of using advanced biofuels? These questions attempt to discover the key issues and how they can be resolved with the values embed research and innovation in second and third-generation biofuel technologies. It begins with a theoretical framework discussed in the section to follow.

1.2 Theoretical and Methodological Process of Responsible Innovation

Since the development in biofuel technologies has overlooked the accountability and sustainability aspects in the process, the reasonability and sustainability of such innovations have become questionable. There is a need to explore such frameworks which enable to analyse these aspects of the evolving or emerging technologies. The Responsible Research and Innovation (RRI) (Sutcliffe, 2011; R. Singh & Kroesen, 2012; Schomberg, 2013; Owen, Macnaghten, & Stilgoe, 2012a; Stilgoe, Owen, & Macnaghten, 2013a; Singh & Setiawan, 2013; Setiawan & Singh, 2015) is being widely discussed these days, where public and civil society stakeholders are involved in the process and outcome of research and innovation which are its key components. It would facilitate finding the values which are socially desirable, acceptable as well as sustainable (Andri D. Setiawan and Singh 2015; Andri D. Setiawan, Sutrisno, and Singh 2018; A. D. Setiawan 2018) for the adoption of second and third-generation biofuels. Therefore the study deploys the framework of responsible innovation to deal with the questions of accountability and sustainability in biofuels technology innovations by embedding specific values. The values here mean those characteristics we desire to have in the emerging technology to make it adaptable and sustainable. It is, therefore, crucial to find the relevant values given the particular technological development, as these values dictate

our environmental and sustainable outcomes (Hakim 2008). The study, therefore, combines quantitative and qualitative data to identify, anticipate and evaluate the values arising in the production and adaptability of third-generation biofuels. In the coming section, we have evolved with RI as an analytical framework, including the five dimensions and process of RI, which are like guiding principles to attain the larger sustainability goals.

2 Analytical framework

Scholars have developed and proposed many concepts, systems and theories of innovation as the production of scientific and technological knowledge has been gaining a base in academic circles and policy for the last few decades (Dantas 2005). The Systems of Innovation (SI) approach has existed and was enhanced because of the pivotal work by Freeman (1987), Lundvall (1992) and Nelson (1993). Their seminal contribution in developing the theory is based on the idea that processes of innovation are extensively recognized by interactive learning, this “interactivity paves the way for a systemic approach” (Edquist 2013). The system approaches such as National System of Innovation (Freeman 1987; R. Nelson 1988; Niosi et al. 1993), Sectoral System of Innovation (Pavitt 1984; Malerba 2002) and Technological System of Innovation (Carlsson and Jacobsson 1997; Hekkert et al. 2007) have been widely used across the world. However, with the changing social and environmental landscapes, paradigm shifts have been observed in the innovations and the new concepts of innovation started to evolve. The new innovation based approaches like Open Innovation (Chesbrough 2006; Gassmann and Enkel 2004) which is a process-based innovation, discusses a fierce competition where customer values are evolving, hence, resulting in more stringent regulations giving ethical credit in the innovation process, yet it limits to discuss the accountability and the process of innovation to be carried out. The innovations differentiating which are capable to support sustainable development have been encouraged in the developing economies (Brundtland 1987). Thus, Eco-Innovation (Johansson and Magnusson 1998; Rennings 2000), Sustainable Innovation (Larson 2000; Schot and Geels 2008; Varadarajan 2017) and Responsible Innovation (Owen, Macnaghten, and Stilgoe 2012b) started burgeoning. These approaches to innovation may provide a suitable framework to help firms generate innovative outcomes that are commercially sound, ensure environment and human health protection and are socially desirable or socially acceptable (Ruiz 2015). Therefore, it is pertinent to analyze if the new processes in innovation ensure sustainability (socially, economically and environmentally) and responsibility issues. Responsible Innovation is seeded as one such concept as the need emerged to adopt and address these changes, which has a broader vision within its implementation, as discussed by Schomberg (2013). This study will attempt to bring in some conceptual and theoretical virtues (values) or shortfalls related to the development of advanced biofuel in the Indian context. For that, different concepts of responsibility are explored (Owen, Macnaghten, and Stilgoe 2012b;

Schomberg 2013; R. Singh and Kroesen 2012; Stilgoe, Owen, and Macnaghten 2013; Sutcliffe 2011), and based on that understanding, a definition which is found suitable as the working definition of responsible innovation for the emerging innovations (also this study) as given by Singh and Kroesen (2012):

“Responsible Innovation means being caring or ensuring care for certain values for social, economic and environmental sustainability by engaging in anticipation, reflexivity, deliberation, responsiveness and participation for bringing up any change in any idea, product, process, method, way of doing business, technology, et cetera, to bring them into a specific market or use them in a society.”

The above definition has discussed the process of achieving the goals of RI by ensuring to embed specific values in the system. Precisely, the concept distinguishes three major elements of RI: sustainability as the goal, values to be embedded in the innovation and five dimensions of RI i.e. anticipation, reflexivity, deliberation, responsiveness, and participation. The concept insinuate that social, economic and environmental sustainability should be taken care of by adopting values in the innovation system. The emphasis is that actors in the innovation process should be sensitive enough or considerate to certain values which are universal or culturally specific. Therefore, the innovation actors have a significant role in acknowledging those values that might involve value differences among actors besides context to achieve acceptable outcomes (Setiawan, 2018). Therefore the Responsible Innovation framework issued as the technologies under constant debates in science and technology is aspired to be developed on the lines of responsible development of products and services (Sutcliffe, 2011).

In the next section, the steps to different methods pursued in the study have been discussed, wherein the five dimensions and the process of RI are considered. The process to ensure values imparted within the innovation system, either culture-specific or universal, is steered by the dimensions, which are like guiding principles to attain RI goals which have been briefly discussed in the following section.

2.1 Dimensions of Responsible Innovation

The five dimensions of innovation (Singh & Kroesen, 2012), as mentioned earlier (section 1.2) operate at a wider stance as they can function laterally and iteratively (Setiawan, 2018). These are discussed as follows:

1. Anticipation- refers to looking forward by innovation actors or stakeholders to foresee innovation's consequences or undesirable outcomes (Singh & Kroesen, 2012). This also means seeking the better opportunities while overpowering the risks and challenges beforehand.

2. Reflexivity- is a circular or iterative process of creating and shaping innovation by actors or stakeholders. Being reflexive means repeating planning and actions and referring back to the consequences of each activity (Singh & Kroesen, 2012). This also emphasizes the learning process through accumulating experience to understand the feedback mechanisms or the cause-effect dealings in the innovation processes.

3. Deliberation- requires open and meaningful discussion among actors and stakeholders in the innovation process. It involves a thorough exploration process by actors or stakeholders, carefully and responsibly considering differing attributes through in-depth conversations to harmonize to move ahead (Singh & Kroesen, 2012).

4. Responsiveness- is about how actors or stakeholders should respond to or address certain circumstances that may arise because of different needs, views, values and other issues. The process uses the collective process of reflexivity and deliberation outcomes to adjust and influence the pace and course of innovation through adaptive means, practical tools of participatory and anticipatory governance (Singh & Kroesen, 2012).

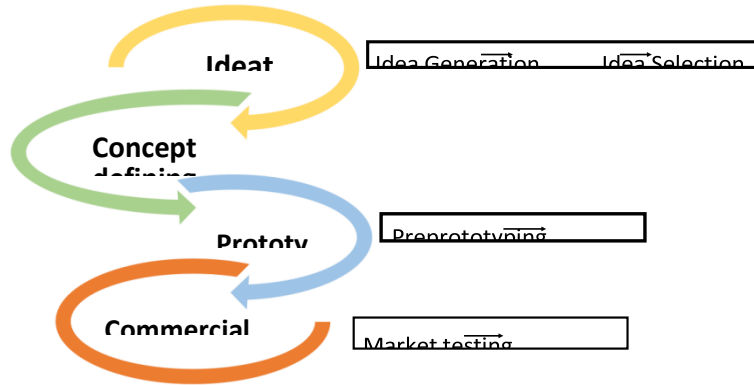
5. Participation- refers to those stakeholders involved and taking part in a process that is considered a crucial component of achieving RI goals (Singh & Kroesen, 2012). Participation entails addressing their interest in issues and recognizing the values specific to their knowledge and opinions.

These dimensions should be incorporated at the institutional level to make it effective for scientific innovations and development. In multiple fields this facilitates striving for technological development and its adoption at a greater extent. In the study, these dimensions have been used to embed the key identified values (Table 1.1) to enable the process of innovation in second and third-generation biofuels to effectively achieve the primary goals of social, economic and environmental sustainability. Henceforth, the process of responsible innovation is discussed in understanding how to operationalize these values, which are brought up in the next sub-section.

2.2 Process of Responsible Innovation

The responsible production of (advanced) second and third-generation biofuel goes through a comprehensive idea generation process to market entry of the product. The stages of ideation (idea generation, evaluation and prioritisation), conceptualisation (definition, detailing and organisation), Prototyping, Piloting, and Market launch have to be adhered into five dimensions of RI (see the figure)

Figure: Different stages of Product development



Source: Author's compilation

The process follows the dimensions of responsible innovation to identify and embed social, economic and environmental sustainability values to attain accountability. The values determined themselves to lower the risk and uncertainties as part of innovation in society. Therefore, with reduced uncertainties about the consequences of new emerging technologies and innovations, following RI process would ensure a better accountability on the part of innovators and stakeholders. The dimensions include multiple methods (Ruiz 2015), and some of those are used for this project. Some methods include focussed group discussion, workshops, participatory observations, interview (one-to-one interactions) and works of literature reviews. The focussed group comprises research scholars, scientists, and decision-makers in the field of the renewable energy sector. The process involved raising questions based on the values required to be imparted in developing and producing advanced biofuels. The following section brings the description of the methods used in conducting the framework.

2.2.1 Data Sources:

The secondary data is obtained through desk-based research and other sources, including research reports, scientific journals and newspapers to get the views and perceptions on the adaptability of this technology. The sources used are reports, media news, articles, research papers, etc. The qualitative research was conducted by bringing through various types of data, that included semi-direct (some were conducted telephonically) interviews with twelve scientists working in the consortium and two industry partners involved basically in both second and third generation biofuels development and production. The interviews were based on technologies used in the production of third generation biofuels and adoptability challenges.

2.2.2 Details of Interview Session

The interviews were conducted with the scientists and research scholars who are actively involved in the research of developing feedstock for third generation biofuel. The direct interviews were conducted with the scientists who are situated in Delhi. In-depth questionnaires about the technologies deployed in biofuel generation have been placed before them followed by one-to-one interactions that helped clarify the kind of technologies used for biofuel production. The focus has been on revealing the values which could be imparted further in biofuels research and innovation.

Table 2.1 Summary of all the participants and respondents involved in the study

Type of respondents	Description of respondents	No. of respondents
University Professors	As involved in the Project IUABC*	7
Researchers	As associated with the IUABC project	3
Scientists	As actively involved in the development of biofuels	6
Government Officials	As associated with the policy- making and discussions around biofuels development	3
Ministry of New and Renewable Energy (MNRE)	As involved in the successful execution of the biofuel policy	2
Industrial officials	As part of the IUABC Project	2
Bharat Petroleum Corp. Ltd. (BPCL)** R&D Centre	As involved in expediting and	4

	achieving blending targets	
Indian Oil Corp. Ltd. (IOCL)**	As involved in the expediting and achieving blending targets	1
Farmers	As involved in the rice and sugarcane cultivation	7
Grand Total		35

*Indo-US Advanced Bioenergy Consortium Project funded by Indo-US Science Technology Forum (IUSSTF).

**BPCL and IOCL are oil refining-cum-retailing public sector entities.

A few instances of questions asked are as follows:

1. Are third-generation biofuel technologies involved with food and water nexus, which was observed with the first-generation biofuel technologies? How?

The above question intended to determine the linkages third-generation biofuel would have with the food and water in any stage of its development. If there is any connection, how critical could it be for food and water security? The question tries to bring about the issues one might face regarding resource consumption in the whole biofuel production process and initiate working out for better pathways from the beginning. Therefore, certain feedstock produced with a lower life-cycle consuming less water and minimal greenhouse-gas emissions and have almost zero competition with food production would be preferred (Mureed et al. 2018; Tilman et al. 2009; Wang et al. 2008).

2. How much water is consumed in producing 1 litre of biofuel? And how can we reduce water consumption?

The question posed a direct challenge this technology might face in its production stage, the amount of water it consumes in the process. The growth of microalgae in the open and closed water system differs, considering the barriers (nutrients and optimal growth media) and issues (water contamination and eutrophication) that are encompassed in the third-generation biofuels (Lackner 2017).

We put in efforts to establish a discourse where the scientists indicate their scientific performances, which are considered values in the literature. We

interview them with the point of view that if scientists can ensure these values as part of the technology development, for example: if they can demonstrate the water consumption level or embedded water, i.e. a significant difference in water level than other available technologies, this is crucial as sustainability viewpoint. All of these factors are considered relevant by the scientists or technology developers, enabling the advanced biofuel technologies to be better adapted.

2.2.3 Participatory Observations

This method gives an excellent opportunity to grasp the kind of interactions that happen within a working (social, professional) group, remarkably discussed by DeWalt & DeWalt (2010). In such groups, both participating and observing the informal discussions bring up interesting and relevant questions, which sometimes offset the talks in a formal set-up and one-sided presentation.

One of the critical components of the project in the development of biofuel is its social adaptability, for which it has to be socially desirable, economical and environmentally sustainable. Therefore, raising questions which directly address these aspects is crucial under the RI framework.

Henceforth, the partners (like, we, in this case) who are dealing with the critical analysis of the research are deemed to raise those questions which may have impacts on social, economic and environmental fronts.

For instance:

While participating in the meetings, we raised questions on water consumption data in the microalgae growth up to biofuels production. Initially, the scientists were hesitant to argue and represent their data regarding the virtual water consumption in the process. We tried to acquaint them with the values (discussed in section 3) derived with this factor, by asking relevant questions that the decision makers would anyways ask in due course. We were able to make them understand the importance of the value-laden factors which are highly significant in considering throughout the development of biofuel technologies.

Henceforth, participatory observation allowed us to closely observe how these scientists perform and come up with their outcomes in a particular project.

2.2.4 Focussed group discussion

In this method, a small number of participants (mainly experts) are involved to keep the focus on the broader objectives of the project. The discussion happens in the presence of a moderator (from among the partners). In these discussions, the company of decision-makers facilitates maintaining the project's relevance value.

Specifically, in the case of third-generation biofuels, the scientists involved in the innovation and production of biofuels using microalgae, and their interactions among their peers and decision-makers have been analyzed through the RI framework to address the sustainability challenges.

The instance of water consumption (discussed in previous section) raised in the focused group discussion, have been positively taken and appreciated by the scientists. They would now be able to quantify the water consumption to monitor the actual percentage of water being used in the whole process of biofuel production. The quantification basically demonstrates how much water is being consumed directly/indirectly. This infers how much water we could save in the process.

This empirical exercise highlighted how the researchers, scientists, and decision-makers perceive and understand the values relevant throughout the innovation process as a key feature for handling accountability and maximising its sustainability. Therefore, while designing the whole system, specific universal values based on the adopted RI framework such as safety, cost-effectiveness, competitiveness, non-polluting, healthiness and efficiency are considered. The next section hereby follows with the theoretical underpinnings about responsible production of third generation biofuel, wherein some relevant literature on values have been explored and significant values have been identified that have been attempted to be embedded in the third-generation biofuel innovations.

3 Responsibly producing biofuels

The current interests around Responsible Research and Innovation (RRI) are growing among scientists, civil society groups, policy makers, and businesses due to many specific factors (Sutcliffe 2011). The factors being its process based approach, and operationalizable dimensions which are the tenets of RI to create deliberative and participative ways of innovation where people have an important stake in decision-making or rather deciding the fate of the innovation.

In India, the cultural perspective is an integral part of science, technology and innovation. In global scenario, nations exhibit the culturally specific values along with the universal values. The considerations regarding these values are perceived differently across different societies and hence, are required to be acknowledged for any innovation to be well-adopted, for enhancing its positive impacts and avert the negative ones (Singh & Kroesen, 2012). There are certain values that have to be embedded in the system since the inception of the idea itself. Thus, it is argued that the emerging innovations like production of biofuels need to be aligned with the values which are relevant to the context or in the field where it is applicable. The list of values considered for successful innovation creation, shaping and adoption consists of: cooperative,

transparency, safety, autonomy, accountability, ownership, community, collaboration, universal usability, trust, identity and poverty (Singh & Kroesen, 2012).

In reference to the localized values in case of biodiesel production in Indonesia as discussed by Setiawan et al. (2018) it is evident that embedding the values of efficiency, healthiness, pollution-free, low-cost, high productivity, employment are significant for its development and production. The major issue of food and water security in biofuel technologies posed a greater need to revisit these technologies and lay thrust on the advance and innovative technologies which are capable of settling these linkages. The nexus between food, water and energy is indicating social, economic and environmental concerns. The value of resource efficiency in terms of land/water use, fuel-production and non-competing to the food crops keep relevance in advanced biofuel production. As biofuel production from edible feedstock raises the issue of food security therefore becomes uneconomical choice. So the feedstock for advanced biofuels are mainly suggested to grow on marginal lands and lands with drought and saline conditions.

The recent developments regarding research and innovation in advance biofuel technologies across India variedly discuss the aspects such as waste water treatment (Miranda et al. 2017), CO₂ sequestration and mitigation of global climate change (Sharma et al. 2018). The focus on utilization of microalgae to produce biofuels, creating high biomass producing capability over terrestrial crops, high value products and for bioremediation (Mathimani and Pugazhendhi 2019); engine compatibility and emission characteristics (Sakthivel et al. 2019); innovating alternate sources to produce low cost growth media for microalgae (Gebremedhin, Mishra, and Mohanty 2018) are showing significant values towards a better production pathway.

Specifically, in case of third generation biofuels, the scientists who are involved in the innovation and production of biofuels using cyanobacteria and microalgae analyzed through RI framework to critically view the responsibility and adoptability challenges. Therefore, while designing the whole system, certain universal values based on the adopted RI framework such as safety, affordability, competitiveness, non-polluting, healthiness and efficiency are considered. In addition, the identified culture-specific values through literature, such as, employability (livelihood), equality and energy-security are identified as crucial values.

With the help of deliberative and participative process in the innovation and development of third generation biofuel, the scientists working in the consortium are made aware of the values. Certain values that are significant to be considered in carrying out the innovation in development and production of third-generation biofuel. The engagement of the stakeholders from the

beginning itself helped in scrutinizing the values identified which are appropriate in our context.

There are some identified universal and culture-specific values which have been retrieved from the existing literature on responsible innovation (Mishra 2016; Ruiz 2015; A. D. Setiawan 2018; R. Singh and Kroesen 2012; Stilgoe, Owen, and Macnaghten 2013; Tripathi 2017).

This section focussed on how this technology can be sustainable and how it can create better values over other alternatives in terms of safety (burning or usage etc.), emission rates etc. The whole process helped in evolving third generation biofuel technologies as an effective way to produce biofuel.

We are looking into the ongoing process of biofuels innovation where we are trying to both analyse and implement the framework of RI in the Indian context. The aim of this chapter is thus to introduce a practical, yet theoretically argued, ex-ante evaluation approach to embed responsibility thinking into ongoing innovation platforms.

Based on the interviews collected from the field work, the following table illustrates the frequency as to how many times a particular value (as codes) were mentioned and interpreted from the transcripts by using a qualitative analysis technique i.e. Delve-tool followed by content analysis.

Table: Values in the order of their importance based on the snippets

Values (as codes)	Number of Snippets
1. efficiency	17
2. collaboration/Sharing	16
3. awareness	15
4. Non-polluting	15
5. capacity/capability	15
6. availability	14
7. environment-friendly	14
8. employability	14
9. safety	14
10. utility	13

11.	ease of use	12
12.	renewability	12
13.	inclusion	11
14.	cost-effective	11
15.	coordination	10
16.	economical	10
17.	Health	10
18.	security	10
19.	cooperation	9
20.	standardized	8
21.	competitiveness	8
22.	responsibility	8
23.	freedom	8
24.	accountability	7

Source: Author's Compilation

Viewing the above listed values, the selection of important and relevant values was made based on the number of times those were mentioned in the snippets¹, marking the highest number of frequencies as the most important value in the biofuel's innovation based on the collected data and information. Hence to shortlist and elaborate on the specifically important values were limited by the frequency of upto ten, which brings us down to 18 values which are: Efficiency, Collaboration/Sharing, Awareness, Non-Polluting, Capacity/Capability, Availability, Environment-Friendly, Employability, Safety, Utility, Ease of Use, Renewability, Inclusion, Cost-Effective, Coordination, Economical, Health and Security as sequenced in the table.

The reason behind the shortlisting is centred on the near-term and long-term values relevant for the sustainability of biofuel's development in India. Therefore, the selected values are deemed to have significance in achieving the near-term sustainability to achieve sustainable biofuels in the near future i.e. from five to ten years or so. For the long-term sustainability in biofuels innovation system, the remaining values are:

Cooperation, Standardized, Competitiveness, Responsibility, Freedom and Accountability.

3.1 Safety

Safety is defined as the absence of risks and hazards (van de Poel 2015). It is a significant value which ensures the production and consumption of biofuels as a safer alternative. There are certain concerns regarding biosafety of algal biofuel production and regulatory issues while assessing Genetically Modified (GM) algae risks and opportunities in India. If critically analysed, the questions remains on the adoption of biofuels developed through advanced technologies such as genome manipulation, DNA sequencing, and bioinformatics, in the light of weak biosafety regulatory system and inadequate capacity building (Adenle, Haslam, and Lee 2013).

However, when it comes to implementation, biofuels production by farming (mostly in case of second generation) is considered safe as also because spills of biofuels can be further degraded and absorbed naturally (Alaswad et al. 2015). With the interviews from scientists involved in the project, the safety concerns related to its production which embarks on the use of resources such as water and land have been indicated. In anticipation of the consequences, this also should not interfere with the natural surroundings and its activities. This might not have been achieved so far, but the use of biofuels should help maintain the vehicle emission standards to check air pollution. As, the safety in terms of its transportation depends on the ignition temperature range at a commercial scale, where it should range at an optimum level which is not harmful for any means of transportation have been emphasized.

3.2 Compatibility

It is the “ability of product to adequately perform its function in conjunction with other apparatus and infrastructure”. It can be analysed with parameters like performance of artefact with other and in an existing infrastructure (van de Poel 2015). The compatibility of biofuels produced from different potential feedstocks, might reflect differences in the ecological compatibility of the growing practices and its environmental effects (Groom, Gray, and Townsend 2008). In the innovation process with scientists, these differences can be analysed with parameters like performance of the artefact with other which can be certified based on the existing infrastructure. For this, certification standards customised to deal with such differences would be necessary in biofuels development (Groom, Gray, and Townsend 2008). With the engagement among scientists and technology developers, it has been realized that the disruptive situation might arise if the advanced biofuels could not fulfil the compatibility value in its innovation. For instance, the end users would not likely to prefer a fuel which compel his/her to replace the vehicle, whereas, minor changes in the engine can be acceptable as found from the user’s viewpoint. Hence, in our context, the compatibility of third generation biofuel technologies with the existing internal combustion engine after proportionate blending of biofuels with fossil fuels derived products like petrol and diesel is significant. The

blending process should be as simple as mixing two liquids together. The proportionate mixing needs to be optimized as much as possible through the use of these technologies. There can still be some level of compatibility that has not been explored yet, but might be done in the future.

3.3 Cost-effectiveness

The cost-effectiveness can be simply understood as the degree to which something is effective or productive in relation to its cost. One should be aware that what is cost-effective, may not be affordable, as they are two different notions. For instance, the water consumption, intake of nutrients, energy consumption etc. with their respective costs. At the initial stage of third generation biofuel production it might be difficult to make it cost-effective, however, the effectiveness can be enhanced as we move towards larger scale of production. With this value, we intend to represent the fact that cost-effectiveness is valid at a mass production itself as on a time scale of medium and long term, it may become cost-effective over a period of time in Indian context. For instance, the use of wastewater-grown microalgae have shown high biomass production and sometimes high lipid productivity demonstrating its real potential in a cost-effective production of biofuel (Y. C. Sharma, Singh, and Korstad 2011; A. Singh, Olsen, and Nigam 2011). It has been discussed that the cost of production from the production to the commercialization should be optimized according to the incurring cost mark of the existing fuels in the market. Hence, the cost-effectiveness greatly influences the adoption and consumption of biofuels produced through this technology in lower and middle-income group of countries.

3.4 Employability/livelihood

This refers to having a set of skills, knowledge, understanding and personal attributes that make a person more likely to choose and secure occupations in which they can be satisfied and successful (Pool and Sewell 2007). The economic development and employment generation of an expanded biofuels sector will depend on the scale of industrial activity and regional concentration as well as oil prices (Solomon 2010). As in the Indian context, the production of third generation biofuels till now runs on pilot-scale; the establishment of the infrastructure has yet to be accomplished. There are chances of modest, positive regional economic effects during the time of plant construction (Solomon 2010) in addition to the use of utilizing low-cost residues for feedstock integrating into biorefinery platform. In word with some stakeholders, it has been emphasized that the technology must look upon the features where it can foster income-generating opportunities in the country. Without affecting the other means of livelihood, deployment of skilled or unskilled (can be trained in the process) individuals can create further possibilities in the whole production/manufacturing chain which can first be scrutinized and recruited accordingly. It is likely that If the input costs are controlled and higher output

can be generated, it may prove to be a viable technology. Third generation biofuels have additional applications apart from using it as a fuel. Since microalgae used as a feedstock can also have other commercial application for instance in the food industry as 'health' products, animal feed, human food and also for stable isotopic biochemicals (Milledge 2011; Raja et al. 2008). It is anticipated that scientists and industrialists are likely to explore these avenues in India. It has been assured through the policies as well to see the addition in the bio economy of the country.

3.5 Efficiency

This is defined as “the ratio between the degree to which an artefact fulfils its function and the effort required to achieve that effect” (van de Poel 2015). It also depends on the risk-taking ability of the technology while ensuring care and responsiveness of the consequences (Chamuah and Singh 2019). Through participatory observation in the committee meetings, it has been highlighted that how we can ensure the energy efficiency in biofuels development in India, since the country itself depends on large chunk of crude oil imports. Technological advancements in biomass energy conversion comes from three sources - enhanced efficiency of biomass energy conversion technologies, improved fuel processing technologies and enhanced efficiency of end-use technologies (Shukla 1997). The energy efficiency or net energy balance (energy output: energy input) over the lifecycle of the biofuel combining its fuel yield per hectare, functions as a factor to ecological footprint (Groom, Gray, and Townsend 2008) in case of second generation biofuels. Another factor identified to be crucial is conversion efficiency which is energy output over fossil energy input. The scientist have attempted to explore new pathways and optimization tools which can save the energy as well as cost of the process. As per green chemistry, the addition of glycerol into biofuel improves the efficiency of the process without changing its physico-chemical properties (Solomon 2010).

The committee emphasized that the economic efficiency in terms of the energy return on investment (EROI or EROEI) is important to verify. Especially alternatives to petroleum for transportation, such as biofuels, must compete against each other in this environment of decreasing EROI that places a premium on the efficiency of energy options and investments to maintain, replace, and expand economic activity (Solomon 2010). It is argued that the shared knowledge and co-creation from innovation through collaborative approaches for conversion technologies might enhance the efficiency and reliability of the biofuel technology.

3.6 Poverty alleviation

Poverty alleviation is a central aim of economic and social policy, however it has not been sufficiently defined (Nolan and Whelan 1996). India has the

biofuels policy that encourage use of 'wasteland' which invokes discourses of energy security and poverty alleviation (National Policy on Biofuels 2018). As the geographic and climatic conditions in different regions across India vary greatly, it is imperative to substantiate the equal distribution of resources interjecting the barbaric economic structure in the country. Since, the development intends as national ambitions for alleviating poverty and improving rural infrastructure and services (Hunsberger, German, and Goetz 2017). From the group discussions and interviews, the emphasize has been laid on how to make this technology poverty-alleviating especially in rural areas. Because most of the feedstock are located in rural surroundings (except, municipal solid wastes), the programs of biomass energy will have a great influence on rural economy especially, on small farms used for energy resource development (Solomon 2010). It is likely that during implementation stage of the biofuel development in rural areas will create additional income to farmers or skilled labours. It is anticipated that it will offer development opportunities in terms of small and medium sized electric grid, better roads and transportation etc. at the village level. It is suggested that, the establishments of biorefineries in the peri-urban or suburbs of cities might encourage the employment for city-inhabitants as well.

3.7 Effectiveness

Effectiveness can be defined as the degree to which an artefact fulfils its (van de Poel 2015). We try to recognize the effectiveness in terms of social effectiveness and environmental effectiveness, in addition to the economic effectiveness which has been thoroughly discussed under the section 3.3 – cost-effectiveness. After the focussed group discussions among scientists, it has been noted that, the effectiveness of biofuels should be expanded from the narrower interpretations of being effective only for energy security, employment creation etc.

Instead the effectiveness of the biofuels will have implications on how our policies offer suggestions to enhance its development for the society as based on the review of evidences (Hunsberger, German, and Goetz 2017). Some challenges have been found for better effectiveness which can be addressed through some initiatives which the policy could not fulfil. The interventions like awareness among people, the importance of non-polluting energy choice, lowering carbon emissions, deliberative discussions to engage people in developing the biofuels with participation from civil societies at large need to be performed. For instance, as Singh and Kroesen (2012) have suggested that how the role of alternative technology in life would change people's views about it, by developing the capability effect that connect the human potential to contribute and what they are able to perform effectively. Moreover, the use of waste materials very likely decrease the environmental pressures and will add an extra value to the resource input in the form of energy production (Stoeglehner and Narodoslowsky 2009). Such interventions are likely to expand

the social effectiveness as providing a better alternative which is least-polluting and degrading to the environment, eventually giving them a healthier environment, which also corresponds to the environmental effectiveness of the biofuels.

3.8 Affordability

It is the ability to afford (bear expenses) any product or service (Mishra, forthcoming). Affordability is measured in terms of users purchasing/paying capability which may vary with different contexts. The capability indicates developing certain abilities or power to perform something (Chamuah and Singh 2019) which can be associated with improvement in the earlier skill/ability in context of an individual or a technology. Here capability refers to individual's paying ability which might develop with time or depends on individual's preference in order to pay for a product. Sometimes, for larger public interest there is not much scope for affordable options. The commercialization of biofuels or making the end product available for the users, some concerns are needed to be fulfilled. Our efforts in the innovation process revolved around the adoptability of third generation biofuels. It has been found through interviews, the adoptability cannot be achieved without affordability in the Indian scenario. Since, the fuel prices involve many factors like excise duty, value added tax (VAT), and dealer commission which nearly doubles the retail selling price (Economics Times 2020). The scientists and technology developers from the project have argued on the concerns related to the affordability issues among the users as it would not give them an affordable option to choose the particular kind of fuel. Nevertheless, there can be a possible argument that how to make biofuels affordable when it is not cost-effective at present? It is then suggested that by deploying different tools and mechanisms, it is likely that government initiatives can be made effective, since it is a clean energy choice. It is therefore necessary to have the governmental interventions in terms of carbon credits, subsidies and other provisional benefits as incentives like tax exemption to amplify the adoptability of third generation biofuels. Apparently, the user is able to pay the amount in his/her required capability while fulfilling responsibility towards better society and environment.

3.9 Accountability

It will be imperative to argue how the design of biofuel technology will affect the accountability (at large responsibility) of stakeholders. As design can affect both individual accountability and the distribution of accountability (Mishra, forthcoming). There is a significant factor which can be a deciding factor as well, which is, the geo-political pressure on countries like India which are mostly dependent on the import of crude oil, seems to be a bit complicated at present. As India has conceded to adhere with the directives of the USA administration, the import from Iran is completely closed (Basu and Venkatesh

2019). India's top crude oil suppliers are Iraq, Saudi Arabia and Iran, wherein New Delhi imports 80 percent of its crude oil requirements. In such a scenario we as the partners in innovation raised the questions, if the imports are being stopped, how will the gap between demand and supply be managed in India given its high population? What about the cost of imports if negotiated with other countries like UAE and Venezuela? This emphasis on India to have a profound establishment of the domestic production of liquid fuel to meet its internal requirements and blending targets in the transportation fuel using alternative fuels like biodiesel, bioethanol etc. Such deliberations are crucial to investigate so that more understanding can be achieved on power relations and contested, place specific outcomes and the politics embedded in the governance of the whole process in developing sustainable biofuels (Hunsberger and Ponte 2014). The question remains, for national environmental goals, how do narratives of responsibility and blame impede its progress. The accountability of the stakeholders in the development of biofuels can happen with active participation where participants have scope of discussion, expression, opine, dissent, agreement, alignment and collaboration within a deliberative process (Singh and Kroesen 2012). The partners in the project made sure that they fully engage in the innovation process by realizing their roles and responsibilities in the endeavour as each task has been distributed based on their field and expertise. Accountability ensures answerability for undesirable action or duties (Mishra and Singh 2018). The process of deliberation and participation through focussed group discussion, participatory observation, workshops, progress meetings and discussion ensured the higher chances of accountability. While it is an important element of research and innovation, the stakeholders will be held accountable for whatever consequences emerge through development of biofuels.

3.10 Renewability

The renewability is about relating to or being a commodity or resource which is inexhaustible or replenish to replace by new growth in a finite amount of time in a human time scale, such as solar energy or firewood. The biomass materials which can produce biofuels can be re- produced continuously (Alaswad et al. 2015). To support sustainable development of biofuels, it is imperative to think about the raw material and an environmentally friendly production potential (Stoeglehner and Narodslawsky 2009). Since the import scenario of India concerning the crude fuel requirements looks blurry (Basu and Venkatesh 2019), the emphasis on alternative fuel is highly looked upon. Third generation biofuel which uses microalgae, grows in a short time, is highly recommended by the scientists and biofuel technologists. The scientists in the project are developing improved strains that can be grown faster and provide higher yield by using indigenous strains. The algal biofuels can be used to produce different types of renewable biofuels in addition to and other than biodiesel and bioethanol (Ho et al. 2013). The interviews with scientists suggest that

renewability is best applicable for third generation biofuels than first and second generation biofuels, which make them a better alternative energy source in terms of convenience, availability and disposal.

At the end of the section, the identified universal and cultural values are embedded in the innovation of third generation biofuels with the help of five dimensions of RI through the innovation process. This enabled the whole process from the idea to the final innovation and the potential values to be assessed as part of the major goals of RI i.e. social, economic and environmental sustainability. We are trying to ensure that technology must give us the results by embedding or ensuring the above discussed values and providing maximum benefits. The credibility of the responsible production of biofuel premise on the key factors like research and innovation, adequate economic incentives, providing the right regulatory policies in terms of blending targets, tax credits and subsidies (Tempels and Van den Belt 2016).

A shift in the mechanisms of production can be observed, as earlier it was affecting the food supply chain which now cater to energy supply chain in this line of production and supply. These aspects need to be understood by the scientists and bioenergy stakeholders, while putting such questions before them, we try to address the issues of accountability and sustainability both. Therefore, the risks are minimised and the gains are maximised with the identified values.

Hence, if these aspects are considered by the scientists who are working in such projects, then third generation biofuels will be competent to create and become a more sustainable option in the near future.

Nonetheless, there are some issues that correspond to the values we desire to embed to achieve the viability of third generation biofuel and hence, its adoption. In the next section, we will be highlighting the key adoptability challenges for third-generation biofuel and discuss how it can be addressed with the values discussed above.

4 Adaptability Issues of advanced biofuels in India

The scientists and technology developers have not been able to fully embrace the social, economic and environmental attributes of the development. It perhaps being reflected with multitude of adoptability issues of biofuels in India. The issue of food crops, land and water consumption for the biofuel production have been the major friction for its adoption in the society (Ribeiro 2013). Since the cultivation of third generation biofuels involve closed pond, open pond, photobioreactors and hybrid technology (Chisti 2008; Ghasemi et al. 2012; Narala et al. 2016; Scott et al. 2010), the challenges are seen to be intersecting across the social, economic and environmental aspects of the technology development. Some of the key adoptability issues have been discussed as follows:

4.1 Challenges in Mass Production

There are different risks associated when cultivating algae biomass for third generation biofuel in open water raceway pond. The predation by grazers or invasion by algal pathogens could reduce biomass culture affecting the production stability; influencing the temporal algal biomass production; lipid extraction from wet biomass could lead to additional energy and environmental costs (McBride et al., 2014). Most of the times, algal biomass production while translating lab-scale experimental results to farm-scale production is quite challenging as its not fully understood and developed yet. The reason being extrapolating laboratory scale data under controlled conditions for shorter span, do not necessarily represent large scale function and the highly variable field conditions (Quinn and Davis 2015; White and Ryan 2015). It would require efficient technological as well as operational know-how to significantly bridge the biotechnological and agricultural approaches at commercial scale (White and Ryan 2015).

4.2 Optimum Water Utilization

The concern over water consumption in the large production of algal biomass is rather crucial than the optimum utilization of water in the whole process. Recycling and recovering water after harvesting of algal biomass is seemed to be a critical step towards economical as well as sustainable production especially in arid regions (White and Ryan 2015). Again, to take a cost-reduction measure, recycling water post-harvest could prove advantageous in terms of preserving salts and nutrients rich water (which apparently get replaced by fresh media) from being wasted as the process involve a significant step that requires efficient water separation i.e. dewatering of the algae (White and Ryan 2015). Consumptive water²used for the algal biomass production is not significant in case brackish or saline waters are used (Efroymson and Dale 2015). These measures bring out optimal water utilization involving maximum water recycling and least consumption.

4.3 Techno-economic challenges

The significant investments have been spurred in algal biofuel recently. It is being realised in light of the regenerated interest stimulated by uncertainties in energy prices and encouraging impacts of algae than terrestrial feedstock. However, technical challenges in algal biomass production correspond to the economic feasibility of the third generation biofuel production. Some of the foundational tools like Resource assessment, techno-economic assessment (TEA), and life cycle assessment (LCA) have been used in evaluating the feasibility of algal biofuels (Quinn and Davis 2015). There are certain factors such as over estimation of yield, seasonal and geographical variability, resource-intensive validation process which lead to economic limitations in plant sizing and resource delivery which also challenge current sustainability

assessment (integrating emissions with construction and production assessment); also, other parameters as economic hurdles like facility lifetime, financing assumptions, on-stream operating factor, discount rate and so on (Quinn and Davis 2015). Given the economic constraint of third-generation biofuel, the use of the enzymes (as a catalyst to enhance the reaction) in its development raises the cost of production which is a major tipping point (Barry, Starkenburg, and Sayre 2015).

4.4 Inappropriate Yield

The variety of yields is produced in the biofuel processing unit. However, the yield factor might not be sufficient to make a profitable business model. The acceptability of algal biofuel as a substitute of fossil fuel derived diesel is required to be amenable with the existing standards and biodiesel properties (like density, viscosity, cetane number, flash point and solidifying point); otherwise, poor standard can negatively affect the IC engine, which apparently reverse manufacturer warranties of engine (Rawat et al. 2013). As, biolipid algal oil consists of hydrocarbon compounds i.e. tri-acylglycerides are not found suitable for diesel engines; the high viscosity hinders good flow and combustion (Gallagher 2011). Although the problem is resolved by applying a chemical process known as transesterification³ making it suitable for diesel engines which depends on biomass yield and lipid content (Rawat et al. 2013). The biodiesel produced this way, basically adds up an additional cost which is compensated by glycerine produced as a by-product in the conversion process which is used for various purposes.

4.5 Lack of commercial facilities

The algal biofuel production show promising results in laboratory conditions, while in normal outdoor conditions the hassles are quite different despite commercial scale technologies being available. The major factors that concern while shifting to a plant scale production are: when to scale up (require full optimization study), volumes (biomass production), procedures for scale-up, seed-culture preparation (choice of media), cultivation method (open pond, closed systems or hybrid and photobioreactors) and outdoor conditions (Rawat et al. 2013). For instance, the requirement of efficient use of sunlight for higher biomass and lipid yield and cause effects like photo-acclimation and photo-adaptation (Mureed et al. 2018) emphasis on the better research and innovation in algal biotechnology. The commercial production is mostly associated with high-value products worldwide, as they have well-established harvesting and processing facilities where energy input gets compensated due to the very nature of high-value products, henceforth the added products (Rawat et al. 2013). Due to lack of commercial strains which can be engineered and taken to the fields, the approaches for reducing the cost of biofuels from microalgae like co-production of high value products should be considered (Barry,

Starkenbourg, and Sayre 2015) and indigenous strain should be developed (Bahadar and Bilal Khan 2013).

4.6 Use of Genetic Modification (GM) for algal biofuel

The use of synthetic biology and genetic modification (GM) in algal strains have resulted into advancement of the biofuel research and development making it more prominent and better feedstock for algal biofuel production. Apparently, most of the strains that have been modified are model organisms, hence, leaving not much choice for commercially viable candidate for biofuel production (Kumar 2015). As some microalgae and cyanobacteria can grow abundantly under suitable conditions, they might result into blooms causing severe human health and ecological problems; the toxins (such as neurotoxins, hepatotoxins, cytotoxins and endotoxins) can accumulate in water affecting fishes and other marine animals which can enter human food- chain (Kumar 2015). The concerns sometime deviate from technical/functional to cultural/ethical aspects of development in a technology for instance, the resistance to accept Genetic Modifications (GM) driven products in some countries.

4.7 Exposure in ecosystem

The emissions being one of the exposure mechanism in the form of GHGs are one of the major concerns in the energy sector. The GHGs flux is also associated with algal biofuels as losses of CO₂ from an open pond impact net emissions at every step of the supply system; along with high energy-intensive processes (such as stirring cultures, moving water to and from dewatering and thermal drying) that can possibly lead to comparable CO₂ emissions (Sullivan 2013). One of the critical yet ignorant factor in emission evaluation is associated with the construction of the facility that could influence infrastructure GHG emissions, yield-wise (Quinn and Davis 2015). As discussed previously in section 4.6, the commercial scale cultivation using GM algae has many risks of exposure in the environment while mass cultivation of GM algae remain a competent option compared to existing non-GM strains (Kumar 2015). These factor can critically impact the acceptance of the biofuel in a society, therefore, it would require an in-depth analysis of exposure routes by which an organism may interact in/ with its surroundings (Kumar 2015; Sullivan 2013).

4.8 Lack of awareness

There can be further challenges to adoption of third generation biofuels, which are specific to a region or country. The people's perception regarding its production and development should be transparent and well-informed. To avoid resistance among people, the GM technology used for biofuel production should be enhanced for non-edible energy crops rather than food crops in which case it would be better accepted (Koh and Ghazoul 2008; Ribeiro 2013). Apart from the technological and economic challenges, it is important to ensure

all stakeholders to have a viable business case which would stimulate user's adoptability for a safer renewable alternative (Autotechreview, 2016). It is pertinent to learn the consumers' confidence and acceptance for the development of any new technology, where acceptance being viewed as a function of users participation in systems development (Taherdoost 2018). In the case where the product is at introductory phase or relatively new on the consumer market and for diffusion of any innovation (Rogers 2005), it is imperative for the endorsement of sustainable innovations (Noppers et al., 2015) and other emerging innovation applications.

These factors decide and enable the continuous production of biofuels to ensure the energy security. Therefore, the RI enables to create a mechanism that involve public, scientists and other stakeholders bringing them together to perform in a coherent manner to produce favourable outcomes. Therefore, it is important that how do we embed certain values that might enhance the adoptability of third generation biofuels. We need to ask some relevant questions which can be addressed through the innovation process. If all these barriers are resolved, the producers can sell it and consumers can buy it in the free market, directly.

2.3 Conclusion

The promising research and innovation towards green energy mixes in India are being emphasised to create viable alternative and renewable energy forms. The study mainly conducted with an aspiration to go into the nuances of production and adoption of third generation biofuels keeping the RI framework at its centre. The focus has been laid on the responsible production of third generation biofuels with certain values embedded in its innovation and the values crucial for its adoptability in the society. The comprehensive methodological discussion suggests that deliberation and participation of the scientists involved in the innovation process makes it a unique case of responsible biofuel development. The emphasis that actors in the innovation process should be caring, sensitive or considerate to certain values which are universal or culturally specific to the society. The identified values are safety, compatibility, affordability, efficiency, renewability, effectiveness, poverty alleviation, employability and accountability. It has been realized through the study that we may overlook the cost-effectiveness value at present, however, the issue of accountability has to be aligned. The compatibility of the technology is important from emission standards and adoptability point of view. It should be noted there are some critical values which can be held at priority level depending on the context. For Indian scenario, the values that are found highly critical at this juncture are safety, compatibility, accountability, affordability, employability and effectiveness. On the other hand, the values like renewability, cost-effectiveness, efficiency, poverty alleviation are the long term achievable aspirations, which can be resolved with large-scale production. These values can be embedded in the innovation of third generation biofuels

with the help of five dimensions of RI through the innovation process. This has enabled the whole process from the idea to the final innovation and the potential values being assessed to achieve the major goals of RI i.e. social, economic and environmental sustainability. Consequently, the long term sustainability can be achieved through anticipatory measures (as values) taken under RI framework which have been thoroughly discussed in the paper. Along-with the consultation of the research group, we have tried to reach at a benchmark to understand the building up of this whole process. It also creates a vision through partnership and co-creation, with this approach we can assure more success compared to existing research and approaches in the innovation system which has the impetus to create potential sustainable possibilities in renewable energy sector.

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Notes

¹ Snippets indicate a brief quotable part or piece in any information. In the delve tool, by clicking on a code when text is selected applies that code to the selected text. These segments of texts that have been coded are called 'Snippets'. It is important to mention that as many codes as required can be applied to the same or overlapping snippets.

² Consumptive water use is water withdrawal and loss through evaporation, runoff, or incorporation into a product. Consumption or withdrawal is useful for evaluating water-use efficiency of particular technologies or pathways.

³ This process involves adding alcohol (methyl alcohol) in a base mixture to convert the triglycerides into three smaller hydrocarbon chains to make an alternative fuel for diesel engines.

⁴ IUABC comprises twelve consortium partners in India, one leading University in the US and two industrial partners as member organizations in India

⁵ The production tasks focus on making significant step changes in the conversion processes for plant lignocellulosic (second generation) as well as algal biomass (third generation) to biofuels. They include the use of advanced genomics based approaches for biological conversion. Special emphasis is placed on using synthetic biology tools to create high- energy designer fuel molecules that can directly replace petroleum

Multi-level interaction dynamics towards sustainability in developing countries: Evidence from the Waste-to-Energy transition in Ghana

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Abstract

Worldwide efforts to accelerate sustainability transitions of socio-technical systems intensify with the aim to meet climate change mitigation targets. Empirical research in developed countries dominates transitions research, but it is imperative that transition processes in developing countries receive analogous attention owing to the global nature of climate change. A range of frameworks for the analysis of transition processes exists in transitions literature, with the Multi-Level Perspective (MLP) and the Technological Innovation System (TIS) being the most prominent ones. Their suitability and efficacy for transitions in developed countries is flagged as an issue in many studies that discuss ways the frameworks could be further advanced to capture the greater level of complexity inherent in developing country contexts.

In response, this paper builds on these literature findings to contribute to the analysis of sustainability transitions in developing countries. More specifically, it distinguishes between sustainability transitions in developed and developing countries based on the latter's (i) higher intensity of influence of the landscape factors, (ii) greater level of fragmentation that characterises their socio-technical systems, and (iii) lower level of resilience of their (sustainability-oriented) innovation systems.

This paper reviews empirical applications of the transition frameworks in developing countries, consolidates findings in an integrated transition framework, and discusses how the interaction dynamics across different levels can influence transition processes in developing countries. This is then used to show how the interaction dynamics shape Ghana's transition pathways towards a greener waste management system. A causal loop diagram is developed to represent the variables and feedback loops that influence the transition pathways of the system. This model also shows how an appropriate mix of policy interventions in different system levels

may lead to sufficient performance improvements and support the emergence and diffusion of waste-to-energy niches.

In summary, this paper yields insights into the complex dynamics of transition processes, augments more general conceptual advances on the sustainability transitions of developing countries and provides an evidence-based case study to verify these contributions. The developed causal loop model improves understanding of the interconnections between different transition dynamics and promotes the use of transition frameworks as policy tools. Moreover, by recognising the dynamic interplay among the transition factors, it helps to identify opportunities for the development of new, more sustainable technologies and recognise windows of opportunities.

1. Introduction

Lack of clean water, increasing waste production and dumping, heavily polluting energy systems, and inefficient mobility are just a few of the grand sustainability challenges the world is facing today. These are becoming even more pressing, especially in developing countries. In response, efforts in the policy arena and the academic world are widely centred on fostering transitions of the corresponding socio-technical systems towards more sustainable states of operation.

Transitions toward sustainability are likely to unfold differently in developing countries as compared to the more developed ones due to their systemic differences and therefore transition frameworks used to address and analyse socio-technical transformations in developing countries should be able to reflect these distinct characteristics. While the body of work on sustainability transitions in developing countries is growing, there is still a lack of knowledge on how transition frameworks (MLP, TIS) might work out in these contexts (Bergek et al., 2015; Ramos-Mejía et al., 2018; Wieczorek, 2018). This realisation triggers the need for further thinking on the specific characteristics that rule and guide transition processes under diverse contexts. Second, limited attention has been paid to the potential interactions among and between landscape, regime and niche-innovation factors, and how these play a role in accelerating or hampering the transition processes. Although the influential relations among landscape, regime and niche-innovations have been explicitly addressed, the role of TIS functions remains largely implicit and its interplay with landscape and regime elements has not been adequately addressed.

To address these constraints, this paper unifies the MLP and TIS frameworks to support a better understanding of how socio-technical change for sustainability transitions unfolds in developing countries, what are the transition dynamics that interact and how they influence the transition

processes. It aims to contribute to the ongoing debates evolving among transition researchers, about the suitability of the prevalent transition frameworks in the context of developing countries, and the need to reconceptualise them. This paper shows that the existing transition frameworks are sufficient for the analysis of transformation processes in developing countries, yet what is needed is a more comprehensive approach to the analysis of the dynamics occurring at (and within) the different levels.

The paper follows a three-step methodology to arrive at the main results. First, the literature on application of the MLP and the TIS function approaches to developing countries is reviewed, to identify a set of variables relevant to modelling of sustainability transitions in contexts of high complexity, instability and insecurity, which could be applicable to both developed as well as developing countries. For this purpose, an article search in Science Direct and Scopus databases searching for the following string in the title, abstract or keywords: ("sustainab* transition*" OR "socio-technical transition*") AND ("global south" OR developing OR emerging) AND (management OR framework*), for articles published between 2022 and 2012 was performed. In addition, peer-reviewed articles on sustainability transitions in developing countries that employed the MLP or TIS frameworks were also searched and included in the analysis. The main inclusion criteria were that studies had to explicitly position themselves in the transition field, with empirical applications in a developing context and with particular focus on either the management of transitions or the utilisation of a transition framework. The abstract of each article was reviewed manually to decide whether or not the article would be included in the analysis. Eventually, 39 articles were selected for complete reading. Second, based on this review, the characteristics of transition processes at different levels are conceptualised for the analysis of sustainability transitions in developing countries. Third, the findings are illustrated with the case study of Ghana and its solid waste management system, to explore what are the most influential factors in the diffusion of waste-to-energy technologies, and how these could explain its slow progress towards a more sustainable state.

The paper makes two original contributions to the existing literature on sustainability transitions.

First, it develops a comprehensive approach to map all potential transition dynamics of socio- technical systems in highly complex contexts, such as cities and regions in developing countries. This paper provides a solid basis for the identification of the reinforcing or preventive forces imposed on a socio-technical system, and which influence its transition pathways. It expands upon existing studies in the field, by incorporating MLP layers (landscape, regime, niches) with TIS functions, by recognising bilateral relations existing among them, and accounting for the specific characteristics of these dynamics in the context of developing countries.

Second, the paper illustrates these frameworks, with case study of ongoing circular economy transition in Ghana and evaluates the strength of each of its factors in impacting the speed and success of the envisioned transition in Ghana's solid waste management system towards waste-to-energy.

The remainder of the paper is organised in six sections. First, section 2 sets the background on development pathways. Section 3 reviews the literature on sustainability transitions in developing countries and revised the integrated framework of paper 2b, based on these findings. Thereafter, section 4 develops the case study in Ghana. Finally, section 5 discusses future avenues for the empirical application of the frameworks and their value added to existing studies.

2. Setting the background

This section briefly touches upon selected works that are relevant to the study of sustainability transition in developing countries. Section 2.1 sets out country classifications and my focus. Section 2.2 reviews the development efforts and pathways of middle- and lower-income countries to provide deeper insights on their structural realities, but it does not purport to be a comprehensive review.

2.1 Country classifications and thesis focus

The definition and focus of 'development' has evolved and changed over time, from a purely economic phenomenon to one with strong social, political, and institutional dimensions as well. As different countries grew and developed at different rates, it became useful to distinguish emerging countries from the remaining developing countries during 1990s. Emerging markets (or emerging countries) share some essential features of other developing countries; that of high degree of volatility and the transitional character, with transitions occurring in economic, political, social and demographic dimensions (Mody, 2003). At the same time, emerging markets represent regions of opportunities and threats for high income country firms and vice versa. Overall, they entail the characteristics of a developing nation that is becoming more engaged with global markets as it grows.

Overall, different categorisations of countries exist. The World Bank makes it on the basis of GNI (Gross national income) per capita. Based on this methods, for the 2023 fiscal year, low- income economies are defined as those with a GNI per capita of \$1,085 or less in 2021; lower middle-income economies are those with a GNI per capita between \$1,086 and \$4,255; upper middle-income economies are those with a GNI per capita between \$4,256 and \$13,205; high-income economies are those with a GNI per capita of \$13,205 or more.

United Nations classifies all countries of the world into one of three broad categories: developed economies, economies in transition and developing economies, to reflect basic economic country conditions (UN, 2022). A

subcategory is the Least Developed Countries, which are defined by the United Nations as the countries with the lowest levels of per capita income and socio-economic development¹.

OECD adopts another categorisation for countries according to their income level (based on World Bank standards) and OECD membership status for the purpose of determining their repayment capabilities². According to this, High Income OECD countries are classified in Category I and all other countries are classified in Category II. Ghana is considered a lower- middle-income economy under The World Bank definition, a developing country under the UN definition and falls under Category II of the OECD classification.

This thesis focuses on the analysis of 'middle- and low-income countries' following the World Bank classification, which I generally refer to also as 'developing countries'. I adopt this term even though the countries coming under this umbrella are extremely heterogeneous, because I assume that they share some common social, cultural, political and economic characteristics, which differentiate them "developed countries" such as:

ill-functioning institutions: a weaker state apparatus, relatively high levels of economic and social inequality, less efficient bureaucracies, higher levels of economic instability, less transparent legal proceedings and enforcement of legal frameworks (Lachman, 2012; Ramos- Mejía et al., 2018)

relatively high reliance on foreign sources of technology, knowledge and financial resources, and high involvement of external donor interventions (Hansen et al., 2018)

less advanced industrial capabilities, a dominance of low-tech (primary) sectors, reliance on extended family ties and clientelism (Bell, 2007; Viotti, 2002).

unstable political institutions and armed conflicts (Buhaug et al., 2008; Edsand, 2019)

a high share of non-state, informal actors in the system (Hansen et al., 2018).

It is noteworthy that even though these differences are more pronounced in developing countries, it cannot be assumed that they are irrelevant for developed or high-income countries. For example, although the majority of the 110 conflicts that are monitored today³ are taking place in Africa, Asia and Middle East, 7 of them are occurring in Europe and many more involve or affect developed countries. Moreover, while informality represents 70% of all employment in developing and emerging economies, it is also existent in developed countries, ranging about 18% (OECD, 2019). Similarly, corruption might be more prevalent in developing countries, but it exists in different scales and forms in all nations around the world. Therefore, the frameworks proposed in this paper while integrating features of developing country contexts are deemed relevant also for attaining the national missions of developed regions like in Europe.

2.2 Brief outline of post WWII discourses on development paths of middle- and lower- income countries

The development trajectories of developing countries have attracted the attention of many economists. In the midst of WWII, Rosenstein-Rodan (1943) introduced the notion of The Big Push, as a way to foster development. He argued for a coordinated, broad based investment program targeted on the industrialisation of a country's various sectors simultaneously. According to Rosenstein-Rodan, given increasing returns to scale, government-induced industrialization could break the poverty traps in developing countries. The Big Push called for integration of the demand-side in the "balanced growth" theory—the idea being that different parts of the economy should remain in sync as they develop.

Hirschman supported the same "balanced growth" school of thought albeit with a different understanding of the obstructors to development. He was of the view, that policy should promote a few key sectors with strong linkages before moving on to other sectors to correct the disequilibrium generated by these investments. In his classic work on *The Strategy of Economic Development*, Hirschman (1958) introduced the idea that the main limited resource constraining economic development is not capital, labour, technology or any other material factor, but rather the ability to make and implement development programmes.

As developing countries emerged out of colonialism, debates reigned over two kinds of decisions. First, how to catch up to be on par with developed countries in terms of industrial capabilities. Second, how much to accept the help of the developed countries through trade or aid to achieve this state. The catch-up hypothesis claimed that lagging countries would enjoy a higher rate of productivity increase, since they would have the 'advantage' of imitating foreign best practices, which is supposed to be considerably easier than to innovate (Abramovitz, 1986). More recent developments on the field of catch-up studies however have proved that catch-up processes are complex and costly requiring prior investment in building scientific capabilities and then technological and innovation capabilities as well as an enabling environment (both at the national and international levels) to build sectoral capabilities (Ramani, 2014; Ramani et al., 2018). The Trade VS Aid debate was built on Bauer's hypothesis that the relationship between aid and growth is inverse, since aid can delay adoption of growth policies and have damaging effects (Bauer, 1966). On the contrary, opening economies to trade stimulates greater demand for international capital flows and competitiveness, leading to sustained growth and poverty alleviation (Hughes, 2003).

Later, these different views on development took a new form under the Open versus Closed Economies approaches and the impact of national and international monetary policies on economic growth (Clarida et al., 2001;

Gundlach, 1997). The processes of industrialization and studies around import and import substitution were also heavily discussed in the literature (Baer, 1972; Bruton, 1989), driven by the same conflict between serving the domestic market or the international one. The common element in all these discourses was the acknowledgement that countries must build a variety of capabilities in order to become developed and be on par with high-income countries.

This recognition was the underlying premise of the 'national system of innovation' (NSI), spearheaded by the seminal works of Lundvall (1992), Nelson (1993) and Freeman (1995). The NSI encapsulates all the institutions, capacities and processes involved in the creation, adoption and integration of a new technology (Ramani, 2000). This construct is used to characterise a country's collective efforts towards fostering technological innovation, from the initial generation of new scientific ideas to their transformation into usable technology, and to the final integration of the new technology into the production processes of firms. The capacity of a NSI to build capabilities and foster economic growth depends on the resources available, the prevailing market and non-market incentives for investments in the new technology and the responsiveness of the firms and other entities to such incentives (Ramani, 2000).

Social capability (Abramovitz, 1995; Temple et al., 1998) is another determinant that could be used to explain differences in development pathways among countries. This term encapsulates economic functions such as entrepreneurship, learning by doing, organizational and institutional aspects related to transactions and information costs, the general economic and political framework which determine the relative costs of doing business in different countries, as well as their efficiency of savings and investments (Lal, 1995).

To conclude, while scholars continue to explore the drivers of economic growth and development, it is widely acknowledged that there is no single cause for economic progress. As Debraj Ray, one of the most accomplished theorists in development economics today, expounds, it is a combination of factors, including social capabilities, such as the improvement of physical and human capital, and governance and regulatory capabilities that consistently favours development Ray (1998).

3. How sustainability transitions differ in developing countries?

Any societal problem is embedded in one or more socio-technical systems (STSs), comprising interlinked components along technical, social and governance dimensions. The transition dynamics of STSs can be grouped in three main levels based on the MLP configuration. Socio-technical landscape represents the exogenous macro-events and trends (Schot et al., 2016). The socio-technical regime is the so called 'grammar' of the system, which denotes the paradigmatic core of a sector, that results from the co-evolution of

institutions and technologies over time (Fuenfschilling et al., 2014; Geels, 2004, 2011). Finally, niches encompass emerging and generally fluid assemblages of innovations, institutions, practices, and actor networks that aim to alter established patterns (Kemp et al., 1998). They represent the incubation rooms of the innovation process, in which new technologies or socio-technical practices emerge and develop isolated from the selection pressures of 'normal' markets or regimes (Geels, 2005b; Kemp et al., 1998). They typically take the form of important testing fields around which actors of a TIS assemble and coordinate their actions (Markard et al., 2008).

To better understand the distinctive specificities of transition processes in developing countries, I categorise them in three main types, based on the MLP and TIS derived concepts: landscape factors, regime elements, and niche-innovation functions. In the following sub-section, I explore how scholars are applying specific transition concepts to developing country contexts.

3.1 Landscape factors

In developing countries, macro-level institutional capabilities, such as weak and fragmented governance structures, low legal transparency, inefficient bureaucracy, economic and social inequality, political and economic instability, illiberal political contexts, weak or illegitimate states, low regulatory enforcement, unequal access to education and lack of environmental awareness influence sustainability transitions (Canitez, 2019a, 2019b; Edsand, 2019; Hansen et al., 2018; Jayaweera et al., 2022; Linda M Kamp et al., 2015).

There is also a very high dependency on international development assistance and associated enforced compliance with externally imposed rules and Northern norms (Oates et al., 2022). This strong influence takes place through transnational linkages of actors, knowledge, capital, institutions and technology (Wieczorek et al., 2015), including through North-South donor relationships (Marquardt et al., 2016) and South-South knowledge transfer (Ulsrud et al., 2011).

Developing countries are also burdened by a greater magnitude of societal challenges, such as the need to ensure access to safe drinking water, provide sanitation facilities and electricity supply to a larger percentage of their populations (Fathoni et al., 2021). Economic instability and poverty, corruption, geopolitical issues, low literacy rate (Linda Manon Kamp et al., 2016; Linda M Kamp et al., 2015), strong patriarchal values (Ramos-Mejía et al., 2018) as well as the impacts of climate change (Edsand, 2019) pose significant landscape barriers to transition.

The exogenous and relatively stable character of landscape forces is questioned when it comes to the analysis of transitions in developing countries (Wieczorek, 2018). Several studies show that the processes that take place at that level are not purely not exogenous but derive as a result of actors' actions, who aim to

promote their innovations and regime destabilisation processes (Romijn and Caniels, 2011; Kamp and Vanheule, 2015; Slingerland and Schut, 2014).

In sum, landscape factors seem to be stronger and more dominant, and therefore having greater impact on early innovations and regime components in developing countries. For example, the widespread poverty in Ethiopia makes it difficult for the locals to invest in biogas plants (Linda Manon Kamp et al., 2016). Another telling example is the case of Colombia, where climate change pressures positively influenced innovation functions in the wind energy sector (Edsall, 2019). Climate variability created insecurity about water availability and forced large hydro generating companies to consider diversifying their energy portfolio, making wind energy the primary alternative amongst renewable energy technologies. This gave rise to formal lobbying (F7a) by existing hydro companies to improve the conditions for wind energy diffusion. Thus, scholars call for an expansion of the original definition on landscape factors of Geels (2002) to include all these elements recognised above.

3.2 Regime characteristics

One of the most significant distinctions noted about developing countries is that often it is not possible to distinguish the elements of the regime from those of the landscape and niche as they interact as a bundle. In other words, more porous boundaries between landscape, regime and niche-level elements are evident in this context. Therefore, dichotomous conceptualizations such as niche/new entrants vs. regime/incumbents are questioned and have to be reconsidered to better understand niche-regime interactions (Dutt, 2022; Van Welie et al., 2018). For instance, the regime in the developing world mostly signals the significant role of power and politics (Dutt, 2022). Studies also reveal the coexistence of multiple, overlapping systems within regimes (Oates, 2021). This is complemented by the fact that STSs services are rendered in a more heterogeneous manner entailing unique ways in which technologies, capacities and power relationships are interwoven in socio-technical configurations (Dutt, 2022). Moreover, regimes are not always tied to one specific technological configuration but embed a great diversity of modes, or different co-existing sub-regimes, that can fulfil the same societal need (Wieczorek, 2018).

Power dynamics is a prominent influencing factor. On the one hand, studies recognise that the market system is widely controlled by powerful elites that affect transition at the systems level (Saculsan et al., 2020). On the other hand, emphasis is placed on the inclusion of marginalized stakeholders (i.e., less literate, comparatively powerless, or associated with marginalized languages) as a vital element for enabling transitions (Bou Nassar et al., 2021). This is particularly important given that a very high percentage of the labour market in developing countries is occupied by the informal sector (Dutt, 2022; Sixt et al., 2018).

Furthermore, regime activities leading to the absorption and diffusion of technologies are generally more fragmented or absent, slowing down efficiency improvements of the incumbent regime (A. Tigabu et al., 2017). These hindrances are augmented by inefficient institutions, market weakness, and insufficient demand (Ramos-Mejía et al., 2018). The future development of these internal conditions is also characterised by significant (deep) uncertainties, partly due to improper data collection for monitoring and scenario analysis (Castrejon-Campos, 2022).

It is also reported, that regimes in the developing countries, show a much higher degree of non-uniformity and internal tensions (Wieczorek, 2018). Regimes in these contexts are not always tied to one specific technological configuration but embed a great diversity of modes that can fulfil the same need (Van Welie et al., 2018).

The adaptability and responsiveness of the regime to different forces and stimuli it receives plays a critical role to the transition process. As it conceptualises the selection environment that determines the development and use of niche-innovations, it has the power to influence their impact on the status-quo of established technologies, institutions and practices. Apart from the readiness of the regime to accept or reject these attempts, its adaptability to change designates, to a great extent, the speed of the envisioned transition process.

3.3 Niche-innovations: formation & functions

By innovation functions we refer to factors that influence the development, emergence, diffusion and adoption of niche-innovations, with a potential to foster sustainability transitions. The TIS functions can be considered as the DNA of innovation systems that define the development, diffusion or death of specific niche innovations, and prescribe the reaction of socio-technical regimes to accept or reject them.

Developing countries are known to exhibit lower innovation capabilities, less innovation generation, usually of lower quality, with merest impact on their economic growth and development. Despite the shortcomings, the creation, development, diffusion and adoption of innovations in its various forms, and from various sources is key for sustainability transitions in developing countries.

Innovations in developing countries mainly emerge outside strictly protected niches. Sources of innovation and transition are mostly associated with meso-level organisations (such as public organizations, industry associations and universities), and macro-level factors (such as global market trends), rather high-end R&D activities (Mohamad et al., 2020). Innovation may originate from less formalised 'shop-floor' based activities as has been expressed in concepts such as 'frugal innovation', 'grassroots innovation' and 'inclusive innovation',

which utilize local assets and involve indigenous knowledge systems, under extreme resource constraints, located outside R&D laboratories (Arocena and Sutz, 2010; Foster and Heeks, 2013; Fressoli et al., 2014; Knorrinda et al., 2016; Pansera and Sarkar, 2016; Swaans et al., 2014; Hermans et al., 2016). Regime-level actors can act as innovators and take the lead in experimentation and niche creation (Rajagopalan et al., 2022).

Moreover, the selection of innovations from the niche level is highly influenced by landscape pressures rather than market forces or meso- level interactions (Edsand, 2017, 2019). A good example to illustrate this point is the case of wind energy in Colombia. In his study, Edsand showed how persisting armed conflicts in the country increased interest rates for investments, making the wind power technology construction particularly vulnerable and insecure project. Other landscape factors, such as low education quality in Colombia, resulted to limited awareness of the local population about environmental issues and the benefits of renewable energy technologies, as well as lack of sufficient qualified personnel to maintain future wind parks (Edsand, 2017, 2019). Rahmani et al. (2022) also explained how political priorities in the landscape influenced the function of “guidance to search” (F4) and led to increasing the social acceptance of wind energy in Iran.

International inputs are important. Apart from the know-how, technology and finance are also to a large extent sourced through connections with international research organizations, foreign investors, foreign companies, and international donors (Nygaard et al., 2018). For example, in their study about transitions in water harvesting practices in Jordan, Sixt et al. (2018) found that the financial capabilities problems that the country is facing make it reliant on donors for a significant share of budgetary needs for knowledge development and diffusion, which results in indirect impacts on the direction of the search (F4), resource mobilization (F6), and creation of legitimacy (F7) functions in both positive and negative ways. Thus, donor interventions (Sixt et al., 2018) and development aid (A. Tigabu et al., 2017) are important additions to local resource mobilisation (Surana et al., 2015) for knowledge diffusion and knowledge development functions.

Weak learning and entrepreneurial culture are some other determining factors for the innovation system in developing countries. Learning processes and actors’ interactions can be characterised as ‘weak, passive, and fragmented’, with high dependence on foreign knowledge, financial and technological resources (Esmailzadeh et al., 2020; Rahmani et al., 2022). The ‘learning by doing, using and interacting’ form of learning is more prevalent and generates primarily more of ‘incremental’ innovations (Kebede et al., 2017). There is general lack of entrepreneurial mind-set (Linda M Kamp et al., 2015).

Resources and capabilities shortages have also a strong influence on niche innovations. Lack of funding and support for fringe activities are cited most

often as barriers to sustainability transitions (Sultana et al., 2022). Furthermore, there are few institutional and technological capabilities to improve technology to address these challenges (Sagar et al., 2014). Other factors include organizational and social elements that do not promote an enabling business environment for the adoption and diffusion of new technologies (A. D. Tigabu et al., 2015). Studies also highlight the need for more concentrated and effective coordination efforts, targeted by a long-term, shared vision between different donors' interventions and local actors to develop critical mass in TIS development (Sixt et al., 2018;

A. Tigabu et al., 2017). This argument is based on the proven urgency to move beyond directly matching local users' needs with imported technologies, by adopting a collaborative approach that empowers market actors to make their own choices and decisions with regard to new technologies so as to influence institutional environments in their favour (A. D. Tigabu et al., 2015).

Thus, TIS functions vis-à-vis developing countries must be extended to include adaptive capacity, i.e., a country's institutional and organizational ability to receive and integrate foreign knowledge or technologies, in addition to own innovation capabilities (Edsands, 2019). This, in turn, will depend on resource mobilization capabilities, type/intention of international inputs, effectiveness informal lobbying, i.e., public support and opinion and legitimacy creation (Edsands, 2017). For example, van Alphen et al. (2008) talked about the incapability of Maldives to develop the appropriate renewable energy technology domestically, so the country has to be able to absorb and adapt imported knowledge to substitute this constraint. Indeed, proposed knowledge sharing/transfer, technological learning/transfer and use of human resources from abroad are innovation functions that often need to be redesigned for impact (Esmailzadeh et al. (2020). Cultural aspects is another element that needs to be strengthened in the TIS function analysis (Blum et al., 2015).

The speed and success of sustainability transition processes highly depends on the strength and durability of the developed niches to gain a place into the market, as well as on their suitability to the broader local context and social desirability. For instance, a niche- innovation can be selected given its favourable cost-benefit ratio (Clausen et al., 2019; Kemp et al., 1998), high expected efficacy (Clausen et al., 2019), the potential to involve more people in a community to build new practices and to create a supportive podium grounded on interpersonal relationships between grassroots innovators and different organisations, and the ability to provide local solutions (Singh et al., 2020).

In summary, this paper distinguishes between sustainability transitions in developed and developing countries based on the latter's (i) higher intensity of influence of the landscape factors, (ii) greater level of fragmentation that characterises their socio-technical systems, and (iii) lower level of resilience of their (sustainability-oriented) innovation systems.

- i. First, landscape factors often have a greater impact on the niche developments and regime trajectories. Influences deriving from the economic, social, political and environmental context have a bigger magnitude because they are deeply rooted in weak institutional factors, highly dependent on external assistance and usually accompanies with other societal challenges that are prevalent.
- ii. Second, socio-technical regimes present a higher level of fragmentation, since they are constituted from a variety of formal and informal actors, performing diverse activities to fulfil STS objectives in different ways, which are usually not aligned and coordinated, resulting to tensions
- iii. Third, sustainability-oriented and other innovation systems demonstrate a lower level of resilience. This derives from the weaker guidance of the research, the inadequate resource mobilization and the lack of coordination among all involved stakeholders. As a result, landscape influences and regime resistance are more detrimental to the success of the innovation systems.

4. Case study: Waste-to-energy transition of the solid waste management system in Ghana

This section shows how the interplay of transition dynamics can shape different configurations that consequently give rise to different transition outcomes. We illustrate this with the case of solid waste management (SWM) socio-technical system of Ghana and its ongoing transformation through the diffusion and adoption of waste-to-energy niche for more sustainable waste treatment processes.

Ghana is presently considered to be one of sub-Sahara Africa's most politically stable economies, while consistently ranking in the top three African countries for freedom of speech and press (European Commission, 2020; The World Bank, 2022). In fact, Ghana is at crossroads as it seeks to create jobs and reduce poverty through several programmes, including its flagship One District One Factory (1D1F) industrialization agenda, while reducing its environmental footprint through adoption of a CE approach to production and consumption.

4.1 Case study description

Counting a population of about 32.83 million, Ghana ranked as the world's seventh 'dirtiest' nation in 2015, due to the country's longstanding sanitation and waste management problems (UNICEF and WHO, 2015). Despite being a prominent member of the Economic Community of West African States (ECOWAS), Ghana's environmental performance index⁴ scores in place 170 out of the 180 countries evaluated by Yale University (2022).

According to most recent estimates, the country generates between 150 kg and 200 kg MSW per capita annually, which translates into about 6 million tons of MSW per year (Nketiah et al., 2022). Organics account for the largest content of

MSW in Ghana (61%), followed by plastics (17%), electronic waste (6%), paper (5%), metal (3%), glass (3%), textile (2%) and leather (1%) (Keesman, 2019). A large portion of the waste generated in the country is improperly disposed of, leading to groundwater contamination and Greenhouse Gases (GHG) emissions and posing multiple environmental and health risks. Current statistics reveal that the Accra Metropolitan Assembly of Ghana spends about US\$ 3.45 million annually on collection and transport of waste for disposal, while improperly disposed waste costs the country US\$ 290 million every year (Abalo et al., 2018).

The aforementioned waste situation in Ghana justifies the need for new strategies to accelerate its circular economy transformation and to treat and manage waste, taking into account its resource value.

The Government of Ghana has fleshed out clear sustainability commitments in its Long- term National Development Plan (LTNDP). With the advent of climate change and its potential to destroy the natural environment in Ghana, there has been a significant amount of interest in transitioning from a carbon-intensive economy to a low carbon economy. Complementing policies to accelerate the transition to a CE, such as the Environmental Sanitation Policy (ESP) in 2010, e-waste regulations Act 917 and LI2250 in 2016. In October 2019, Ghana took a step forward and became the first African nation to join the Global Plastic Action Partnership, thus establishing the Ghana NPAP (National Plastic Action Partnership) as a platform to share ideas among key actors (World Economic Forum 2019). A national plastic policy was then promulgated under the NPAP.

The case study is constructed using multiple data sources such as media content, government documents and academic literature. The data for the media content analysis was collected using the Lexis Nexis© database, including major Ghanaian and African mainstream and business newspapers. The search words used were circular economy, waste, and Ghana.

4.2 Analysis of transition dynamics and interactions

In this subsection, I start the analysis with the emergence and slow diffusion of waste-to- energy technologies in Ghana's solid waste management system and identify what are the most influential transition dynamics that play a role in this process.

4.2.1 Achieving CE through waste-to-energy alternatives

Ghana has already experienced two phases of transition in its waste management regime. After its independence in 1957, waste management was considered the responsibility of the state and the respective municipal assemblies. During this period, and until 1985, Ghana witnessed a general

deterioration and breakdown of public sanitation facilities in the major cities. Then in 1985, the second phase of the transition took place. At that time, a Waste Management Department and a Waste Management Advisory Committee was established with the responsibility of regulating the situation, while private actors joined the regime under private-public partnerships (Fobil et al., 2008). The country is currently in the process of the third phase, towards a more circular waste management system, supported by PPPs and international collaborations.

A waste management regime can become more circular by generating less environmental contamination, preserving the health of its workers and citizens, and creating value from the waste. In this paper, I will focus on the acceleration of the third phase of Ghana's SWM system transition and explore the technological options to generate energy from waste. The waste-to-energy alternatives offer to play a promising role in the circular transformation of the sector, as they are one of the surest ways to produce predictable and quantifiable energy while solving environmental challenges caused by poorly managed waste (Afrane et al., 2021; Ayodele et al., 2019).

Technological options

Waste-to-energy solutions are increasingly emerging as the most sustainable solution to the twin problems of waste management and the energy crisis in the country (Ofori-Boateng et al., 2013). On the one hand, waste to energy approaches can serve as a sustainable management strategy to handle the escalating volume of solid waste, while on the other hand it can also reduce greenhouse emissions and open up opportunities in the transport sector through the use of biogas as a vehicle fuel and reducing national grid peak load (Amo- Asamoah et al., 2020). Nevertheless, it is still considered as an expensive and capital- intensive investment.

There are many energy technologies which can convert these waste materials into electricity, heat and fuel. The conversion technologies include incineration or combustion, gasification, pyrolysis, anaerobic digestion, fermentation, esterification, and landfills gas recovery (Ofori, 2016). While many waste-to-energy technologies are mature and widely applied in other parts of the world, they are relatively more expensive compared to conventional technologies particularly due to the high cost of waste collection and management.

Several studies conducted in Ghana highlight the great potential for energy generation from waste produced in the country (Duku et al., 2011a; Ofori-Boateng, 2013; Mohammed et al., 2013; Kemausuor et al., 2014; Ulrike et al., 2014; Gyamfi et al., 2015; Danquah et al., 2018; Akolgo et al., 2018; Acheampong et al., 2019). Notably, few studies in the last decade have been pursued in the field of Ghana's WtE, but predominantly most of these works have been done in the context of identifying the potential there is in WtE for Ghana's power

sector and assessing the benefits and fitness of different WtE technologies to the local context. A summary of these studies is given in Appendix II.

When it comes to the criteria for the selection of the most favourable WtE technology, the most important one is energy generation per annum, followed by conversion efficiency, initial investment, operations and maintenance, cost of electricity, generation capacity and payback period. This indicates that for a WtE technology to be feasible in Ghana, the highest consideration must be given to the amount of electricity the plant generates annually while the net present value of the said plant is given the least (Afrane et al., 2021). From the economic standpoint, the capital cost carries the greatest weight in the selection of a WtE technology in Ghana, while from the environmental standpoint, CO₂ emissions are ranked as the most significant environmental sub-criterion (Afrane et al., 2022).

Based on these criteria, the most feasible WtE technology for investment in Ghana was found to be gasification, while plasma arc gasification was the least viable technology (Afrane et al., 2021). Gasification can help in the country's quest to meet its energy demands, while it can also reduce waste weight by almost 70%–80%. In addition, given Ghana's limited landfill capacity (LF9), gasification becomes a viable alternative for reducing the quantity of plastic, metal, and ceramic waste, which take up more space in landfills due to their low degradability. Gasification products (heat, syngas, biochar, and fertilizer) may be utilized in a variety of applications, including cooking, transportation, and agriculture, to improve other sectors of Ghana's economy in addition to generating electricity. Also, the climatic condition in Ghana (LF2) is associated with high temperatures and a lot of sunlight which means that MSW can be thermally processed to go into gasifiers with lower moisture content. Another advantage of this technology is that it does not require sorting at source, as anaerobic digestion does.

The studies conducted in this field (as summarised in Appendix II) showed that several factors hinder waste to energy technology in Ghana; key among them was high capital cost, high operational cost and lack of governmental support and policy framework. Other challenges are the high cost associated with the collection and management of waste materials. Nevertheless, the potential of WtE for the Ghanaian cities is high, since the content of waste generated in Ghana has a higher percentage of organic materials, ranged from 48% to 69%. (Ofori, 2016). For example, if the MSW produced in Kumasi alone were converted into energy, it could serve 8% of national residential electricity consumption (Amo-Asamoah et al., 2020). In another study, Ofori (2016) estimated the energy potential of MSW generated in Ghana in 2016 to be 18.5 PJ, which could satisfy 17% of the electricity consumption of the country.

In the following sub-section, the most influential factors that affect the adoption and diffusion of this niche, for the transformation of the dominant regime are

analysed and summarised. This analysis helps us to explain the slow diffusion of this circular technology.

4.2.2 Transition dynamics

I first start with the analysis of the most prominent transition dynamics that influence the emergence and diffusion of WtE technologies in Ghana, as described in Proposition I. I categorise them based on the nature of their influence as driving or obstructing forces. The following paragraphs analyse these dynamics.

Positive influence: Landscape level

High economic growth (LF1), climatic conditions (LF2), urbanisation and high population trends (LF4), impact of international markets (LF5), rising environmental concerns (LF6), and the country's limited landfill capacity (LF9) are some of the significant landscape pressures that create a favourable environment for the WtE transition in Ghana. Other macro- level trends and challenges (LF10) that push for a change are those of the weak energy mix of the country.

To top it all, overall consumption levels have been steadily growing in Ghana, up by 121% in the period from 2006 to 2018, mainly due to increasing population and per capita household expenditures, with country's increasing per capita material consumption leading to higher demand for resources. Moreover, Ghana's urban population has grown from 50.3% in 2009 to 56.71% in 2019 (Plecher 2020) (LF4). Increased population growth and urbanisation resulted in increasing generation of volumes of waste particularly in the two biggest cities of the country Accra and Kumasi (Amo-Asamoah et al., 2020). These escalating crises put pressure on the existing landfill-based regime and trigger the search for alternative waste management methods. Further to this, the country is home to a large proportion of young adults, with the majority (over 50%) of the Ghanaian population are under the age of 25 years. This presents a huge potential for technology adoption and investment in the WtE field (Ali et al., 2021), since young adults are generally more curious and inclined to try and adopt new technologies (Amfo et al., 2020).

In addition, the climatic condition in Ghana (LF2) is associated with high temperatures and a lot of sunlight which means that MSW can be thermally processed to go into gasifiers with lower moisture content (Afrane et al., 2021), which is a positive development for WtE transitions. Further to this, Ghana's limited landfill capacity (LF9) makes gasification a viable alternative for reducing the quantity of plastic, metal, and ceramic waste, which take up more space in landfills due to their low degradability (Afrane et al., 2021).

The urgency to manage the shift to a more value producing waste management system through WtE is also magnified by other macro-level trends and

challenges (LF10), which play an indirect role in this transition processes. For example, Ghana's economy relies heavily on petroleum as the major source of energy. There is yet very little variation in the energy mix of the country to include sustainable renewable energy sources. As a result of this, any difficulty in the generation or purchase of petroleum products to fuel energy generation plants takes a serious toll on electricity production and the economy of the country at large (Amo-Asamoah et al., 2020).

Positive influence: TIS performance

At the level of the TIS performance, positive influence on the WtE emergence originates mainly from the existence of a fertile environment for research and innovation in Ghana, that gives rise to various entrepreneurial activities (F1), supported by the large pool of researchers both in academic institutions and in non-academic research centres (F6a) (Di Ciommo et al., 2019). In addition, Ghana's efforts to accelerate green transitions are boosted by its ability to access global climate funds (F6b) such as Green Climate Fund (GCF), the Global Environmental Facility among others (Ali et al., 2021). The strong international connections of Ghanaian research institutes (F8), including several CE-related projects supported by Horizon 2020, in which Ghanaian research institutes are involved, is another enabling function that could further promote WtE (European Commission, 2020).

Positive influence: Niche innovations

At the level of the niche innovation, the most significant enablers for this WtE transition are the high returns and the profitability of waste to energy generation, and the evident environmental benefits, as they are estimated in several studies. (Ministry of Energy, 2010; Ministry of Local Government and Rural Development, 2010). Another strong enabling characteristic of this niche is the significant contribution it can play in the energy supply and security of Ghana (Afrane et al., 2021; Amo-Asamoah et al., 2020).

Positive influence: Regime characteristics

At the level of the existing waste management regime, signs of adaptation and acceptance of a WtE technology are positive, given that the content of waste generated in Ghana has a higher percentage of organic materials, ranging between 61% and 64% (Ofori, 2016), which is ideal for the generation of energy. Citizens' attitude and preferences (R6) seem to favour a change in the dominant regime. In a study conducted by Amo-Asamoah et al. (2020), respondents were asked to indicate the best means through which waste should be disposed of, with the majority (69.5%) indicating energy recovery. Sectoral policies and government support (R2) are also supporting the system's transformation. With the quest to become one of the cleanest countries in Africa, the Ghana government has increased the allocated budget for sanitation management to

21% from the 2017 budgetary allocation, in an effort to improve the current waste collection system (MOFA, 2018).

Established private sector capabilities are expressed through the efforts from the biggest private company operating in the waste management sector, Zoomlion-Ghana, are targeted towards the improvement and efficiency of the sector's activities (R7). The company has procured 101 new trucks for the collection and transport of waste in several cities in Ghana presented to the public in June 2021 (Magoum, 2021b). These factors among many others, could considerably increase the feasibility of future gasification plants from the waste collection perspective.

Negative forces: Landscape level

At the landscape level what hinders or delays the transition processes towards a waste-to- energy shift in Ghana are the weak national financial and investment system (LF5), the level of corruption in the country (LF3), and the absence of a strong environmental education system (LF6).

More specifically, the national investment environment (LF5) is characterised by barriers in accessing finance and high interest rates for loans, therefore severely hampers the ease of doing business the country (European Commission, 2020). This is further worsened by the issue of corruption (LF3), a major course of worry for many African countries of which Ghana is no exception. According to Transparency International (2022) Ghana performed poorly on the Corruption Perception Index (CPI) dropping from 48 in 2014 to 43 in 2021 and ranked 73th out of 180 countries. The net effect of corruption could go as far as increasing the net cost of adopting a green technology, which would imply excluding majority of Ghanaians. Studies have found a direct correlation between corruption and the cost of establishing a power plant (Debnath et al., 2018; Locatelli et al., 2017).

Further environmental educational programmes are lacking (LF6), mainly due to limited resources and capacity of the responsible agencies (LF1). In general, Ghana has not yet developed a stand-alone national legislation or strategy on neither environmental education nor education for sustainable development (ESD), while the largest provider of basic skills in Ghana, remains the informal apprenticeship system (European Commission, 2020). This situation is clearly reflected in the national expenditures in relevant fields, with Sithole (2020) reporting Government Expenditure on R&D being 0.08 % of GDP, Higher Education Expenditure on R&D 0.265% of GDP and Business Expenditure on R&D 0.01% of GDP.

Negative forces: TIS performance

With regards to the TIS functions, what is found to pose a negative influence on the WtE transition pathway is the weak knowledge development (F2a), weak

creation of a common direction to manage this shift (F4) and low resource mobilisation (F6a,b).

The existing level of knowledge development (F2a) in Ghana does not support the niche development and transition pathway of Ghana. One reason for that is because the STEM subjects (science, technology, engineering and mathematics), on which the country relies in order to create meaningful opportunities for promoting and implementing CE approaches, often lack a tangible link to the everyday life of the pupils, resulting in a general aversion of many graduates to consider a career in the STEM fields (Siemens Stiftung, 2020). Moreover, there is a limited number of local investors in green financing in Ghana (F6a). They further noted that even though local investors have the capacity to promote green financing, little has been done to harness this potential (Amfo et al., 2020). This situation is further worsened by the overall lack of reliable data that does not allow the continuity of knowledge production (Di Ciommo et al., 2019).

There is also limited local investment in green financing in Ghana (F6a). Although local investors have demonstrated the capacity to promote green financing, little has been done to harness this potential (UN-PAGE, 2019).

Negative forces: Niche innovations

At the level of the niche innovation, barriers mostly originate from the high capital costs, high operational costs and lack of governmental support and policy framework (Amo- Asamoah et al., 2020).

Negative forces: Regime characteristics

At the regime level, there are many factors posing resistance to change. Poor cultural practices (R4) in terms of waste handling, such as waste burning and indiscriminate dumping, e.g. in gutters during the rainy season or on open plots of land during the dry season (Kanhai et al. 2019; EPA 2015; Netherlands Enterprise Agency; Keesman 2019).

Neutral

Lastly, certain transition dynamics are categorised as neutral, since although they do influence the transition pathway of Ghana, the sign of their effect is not distinct yet.

Domestically, the existence of a wide-spread informal sector (LF7) still holds a neutral role in the WtE transition at the landscape level. The informal sector accounts for 88% of the country's workforce and 75% of its economic activity and has cast a spotlight onto (often hazardous) informal waste management practices (Wayne Shand 2019). On the one hand, it hinders the implementation of more effective monitoring and enforcement frameworks and promotes illegal

practices. On the other hand, it still remains the key driving force behind waste

	Positive influence	Negative influence	Neutral influence
Landscape factors	- Increasing economic growth (LF1) - Climatic conditions (LF2) - Increased population growth and urbanisation (LF4) - Citizens' belief that energy recovery is much more appropriate than landfilling (LF6) - Limited landfill capacity (LF9) - Costly and inefficient energy sector, which heavily relies on petroleum, Digitalisation (LF10)	- Barriers in accessing finance and high interest rates for loans severely hampers the ease of doing business the country (LF5) - Political instability and corruption (LF3) - Physical endowments (LF9), like lack of land availability	- Promising, yet currently neutral, role of informal workers (LF7) - Ghanaians awareness on negative environmental impacts from human activities is not yet reflected in their education and training capacities (LF6). - Notable absence of EU financial guarantees to support CE-related projects in Ghana (LF5).
Innovation System functions	- Fertile environment for entrepreneurial activities (F1) - Large pool of researchers both in academic institutions and in non-academic research centres (F6a) - Ghana's ability to access global climate funds (F6b) - International connections and collaborations (F8)	- Difficulties in domestic knowledge production and development (F2a) - Weak creation of a common direction to manage this shift (F4) - Low resource mobilisation (F6a)	- Availability of technical expertise in Ghana and the Kumasi metropolis in particular - Donor interventions (F8) hold a promising role for the waste-to-energy transition. - Research and technical cooperation on CE between Ghana and the EU is limited so far (F8).
Niche-level innovations	- High return or profitability of waste to energy generation - Significant contribution to the energy supply and security in the country - Offsets greenhouse gas emissions, avoidance of pollution and unpleasant odours	- High capital cost and operational costs of waste to energy plants	
Socio-technical regimes	- The amount of waste generated in the cities of Ghana are significant and sufficient for waste to energy generation. - Sectoral policies and government support (R2) - Citizens' attitude and preferences (R6) - Investments towards the improvement and efficiency of the sector's activities (R7)	- Lack of governmental support and policy framework to support waste to energy generation (R2) - Landfilling is the commonly practiced means of waste disposal - Established cultural practices of waste handling, such as waste burning and indiscriminate dumping (R4)	

pathway in Ghana

4.2.3 Transition dynamics – Interactions

As explained in the proposition II of this paper, the final outcomes of the transition process are also dependant on the disruptive or reinforcing interactions that take place between and among the transition factors. This section provides examples that illustrate how the interplay of these transition dynamics are influencing or have the potential to influence, in positive or negative ways, the WtE transition in Ghana.

Positive interacting effects

(1) The privatisation of waste management (R1) has given rise to recent engagement of entrepreneurs (F1) in the waste management sector (Abalo et al., 2018), that consequently contribute to the development of new WtE technologies (Niche) and foster their local adaptation.

(2) The government of Ghana has recognised the sustainable economic, environmental and social benefits associated with green economy (LF8) and has committed to mainstreaming programmes aimed at enhancing green economy development of the country. Furthermore, green economy has gained huge support from civil society organizations in Ghana, regional/international development partners/organizations such as Economic Community of West African States (ECOWAS), African Union, and the United Nations, among others (F8). These agencies create awareness at the local level that aim to change citizens practices (R6), provide financial support, and assist government in the implementation of green economy policies in various ways.

(3) Ghana is heavily endowed with natural resources (LF9) which have formed the main economic backbone of the country for decades. However, the depletion of these resources in recent years has necessitated the diversification of the country's economic activities (LF1). This has helped the country to open up to cross-border trade (LF5). As a result, Ghana became the most attractive destination for Foreign Direct Investment (FDI) in the West African region (F6b). With the emergence of green technology development and Ghana's effort to transition to green economy development, the country presents a viable destination for green technology investment and the creation of a niche market for such technologies. Furthermore, the increasing demand for green products and services among Ghanaians provides a huge avenue for green investments (Ali et al., 2021).

Negative interacting effects

(1) Education in STEM subjects (LF6) often lacks a tangible link to the everyday life of the pupils necessary to find employment after their training, resulting in low performance and aversion of graduates to follow research positions in these fields (F2a,b). Further deficits that can be identified in Ghana's educational programmes (LF6) is that public awareness campaigns that aim to raise public awareness on the environment fall within the responsibility of the country's EPA (Environmental Protection Agency), which is limited in terms of resources and capacity (LF1). As a result, Ghana has not yet developed a stand-alone national legislation or strategy on neither environmental education (EE) nor education for sustainable development (ESD) (European Commission, 2020).

(2) Barriers in accessing finance (LF5) severely hamper the ease of doing business in the country, while high interest rates for small- to medium-sized loans (LF5) and the absence of viable long-term alternatives discourage Ghanaian entrepreneurs from expanding their business operations (F1, F6a) (European Commission, 2020).

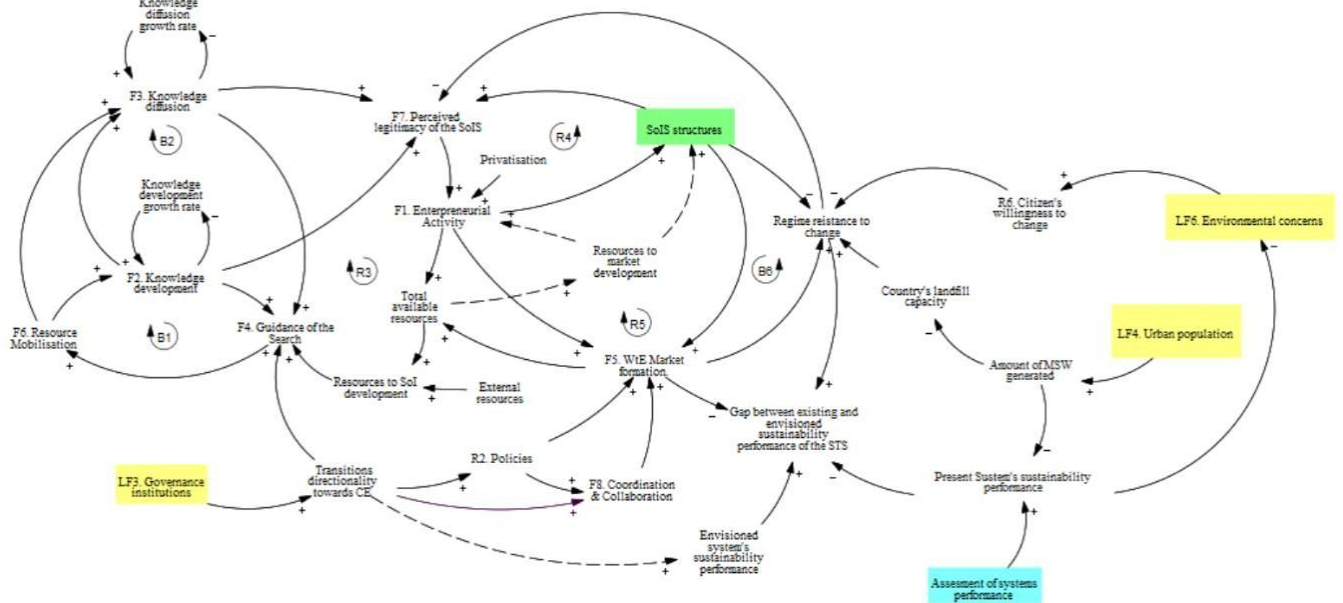
Moreover, local investors and policymakers are sceptical when it comes to green technologies, due to the lack of awareness of the real cost and benefits of these technologies (F7a,b), as well as data unavailability and capacity to access potential green investment risks (F9). All these contribute to lack of adequate local funding for green technology development and innovation (F6a), that have a negative impact at the niche level.

The over-dependence on external support (LF5) coupled with low domestic savings for financing development projects (LF1) poses a serious challenge for green economy transformation in Ghana. The projected rising debt possess a threat to both the fiscal and monetary economy, particularly revenue mobilization exchange rate and inflation. This also effects the financing of green projects and initiatives (F6a,b), especially because Ghana is predominantly an import-led economy (Ali et al., 2021).

(3) Although Ghana has formulated some of the best environmental policies in the West African sub-region (LF8, F4), the country still lacks commitment by successive governments to implement such policies, and the will and commitment to adequately finance green initiatives (F6a). Even though government has expressed the commitment via the signing of protocols in support of green economy development and implementing the relevant policies, the challenge has always been the actual implementation (F7b) (European Commission, 2020).

Neutral interacting effects

Digitization (LF10) holds the power to enable cross-sectoral innovation through, for instance, waste-to-resource platforms (Niche), enable industrial symbiosis (F8), expand the reach of sales channels for refurbished products, support the integration of informal sector, and enhanced consumer awareness (LF6). It also holds a promising role in supporting cross-border collaborations (F8) and shifting commercial interests in driving the development and transfer of green technologies (F2a,b).



5. Discussion & Conclusions

It is evident that the historical and contemporary reality of the developing and developed world differs significantly. This fact is support of the argument that technological and social innovations originate from the North cannot always be absorbed as such by the South. The development trajectories of countries in developing countries are seriously hindered by enduring poverty and social

inequalities, along with major environmental challenges that make the envisioned transition a much more complex process. Moreover, transitions of STSs in developing countries are characterised by external dependencies affecting the (de)stabilisation of regimes and the development of niches, non-stability of regimes due to a high stake of non-state, informal actors involved, undemocratic and non-egalitarian decision-making processes and heavy reliance on donor cooperation and import of already developed technologies from abroad (Hansen et al., 2018). These different patterns of development and the highly different causal mechanisms of change at play might be one of the reasons why the 'mechanical' application of the transition framework to that reality is difficult and point to the importance of ensuring a critical view on the appropriateness and application of basic theoretical and conceptual frameworks that dominate the literature in the context of transitions in developing countries.

Overall, the suggestions provided in this paper make an original contribution to the existing literature on sustainability transitions and specifically the use of the MLP and TIS approaches in developing countries.

The present work utilises literature findings as presented in the previous section, along with the empirical contributions discussed in the previous subsection, to arrive to an integrated framework that can accommodate the specificities of developing countries and contemporary realities of nations in general. While the TIS is primarily concerned with institutions, actors and networks to help explain the performance, growth and decline of a technology, we argue that the overall performance of its function does not only influence the development of new technologies but has also a direct impact on the emergence, flourishing and diffusion of different socio-technical niche innovations, as they attempt to enter socio-technical regimes. Following this argument, based on the MLP three-levels of analysis, landscape factors do not only create pressures on the regime, but also on the functions of the innovation system, as well as the niche-innovations themselves. All these interactions can take both a positive and a negative sign.

Using the example of Ghana's waste management system, we demonstrated how the adoption of a broader framework would enable the advance of research on policy mixes by allowing the identification of root causes, critical problems and intervention points not sufficiently covered by existing instruments. This, in turn, could lead to the design of a more complete portfolio of policy instruments and strategies, facilitating a change in the directionality of socio-technical systems towards increased sustainability. The policy implications of our framework are twofold: first, the design of policy mixes should address all six intervention points

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Notes

¹ <https://www.un.org/development/desa/dpad/least-developed-country-category.html>

² <https://www.oecd.org/trade/topics/export-credits/arrangement-and-sector-understandings/financing-terms-and-conditions/country-risk-classification>

³ <https://geneva-academy.ch/galleries/today-s-armed-conflicts> Accessed date: 19 October 2022

⁴ The 2022 Environmental Performance Index (EPI) provides a data-driven summary of the state of sustainability around the world. Using 40 performance indicators across 11 issue categories, the EPI ranks 180 countries on climate change performance, environmental health, and ecosystem vitality. Source: <https://epi.yale.edu/>

Sustainability transitions in the mineral sector: forces of lock in and change¹

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Abstract

Mining is a fundamental economic activity that provides the material resources of most other economic activities. It is also central for a significant number of countries, especially emerging ones, many of which face important shortages in the material living conditions of their populations. However, it is an activity plagued by serious negative social and environmental impacts that requires a radical transformation.

In this paper, we explore why, despite the importance of the mining sector and the urgency to improve its economic, social and environmental outcomes—especially in light of the increased demand fuelled by the energy transition—the mining sector has not changed its main technologies, why existing studies concerned with radical transformations or transitions have not studied this sector, and propose some interesting avenues for future research. We show how the transition studies toolbox can be useful to describe and understand the mining socio-technical system and its problematic social and environmental trajectories, as well as to reflect on the possibilities to redirect these activities towards more sustainable trajectories. We also propose some directions along which transition studies could help understand and promote transitions in mining, and some important directions that should be considered by policy.

1. Introduction

Mining is the first link of most value chains and the economic pillar of many developing countries. Its importance will increase over the next decades with the ongoing transition towards renewable energy sources worldwide, which will drive increases in the demand for minerals (see World Bank, 2017, Hund et al., 2020; International Resource Panel, 2017; Bazilian, 2018) of up to 1000%. It has, however, a strong negative social and environmental footprint, and is responsible for significant socio- environmental challenges and conflicts in low- and middle-income resource rich economies and an increase in the development tensions in countries rich in mineral resources (Marin and Goya, 2022). If these development tensions are not addressed, the global energy transition will only shift the environmental problems of the world economy to resource rich economies, most of which are developing economies (Newell and Mulvaney, 2013; Van den Bergh et al. (2015) challenging not only the justice of the process but also its viability.

In this paper we draw on concepts and ideas from sustainability transition research to investigate why the mining sector has not changed its main technologies, identify emergent forces and drivers of change and propose some interesting avenues for policy and research. Our research fills an important gap in the transition literature, which surprisingly has not investigated driving forces and possibilities of transitioning in this sector. The paper use evidence from Chile, the analysis is done from the perspective of and attending the challenges of a low- and middle-income country for transitioning, filling a second gap in the literature which has mostly been based on global or high-income country evidence and problems.

Sustainability transitions research focuses on understanding the complex processes through which socio-technical systems with unsustainable trajectories have transitioned and can transition towards more sustainable trajectories. This research has produced significant knowledge on transitions to sustainability in energy, transportation and agricultural systems (Köhler et al., 2019), increasingly considering the particularities of developing countries (see Wieczorek, 2018; Ramos-Mejía et al., 2018). However, primary sectors like fishing and forestry have not received much attention, and, most surprisingly, mining has been virtually absent from this burgeoning literature, despite the increasing evidence and awareness on its critical role in the ongoing energy transition (Marin and Goya, 2021).

Three related reasons in our view explain the limited attention that transition studies have paid to mining and natural resources. First, the scope of transitions research has been relatively narrow in two dimensions: systems and geography. In terms of systems, it has focused on the stages of energy, transport and food systems (see Kanger, 2020). In terms of geography, most of the literature takes a national perspective, however, a global one, that takes into account the different

types of national contexts may be required to tackle a system dominated by large transnational players with headquarters in advanced economies (see Fuenfschilling and Binz, 2018). Second, there has been a bias towards positive results: literature on failed transitions is scarce, even though it can provide important insights that cannot be obtained from cases of success². Third, ideas about transitions towards sustainability that do not incorporate economic outputs have limited impact when applied to transitions in emerging economies (Marin and Van Zwanenberg, 2023). For resource rich countries mining generates employment, foreign currency and government revenues, which makes the sectors attractive for those in charge of national finances. What is sustainability from the perspective of these countries? Who should be bearing the present-day costs that a transition to environmental sustainability entails on their current generations? Discussions on “just transitions” have focused too much on workers losing jobs in sunset industries and ignored other aspects of what is just and fair (Bainton et al., 2021).³ This explains to a large extent why policy and even domestic research agendas are slow to incorporate concerns about transitions in these economies.

Questions about opportunities and challenges for transitions in the mining sector, however, are crucially important for both host mining economies, many of which are developing and dependent on this sector, and the world economy, which depends on minerals for sustaining multiple sectors and a successful energy transition. Sustainability transition studies have potentially significant contributions to make to understand these opportunities and challenges, and most importantly, to think of the concrete actions that should be taken to promote sustainable transitions in this sector.

In this paper, based on insights from this literature we analyse the existing mineral regime, which are the main forces resisting changes and those driving changes in positive directions. We would argue that there is a very strong technological, social, and political lock-in in the sector around technologies of governance and extraction (reinforcing each other) that despite being very problematic and questioned in relation to environmental, social and economic impacts, have remained dominant for decades (see Klitkou et al. 2015). At the same time technological, economic and institutional alternatives are not evident, the sector is largely dominated by a few large international companies, and entry barriers are significantly high. These characteristics become more evident if we compare mining with other sectors such as agriculture, where despite the dominance of certain economic, social and institutional technologies, particularly around specific products, like commodity crops it is profitable to operate at different scales, using different technological approaches and production tends to be more distributed across different types of actors (Marin and Van Zwanenberg, 2023).

We identify however, important disruptions in the existing regime, which are opening opportunities for change, particularly in association with the energy

transition and its aspirations of justice, and discuss some emergent less explored forces of change. We emphasise the unexplored and potentially very important role of the resistance by civil society groups and local populations from the sites of extraction and suggest that this role should be better understood and supported in promoting transitions.

The paper is structured as follows. In Section 2, we discuss why mining is important economically, environmentally, and in relation to the energy transition. In Section 3, we introduce central ideas of transition studies and discuss why this research has been silent on mining. In Section 4, using evidence from Chile, we describe the socio-technical regime associated with mining, the main lock-in forces and forces of change. In Section 5 and 6 we take a forward-looking approach, and discuss possible directions for transitions research associated with transformation in the mining. Section 7 discusses policy implications. In Section 8 we conclude and point towards new area of research.

2. Relevance: Why transitions in mining is necessary and urgent

2.1 Increasing significance of mining

First, we want to stress the relevance of understanding and supporting transitions toward sustainability in the mining sector. At least three reasons explain why this is an urgent issue to understand and tackle:

- 1) Minerals are one of the key physical building blocks of everything around us: construction, vehicles, electronics, consumer goods, packaging, the industrial machinery that produces clothes and foods, and notably power generation, all require important amounts of different minerals.
- 2) The global energy transition depends heavily on mining, as clean electricity generation technologies are more intensive in terms of mineral usage than fossil-fuel-based ones (Hund et al., 2020). Minerals including copper, cobalt, lithium, nickel, and rare earths, are fundamental for the success of the energy transition, and we can already observe price rallies and talks of a new “supercycle” as a result of the increased demand resulting from the energy transition (Bloomberg, 2021; Goldman Sachs, 2021).

The conflict here is self-evident: there is a growing tension between the energy transition and resource-extraction activities that threaten not only the communities located next to mining centres but the feasibility and success of the energy transition itself. Consciousness about this tension is mounting, as the issue has been considered from different perspectives, including those who focus on supply chains and potential resource shortages (World Bank, 2017; Bazilian, 2018) but increasingly also its social and environmental risks and complexities (Lèbre et al., 2020; Sovacool et al., 2020; Bainton et al., 2021).⁴ The way in which the mining sector accommodates production to deal with the

increase in demand can have an impact on the cost, speed, and even feasibility of the energy transition (see e.g., Bainton et al., 2021; Marin and Goya, 2022).

There is a high degree of uncertainty in projections about future mineral demand, due to uncertainty about technological trajectories and about the ambition and stringency of energy transition policies (Hund et al. 2020; International Energy Agency, 2021). However, there is broad agreement in the fact that the energy transition will push mineral demand upwards, and that at the same time, that expanding supply is increasingly difficult: social and environmental pressures are mounting, and as easy-to-access and high-ore-grade deposits are exhausted, mining companies have to resort to deposits that imply higher technical challenges, usually associated to higher energy needs and higher social and environmental risks, including increased volumes of waste (Mudd, 2010), as well as higher environmental, social or governance risks (Lèbre et al., 2020). These problems translate into uncertainty about future supply—it can take around 15 years between discovering a deposit and beginning production (IAE, 2021; Bloomberg, 2021)—that can produce volatility in mineral prices, and eventually supply shortages and price hikes that could increase the cost and reduce the speed of the energy transition, ultimately reducing its effectiveness.

There are also geopolitical aspects that should be considered. While some of the critical minerals have relatively developed and diversified markets, others are “thin” and their supply is concentrated in a small number of countries, some with serious governance challenges (Bazilian, 2018; Church and Crawford, 2018; Lèbre et al., 2019). China is the key player in the extraction and processing of critical minerals, especially rare earths, and Chinese companies have been making acquisitions across the globe (International Energy Agency, 2021), further strengthening its position.

3) Besides, for many countries, mining activities play a critical role as a source of employment, foreign exchange and tax revenue. For example, in 2018, minerals represented over 80% of exports for Mongolia, Guinea, Botswana and the Democratic Republic of the Congo (ICMM, 2020). They are also a key sector for middle-income countries like Chile, where mining activities have accounted for as much as 30% of fiscal revenues at the height of the last mineral supercycle (Rodríguez et al., 2015), and even for some high-income economies, such as Australia, where it represents approximately 10% of its GDP (Australian Bureau of Statistics, 2021), or Canada, where it represents close to 20% of exports (Natural Resources Canada, 2021). Low-income mining countries have serious lacks in infrastructure and public investment, high levels of inequality, and serious shortcomings related to the provision of health, housing and education. Mining is often posed as a way out of those problems, but its contribution has often fallen short of expectations.

2.2 The lack of sustainability

Mining is plagued by serious environmental and social issues and is one of the sectors responsible for the largest number of socio-environmental conflicts worldwide.⁵ Some incidents have been dramatic and produced global concern, like the collapse of a tailings dam at Brumadinho in 2019 in Brazil, with over 250 deaths; but in most cases, the damage inflicted by mining activities on local communities has been silent, occurring over decades of governments turning a blind eye in the name of economic “development”. Mining activities can pollute the soil, air, and water resources while they operate. And after closure, huge masses of toxic residuals are left, often with inadequate closure plans (see Bainton and Holcombe, 2018 on the social costs of mine closure). Mining activity is intensive in water consumption—and is often located in areas with water shortage (International Energy Agency, 2021)—and intensive in energy usage—energy often obtained from carbon-based sources. In terms of non-environmental social issues, the sector is associated with accidents and worker safety problems (especially in smaller and artisan operations, see Hentschel et al 2002 and Teschner, 2012), and in some countries, child labour and sexual abuse (Sovacool et al, 2020), corruption and armed conflict (Cuvelier et al., 2014) and violent conflict (Bebbington, 2012; Le Billon, 2012; Sharland et al., 2017; Church and Crawford, 2018). One of the most dramatic examples of the negative socio-environmental “collateral damage” of mining activity is the case of Bougainville. The operation of a copper and gold mine in the largest of the Solomon Islands, through its negative environmental impacts and disruptions in local socio-cultural patterns, is considered to be one of the key factors triggering a decade long civil war which cost approximately 10,000 lives (Hilson, 2006; Lasslet, 2014; Adamo, 2018).

Finally, mining is, by definition, not economically sustainable in the long run, as it is a non-renewable resource. In theory, countries could use mining to develop technological capabilities that survive longer than the sector itself, but that seldom occurs in developing economies, where the sector acts as an enclave with few connections to the rest of the economy.

The popular concept of a “just transition” should in principle consider all these negative aspects of the energy transition. However, as argued by Bainton et al. (2021), the discussion focuses on the jobs lost in industries phasing out and “ignores the difficult questions surrounding the sourcing and supply of minerals and metals required to support renewable energy-systems in a low-carbon economy”.

The issues described here also show why mining should not be analysed as an economic sector, but rather a socio-technical system with an important political dimension and complex interactions with other systems.

3. Transition studies and the mineral sector

Mainstream theories of technological change within economics and economic studies of innovation have traditionally emphasised three main determinants of change: markets, policies and institutions and new knowledge and technology, acting individually and/or interacting with each other.

- Demand is a major market of driver of changes through decisions of which goods and services get selected or no in the markets. This can be exercised by final consumers, other companies or the government. A second important market force of change is competition between firms, which in their aim to gain higher market shares over their rivals permanently introduce product and process changes.
- Policies can incentive changes into more sustainable directions by addressing market failures, e.g., making companies paying the social costs of polluting technologies or creating incentives to companies to invest the direction of environmentally friendly technologies. They can also create regulations that stop problematic activities altogether, invest directly in new knowledge and technologies that address sustainability challenges, and/or create new markets and companies.
- New knowledge and technologies both create new opportunities and restrict the possibilities for change (Nelson and Winter, 1982; Klevorick et al, 1995). They broaden the space of possibilities of changing practices and technologies, creating opportunities for the development of new solutions, e.g., advances in molecular biology have opened new possibilities for drug and seeds development. But at the same time, existing knowledge and technologies restrict the space to what is known and possible in specific historical moments. Existing technologies create path dependencies. So, though markets and policies might be interested in technologies of mineral extraction that do not use water or energy, this possibility is not feasible with the existing knowledge and available technologies and infrastructure. However, knowledge and technological possibilities evolve, to a large extent responding to market and policy incentives, and this possibility might be available in the future.

Transitions studies, interested in the radical changes required for sustainable system transformation, have extended these theories to incorporate a more sociological conception of change in which both changes and path dependence results not only from the constraints imposed (and opportunities opened) by markets, institutions and cognitive processes, but also from dynamics related to culture and power (Köhler et al. 2019; Loorbach et al. 2017). In particular, these studies have emphasised the importance of looking at issues of agency, e.g., where is within the system and how is developed. Creating a “common vision” for transformations is seen as a central part of the process. As argued recently

by Schot and Steinmuller (2018) “the governance of system level transformations should be recognized for what it is: a political process which should provide room for appraising and negotiating the development of a diverse set of pathways as well as making choices for specific ones. In this negotiation process, visions of various groups do not have to be fully congruent, stakeholders need to recognize sufficient commonly attractive elements they can relate to in order to move forward” (Schot and Steinmuller, 2018, pp 1562)

Over the last couple of decades, the rapidly expanding body of literature on sustainability transitions research (see Köhler et al., 2019) has provided important insights on how transition processes have occurred historically in energy and transportation systems, as well as on how to foster and manage the transitions that are urgently needed today. But primary sectors, and particularly mining have remained unexplored even though the literature’s toolbox is well-suited to characterise these activities and possible changes in their systems towards more sustainable arrangements.

As the Sustainability Transitions Research Network’s (STRN) research agenda (Köhler et al., 2019) warns, “we tend to take sustainability for granted by looking at one dimension at a time, by not pausing to unpack it in various contexts, thereby missing potential conflicts and trade-offs”. The tension between the green transition and the negative side effects of mining seems to be one of such missed conflicts.

Sustainability transitions research focuses on understanding the complex processes through which socio-technical systems with unsustainable trajectories have transitioned and can transition towards sustainable arrangements. The unit of analysis is the socio-technical system (Geels, 2004) that fulfills a societal need (de Haan and Rotmans, 2011*), and not an economic sector, as is usually the case in disciplines such as innovation studies. How does mining enter the picture? The activities related to mining—not only extraction, but everything from exploration to processing and consumption—can and should be analysed as a system, one that fulfills the need for materials of other socio-technical systems. Not only it fulfils a need, but understanding mining encompasses much more than the economic activities of the firms within a certain activity code: there are a multiplicity of interacting actors involved, within a path dependent and evolving system of technologies and practices, an important role for government regulation, complex interactions with other systems, and domestic and global political aspects that should be considered.

We argue that three interrelated reasons explain why transitions research has not analysed extractive industries: the relatively low priority of transitions in the public and research agenda of most mining countries, and two characteristics of transitions research: its relatively narrow sectoral and geographical scope and a bias towards positive results, and its normative stance

that clashes with “developmentalist” traditions and can lead to ignoring some concerns that are valid in the context of developing countries.

The point of discussing these issues is not only to identify the causes of the omission. As different authors have pointed out regarding each of them, they are directions of research that could enrich sustainability transition studies if they are addressed, and we attempt to contribute in that line.

3.2 Limited scope

Even though transitions research has broadened its scope significantly over the last decade, there are at least two directions in which there has not been many advances, geography and the types of sectors or systems considered. For both dimensions, the issue of scope is twofold: focus on specific systems and geographic locations, and thinking within specific systems and geographic locations, i.e., with implicit or explicit boundaries that have limited the analysis of global problems and inter- system interactions.

3.1.1 Geography

Although transitions research began in the developed world, developing countries have received increasing attention lately (see Wieczorek, 2018), and specific initiatives are promoting the use of its frameworks across developing countries, such as the STRN’s “Transitions in the Global South” community. Transitions in developing countries are explicitly one of the areas that the EIST research agenda suggests as an important direction for future research (Köhler et al., 2019). However, its penetration in some regions, like Latin America, is still relatively limited.

The second aspect of the geographical scope are the national boundaries Markard et al, 2005. Fuenfschilling and Binz (2018) argue that there is an implicit “methodological nationalism” in transition studies and propose the concept of a global socio-technical regime that allows for a better analysis of the multi-scalar actor networks involved in the regimes and the international diffusion of institutional rationalities. There have also been calls for a more global approach from the technological innovation systems literature (Wieczorek et al., 2015; Gosens et al., 2015; Binz and Truffer, 2017).

Hopkins et al. (2020) stress the need for a worldwide transition towards sustainability, and in the case of mining, attempts at transitions at the national level are unlikely to be enough. A large share of mining activities occurs within low-income, poor-governance countries which do not necessarily have the incentives, or the institutional arrangements required to commit to and to enact the changes that are required. The demand implications of the green transition are also a global phenomenon that will have local consequences.

3.1.2 Systems

In terms of systems, there has been a strong emphasis on energy systems, agro-food systems, and mobility, with voices calling for broadening the scope of the literature (e.g. Kanger, 2020; Turnheim et al., 2020). Several factors can explain the focus on those systems.

First, agro-food systems, transportation, and energy are sectors with large and evident negative impacts on the environment. But why those impacts are evident to most people is an important question: possibly, because final consumers interact directly with their products and services. People get on cars and buses and can see their fumes; they turn on their lights, charge their electronic devices, and thanks to the climate awareness produced over the last decades, they can think about the environmental footprint of those actions; as they buy their clothes, they may consider whether the working conditions of those producing them are acceptable; and as they eat their fruits and vegetables, thanks to the new flows of information that have been allowed by information and communication technologies, they may wonder about possible health risks and the unfair social and economic conditions faced by farmers. But despite incipient campaigns, few individuals question whether their consumption of aluminium cans forces Guinean women to walk longer distances to fetch water; whether there was child labour behind some of the minerals found within their smartphones; or whether the extraction of the copper used for the power lines that bring renewable-based power to their homes resulted in some remote Andean villages drinking polluted water that causes irreversible health damage.

For the cases of transport, energy, food and clothes, consumers can directly contribute to promoting selected alternatives through their consumption patterns, but there is no direct way to do so for minerals. The value-chain distance between extractive industries and final consumers must at least in part explain the different perceptions and the lower societal pressures on mining compared to other activities, as well as general ignorance of its role in environmental and social problems. The fact that the negative impacts of mining are stronger in less developed countries could also matter.

Path-dependence in research trajectories may also play a role. Transition studies were born studying some specific systems, and when the geographical scope has broadened, it has tended to study the same systems that were originally analysed in the context of developed economies.

Finally, there are not as many niches solving the problems of mining as there are for other systems. This is a topic in itself to which we return below.

The issues mentioned above are attempts at explaining why the literature has focused on some areas while others have remained under-researched. Just like with the geographical dimension, one aspect of the scope is the types of systems

studied, and another, the predominance of intra-system rather than inter-system studies (see Rosenbloom, 2020).

The invisibilisation of minerals is the most striking considering its close ties with the energy transition. See for example (Rohe, 2020), who focuses on global innovation systems and the value chain of onshore wind but does not even mention metals or minerals. He does argue that the focus is not in the upstream sector, because it “has been discussed in various contributions already”, however, none of the cited contributions mention mining activities.

The ambitious and broad-ranging STRN research agenda (Köhler et al., 2019) does not consider minerals either, although the importance of value chains is mentioned. Kanger (2020) comments on this agenda and emphasises the need to broaden it towards “neglected” systems. Andersen et al., (2020), also discussing the STRN agenda, warn how what occurs upstream “typically goes under the radar in transition studies” and explicitly refer to raw material providers. They mention this in the context of a proposal to bring together transition studies and the field of industrial dynamics, as a way to align economic and environmental goals, something closely related to the reality of developing economies which we discuss further below.

Finally, taking a further step back and looking beyond value chains, the concept of Deep Transitions proposed by Schot and Kanger (2018) comes into play. A successful societal transition requires changes in “a wide range of socio-technical systems”, where the mining system is a prime example of the interdependence and interconnections across systems—and particularly in terms of their negative outcomes, which must be challenged and transformed.

3.2 Bias towards positive results

Positive results bias is a pervasive problem in research. It has been studied more deeply in biomedical research (see e.g. Dubben and Beck-Bornholdt, 2005; Sarewitz, 2021), but it is certainly a problem in the social sciences too (Peplow, 2014; Franco et al., 2014). In the context of sustainability transitions studies, we can also observe a tendency to favour “positive” results, or more precisely, on understanding transitions rather than non-transitions.

Most of the empirical literature analyses particular dimensions of instances of transitions, often focusing on difficulties, but in contexts where at least some niche with interesting potential can be observed, or a comparison is made between successful and unsuccessful pathways. As shown by Antal et al. (2020), 76% of studies on socio-technical transitions focus on “positive” transitions (towards sustainability) and 20% are neutral, leaving only 4% of works studying transitions “away from sustainability”. They stress the need for the transitions literature to increase research on “negative trends”, to understand their emergence and how to reverse them. In particular, they suggest broadening transitions research towards situations with potentially significant

negative environmental effects and where the transitions approach could enrich the existing literature. What we propose here is slightly different, as the situation of the mining system is not a transition towards less sustainable arrangements but rather a long-lasting lock-in into a negative one. But it is similar in highlighting the need to broaden the field of study to situations that are under-researched, and where the lack of alternative pathways and knowledge about them, make them even more urgent to address.

Theoretical contributions, logically, are about transitions, so they delve into characterising transitions more than situations of no-transitions. But some of the proposed typologies for transitions pathways, such as Smith et al., (2005), Geels and Schot (2007) and de Haan and Rotmans (2011) can be useful to understand situations of lock-in, a case explicitly considered by de Haan and Rotmans (2011).⁶ The macro transformative processes described by Ghosh et al. (2020) can also provide useful insights.

As it will be discussed in detail in the next section, some particularities of mining—most of them true for natural resources in general—have led to situations of strong technological and socio-economic lock-in, which result in the virtual non-existence of alternatives that deal with some of their unsustainable aspects, let alone candidates for replacing the whole socio-technical regimes. The idea that in the developing world “not one but many technologies” (Köhler et al., 2019) can fulfil the same need does not currently hold for some resource-based industries.

The transitions literature aims, correctly, towards ambitious, full-fledged socio-technical transitions, instead of the marginal, one-dimensional improvements in sustainability that can be found in relation to mining and particularly with respect to its negative social and environmental impacts. But this lack of “interesting” cases to describe has resulted in ignoring these negative impacts. This is especially troublesome when considering that the demand shock produced by the impending energy transition may help reinforce the current socio-technical arrangements and increase the social and environmental damage. As long as these issues are not addressed, the potential impact of research and action that accelerates the energy transition will have a smaller net positive effect, as problems simply shift (van den Bergh et al., 2015) from one link of the value chains to another. And the current situation is worrying both in terms of existing alternatives and of knowledge about the system and its workings.

In sum, the current lack of alternatives to the conflictive existing regime makes it even more urgent to explore this system, to understand it and uncover potential pathways for transitions.

3.3 Tensions about the idea of sustainability in developing countries

In developed economies, where transition studies originated, a certain minimum level of living conditions is taken for granted. These countries have diversified economies and technologically advanced industries that generate high-productivity jobs and can provide their government with sufficient funds for quality health and education, and good safety nets. Many of the negative effects of mining are concentrated in low-income and middle-income economies, with weak or non-existent social safety nets and where important shares of their populations lack access to quality education and health services, and even basic issues like housing and sanitation are not resolved for everyone.

Although awareness about the magnitude of the environmental crisis and the urgent need for action has increased, present-day worries and the urgency to satisfy needs perceived to be related to foreign investments and economic growth are still higher in the public agenda. Even more so during and in the aftermath of the pandemic, that has resulted in massive increases in poverty, particularly in developing countries (World Bank, 2020; Ferreira et al., 2021).

Sustainability transitions studies put environmental issues at the centre, and most recently also social issues, in contrast with development economic studies which have explicitly or implicitly favoured economic growth over environmental concerns. Classical economists considered natural resources in terms of the distribution of power across different groups of society. Developmentalists see natural resources mainly as a source of foreign currency to invest in capital goods to develop domestic industries. Neoclassical economics abstracts away from the particularities of different economic activities. Modern development economics, while still rooted in neoclassical theory, does consider some relevant dimensions, for example through the resource curse literature, which considers political and other non-strictly economic challenges associated with these industries. Its focus however remains on economic growth. Its policy toolbox is limited and oriented to this objective. Evolutionary economics and innovation studies have a much more comprehensive approach,⁷ but it is still strongly focused on the development of technological capabilities for economic progress, relegating environmental and social sustainability to second-order issues (see for instance the critique by van den Bergh, 2007), although over the last couple of years the “mission- oriented innovation policy” (Mazzucato, 2018) approach and the “transformative innovation policy” framework (Schot and Steinmueller, 2018), closely linked to the sustainability transitions literature, have attempted to move into the direction of putting the social and environmental dimensions first, and have begun to influence policymaking.⁸

The strong influence of academic traditions with growth narratives on policy thinking, and the particular technological and economic characteristics of the system that difficult the emergence of niches (more on this below), have

allowed the “growth” narrative to dominate the discourse. For policy makers. Mining activities are seen in these countries as a source of prosperity through jobs and taxes (and thus government spending). There has been not much room for alternatives⁹ and no interest from policymakers in promoting them, which translates into a lack of cases to be studied by transitions’ researchers (see the discussion above about the bias towards systems where there are alternatives to be studied).

The domestic political processes in each country are important in determining how strongly economic considerations predominate over environmental ones and understanding them should be a priority.¹⁰ The dominant narrative has been that of an unavoidable trade-off between economic “development” and environmental preservation. This is, however, a self-fulfilled prophecy: the regime is stable, and if left uncontested, without external or internal pressures, it will continue to work as it always has, i.e., producing negative social and environmental outcomes, and there will be no emergence of alternative technological, political or institutional arrangements that can produce significant changes. Instead, the problematic patterns are reinforced as further technologies and institutions are developed within the logic of the existing regime.

Having said the above, in the short run, with a strongly locked-in regime, in the absence of alternatives, there is indeed a tradeoff. Mining provides jobs (especially where small-scale, artisanal mining is important) and much-needed government revenues. What is sustainability? A unique, absolute answer to this question based on ecological equilibria is not necessarily politically and socially valid in the context of developing economies. Any form of investment in the wellbeing of future generations can have a non-negligible negative effect on the living conditions of current generations, which are, for many, already below what are considered the minimum living conditions in developing economies.

Ignoring this short-run trade-off on the argument of the preeminence of environmental concerns is just turning a blind eye on the problem and limits our capability to envision feasible directions for change. Some interesting contributions trying to deal with this tradeoff or in some way bring together transition and traditional innovation policy objectives include Alkemade et al. (2011) on aligning innovation and transition policies, Swilling et al. (2016), who aim to bring together the concerns from sustainability transitions and those related to the “developmental state”, and propose the concept of “socio-political regime”; Schlaile et al. (2017), on how to use the innovation systems framework on sustainability research; Andersen et al. (2020) on the alignment between economic and environmental goals to enhance the legitimacy of transitions; and Marin and van Zwanenberg (2020), who explicitly attempt to bring together insights from development economics, innovation studies, and transition studies. The coevolutionary framework proposed by Foxon (2011) and the

'failures' approach to policy by Weber and Rohrer (2012) are also relevant for bringing together these different lines of thought.

4. The mineral system: key dimensions of lock-in and change

Below we first briefly describe the mineral extraction socio-technical regime, and lock in factors using concepts of innovation and transition studies (Geels, 2002; Hekkert et al., 2007; Jacobsson and Johnson, 2000; Smith, 2007). With this purpose we use evidence from Chile, but only as an anchor, as our interest lies in the global socio-technical regime (Fuenfschilling and Binz, 2018). Second, we explore potential drivers of change, and why they are not working well in the sector. Finally, we analyse some drivers that have started to show signs of impact, global and local forces/drivers.

We are interested in changes that address three types of challenges: environmental, social, and economic.

Environmental challenge includes intensive use of water and energy, pollution, damage of biodiversity and health, and water and soil contamination (van den Bergh, 2007);

Economic challenges include enclave forms of operation. with limited promotion of diversification between, knowledge intensification, and learning and upgrading (Imbs and Wacziarg, 2003; Katz, 1984; Kim, 1987; Hallak et al., 2018) (b)

Social, exclusion from benefits and decisions, problematic working conditions, and interference with local value systems. (Cozzens and Sutz 2014; Ciarli et al., 2020; Konovsky, 2000).

4.1 Characterising mining's socio-technical regime, forces behind the lock-in

Drawing on the literature on both innovation studies and transitions studies we define ten socio- technical-economic practice dimensions (see Table 1) useful to characterise the dominant socio- technical regime of mineral extraction activities and the lock-in forces. Our characterisation begins with a typical innovation studies approach, which focuses on the productive, market and technology characteristics of firms, and then extends this by adding some dimensions used in transition studies to characterise and differentiate mainstream and alternative socio-technical practices.

Firm level	(1) Product
	(2) Process
	(3) Organisational model
Innovation studies of development	
Firm and Meso Level interactions	(4) Industrial organisational model
	(5) Market and user demand
	(6) Policy and institutions
Innovation studies of development enriched by ideas of transition research	(7) Knowledge base
Firms and meso level	(8) Guiding principles
	(9) Cultural values
	(10) Agency, power within the incumbent system
Transition studies	

1. Product

The final product is typically a commodity, i.e., an undifferentiated output that is traded in a global market which defines its price. Minerals are used in the construction industry, to build machinery and vehicles, and in final consumer goods, they are never bought in raw form from mining companies by individuals.

2. Process

Mining begins with the search for mineral deposits (exploration), and after finding one, a project is developed, evaluated economically by the firm and then in terms of regulatory requirements by the government, and eventually, the mining operation is constructed. Then it operates, usually for decades, and finally comes the closure, which in most countries involves regulations over how to handle the disposal of dangerous residual materials, for which a plan is generally demanded for the initial authorisations. During operation, the projects are in general subject to control from different public agencies, on issues including safety, water usage, and emissions, to name some.

The technologies under which the project operates are essentially the same during the lifetime of the project, as they involve large capital investments (for instance the grinding machinery) that are dependent on the initial plan for production, in contrast for instance with flexible manufacturing systems. Some key inputs, for example like high tonnage trucks, are designed to have long lifespans to be resistant to harsh conditions which can be a constraint for significant process innovations, during the lifetime of the project.

Operation always involves extraction, and beneficiation, i.e. separation of the ore from other materials with the aim to increase as much as possible. Depending on the type of mineral being processed, and more specifically, the composition of the ore or substance where the minerals are found, different processes are required, starting with extracting and then grinding rocks in large mills (or pumping processes for minerals found in liquid compounds, such as lithium). Then, processes like flotation, lixiviation, extraction by solvents, pyro-refining, smelting, electrowinning and biolixiviation are typically used. These technologies are not in general interchangeable across ores.

Some of these processes are highly intensive in energy usage, others in water usage, and some use dangerous chemical substances (i.e., the environmental impacts are specific to the extraction and refining processes used). Final beneficiation stages required to achieve ingots or similar products often occur in countries different to the ones where mineral extraction happens. [108] China is a key player in this respect for rare earths (see e.g., mining.com, 2021; and Kalantzakos, 2017 on the geopolitics of this dominance) and minerals like copper.

3. Organisational model

This is a concentrated sector, with a few large companies that have strong presence in most mineral rich countries. The top five mining companies in terms of revenues and global presence are Glencore, BHP, Rio Tinto, Barrick Gold and Anglo American. These are all global private multinationals, which have subsidiaries in several countries, which operate with more or less hierarchical management models. They typically raise funds in the stock markets, so they are monitored by both internal and external stakeholders. A few State-owned companies have also become prominent around certain minerals, like Codelco from Chile in copper.

4. Industrial organisational model.

In terms of industry structure, mining activity is generally divided into different scales: large-scale mining, medium-sized mining, and artisanal and small-scale mining. The key parameters that determine--under current technological conditions--what type of operation exploits a deposit, is the total amount of mineral available, and the ore grade. Low-ore-grade deposits are not, with existing technologies, economically viable to be exploited on a small or

medium-size scale. Large scale operations are needed to attain the economies of scale necessary to obtain the minerals at costs that are low enough to ensure profits from low-ore grade deposits. Exploitation at large- scale is done mostly by large multinational corporations, which are responsible for the lion's share of global mining output, although state-owned companies also play a relevant role.¹¹

Relatively small deposits, which may not be of interest to large corporations, can be economically exploited at smaller scales that require a lower capital intensity, if the ore grade is high enough to obtain the mineral in a cost-efficient way with the technologies currently in use at medium-sized operations.

Small-scale or artisanal mining is more relevant for high-price minerals, such as gold, where it has been estimated to represent up to 20% of global production (Seccatore et al., 2014). Smaller scale operations tend to have lower safety standards (they are often informal) and have low technological intensity, thus they require a relatively high ore grade, as well as a high mineral price, to be economically feasible. There is some evidence of specific scenarios where the technologies used in small scale operations are related to local cultural, political and sociological factors (see Seccatore and de Theije, 2017).

Exploration is done by the large mining firms or the so-called junior companies, which specialise in the exploration stage and aim to develop projects and then sell them to larger corporations.

Large scale mining firms therefore concentrate most of the knowledge and capabilities required to handle the exploration and extraction processes.

Other key group of actors are the suppliers, which often are global. Some domestic suppliers from mineral countries like Chile, Brazil and Argentina have been able to break in offering, to being with, locally adapted solutions. In these countries however, despite the fact that there have been technological developments both within mining companies and across mining suppliers, related technology exports and internationalisation of suppliers remain marginal.

The more sensible/complex the product or service and knowledge required it is, however, the more is likely to be concentrated in a few global suppliers.

5. Market and user demand

Regarding markets and users, there are at least four key points that characterise the regime. First, minerals are commodities, exchanged in a global market. Second, their prices are set by these international markets and are strongly dependent on the situation of the global economy and subject to cycles of high and low prices. These price cycles have direct effects on the operation of the system; high prices encourage the development of new projects and incentivise

the maximisation of output (regardless of social, environmental, and even operational costs); low prices, on the other hand, can mean the temporary closure of higher-cost operations,¹² and move firms towards minimising costs (and looking for technologies that help in that direction). Third, the output of the mining system, whether in more or less processed forms, are never sold directly to final consumers. They are used either as inputs or in other ways in the production process of essentially all goods, but consumers only relate indirectly to mining. Fourth, global demand is driven by developed economies, especially those with a strong manufacturing sector, and by large industrialising countries like China and India. Much of the expected growth in demand is due to the energy transition, including the production of electricity-generation equipment and batteries. Current concerns in non-mining countries seem to be about securing a sufficient supply of minerals, without necessarily considering weighting the social and environmental costs behind that supply (e.g. World Bank, 2017; Bazilian, 2018).

6. Policy and institutions

The lock-in situation in mining is not just around hard technologies, but also soft and institutional. The principle of free entry, for instance, which endows mining companies with the right to gain unrestricted access to territory with mining potential and to obtain mineral lease, was first introduced in the 1880s and it is still prevalent (St-Laurent and Le Billon, 2015).

Governments in mineral-rich countries must deal with the conflicting objectives of promoting economic activity and obtaining funds for social services; and protecting their citizens' health and the environment. They deal with these through many different policies: they are responsible for setting and enforcing the rules for exploration, for the approval of new projects, the environmental regulations for their operation and closure, taxes and labour policies, among others. The rules on how the rights to exploit mining deposits are allocated, and possibly associated royalties, are an important area where very different approaches can be applied. Mining activities are an important source of tax income for many countries, and in some cases (as Chile or China), the State is directly involved in mining through state-owned enterprises. The way that the government deals with the sector is determined in part by the political leaning of each government, but with a strong path- dependent component due to the length of the project cycles in the sector, and the difficulties involved in changing some regulations, like taxes. The relative political strength or weakness of governments, and their power relative to vested interests, are also determinant.

7. Knowledge base

The project design and construction phases require capabilities in engineering, as well as project planning and economic and environmental evaluation. The

extraction, operation is intensive in geological, metallurgic, mechanical and chemical knowledge.

As described in the process section above, there are several technologies available for the core of the extraction and beneficiation phases, but what determines which one is used is generally the type of ore of the mine, as a certain technology will be the most efficient (or the only feasible) one to extract it in an economically convenient way.

There have been a small number of key technical innovations over the last century, but most technological developments have been oriented to improve the efficiency of the traditional production methods, to obtain more minerals from deposits with declining ores or reduce input intensity.

To put the ore grade issue in perspective we can use the example of Chile. Ore grades in Chile, which has been the world's main copper exporter for much of the last century, went from "native" (pure) copper in the pre-colonial era, to around 4% at the beginning of the twentieth century, to an average of approximately 0,6% today (Ministerio de Minería, 2018; Comisión Chilena del Cobre, 2019; Nueva Minería y Energía, 2021). These numbers translate directly into higher input requirements to maintain production levels. A small number of key technological innovations, together with foreign investment (especially in the first and last decades of the twentieth century), have allowed production levels to increase despite the sharp fall in ore grades. An example of a highly innovative technology to extract more resources from low ore grades is biolixiviation (see Aguamarina), which although promising, has not lived up to what was expected. Another example is the new technologies to extract lithium from salt lake brines: instead of concentration through water evaporation, they extract lithium directly from the brine, and have much higher recovery rates (and reduce some environmental impacts).

Regarding input intensity, the key ones are energy –in a context of increasing pressures to decarbonise – and water, with projects often in areas with a shortage of this resource (International Energy Agency, 2021). Mining is moving towards renewables as the rest of the economy, but an important challenge are scope 3 emissions (suppliers), which involve, for instance, tyres, explosives, transportation, and iron balls for grinding. A combination of electrification and use of green hydrogen seem to be the way for the complete decarbonisation of mining, and this process is also associated with important opportunities for technological development. For example, adapting trucks to hydrogen, or developing technologies to produce "green" iron and explosives. Several technologies have been developed to reduce use of fresh water in mining processes, including some that increase efficiency (e.g. thickened tailings), and more radical ones, like the use of seawater, which present important technical challenges but can be critical to viabilise projects in some areas).

Most technologies, however, aim at marginal improvements along the long-dominating technological trajectories. For instance, technologies of extraction based on grinding rocks in large mills and the use of dangerous chemicals, despite being water and energy intensive, have seen little modification for decades. The learning effects and other processes associated with this specialisation promote a situation of lock-in (see Klitkou et al., 2015).

Most R&D efforts are oriented to improving the production processes, to gain efficiency, and/or reducing environmental impacts and are highly concentrated in multinational corporations based in countries like Australia and Canada and their main suppliers (Mining Association of Canada, 2012; Jenkin, 2020).

This is a sector where innovation comes mainly from suppliers of machineries, chemicals, control systems, building, and laboratories. They develop the new knowledge and innovations, but mining companies also invest in R&D to support their activities, and exchange and collaborate with the suppliers.

8. Guiding principles

From the perspective of mining companies, the main guiding principle is maximising profits, through reducing costs, increasing productivity, extracting as much as mineral as possible. To achieve this, they are increasingly forced to consider as principles a good relationship with communities, the minimisation of health and environmental risks, and the reduction in the use of resources such as water and energy. But they do so only to assure that projects advance, and benefits are collected. Similar to companies, from the perspective of governments, raising revenue, ideally capturing economic rents, is an ever-present principle. Minimising environmental and social costs tend to be seen as secondary. Finally, there is a principle that is strongly embraced by some governments, considered but only as secondary by others, and even disregarded by others: the idea of promoting backward and forward linkages, and in general exploiting productive development opportunities associated to mining

9. Cultural values

In terms of symbolic meanings, copper in Chile was, at least until the early 2000s, seen as a synonym of wealth and development, and something similar occurs in other mining-dependent countries. But over the course of this century, in line with global trends, awareness of the environmental impacts of productive activities has increased dramatically, as well as the demands of local communities that directly suffer their negative effects (see e.g. Scheidel et al., 2020). These increases in public awareness and communities' demands have occurred across the world, although with differing degrees of intensity depending on how serious the environmental and social problems were, the degree of organisation of civil society and the degree of political freedoms across countries, among others. The concept of the social license to operate has

become part of the regime, although its meaning might be different for firms, communities, and the government (as it occurs with the concept of just transitions, see the discussion by Bainton et al. (2021).

10. Agency and power within the incumbent system

Politics and power relations have played a key role in the development of the sector worldwide, determining technological trajectories, industrial structures, and the distribution of costs and benefits between different stakeholders. Multinational corporations, with their lobbying capabilities, potential to execute large investment projects (and threats of not doing it), and sometimes already deployed production capacity, have tended to get the upper hand in negotiations. As argued by Newell and Taylor (2018), the control of production, finances and technology by transnational capital delivers them power. In many cases, outright corruption is at play. A paradigmatic case in Chile is how Pinochet's son-in-law acquired control of lithium production from the State, and after the return to democracy, funded the whole spectrum of political parties to maintain privileged access to the resource (Cofré, 2019). The high economic rents associated with mining make it fertile ground for corruption, in a vicious cycle of concentration of economic and political power that also acts against any attempt to redirect the economy away from its dependence on the resource. In other words, this is not "mining versus environmentalists", it can also be mining against potential new sectors, and against other incumbents.

Also governments of countries of origin of these companies have more power to affect processes as well as those that host the MNCs that lead the sectors key for the energy transition like those producing electric cars. However, governments of the sites of mineral extraction, typically in low- and middle-income countries have less power to affect companies behaviours since these can move around if local regulations do not favour them. When resources are very concentrated in one location, local governments could have more leverage in principle, but this is reduced if the country is very dependent on the exports of the minerals, as it is often the case for mineral countries. Social and environmental movements were historically weak in most mining countries, particularly in contrast with multinational companies, under the dominance of the "growth" paradigm. Mounting environmental consciousness and concerns have allowed social movements to gain increasing power over the last decades, but with varying results across countries. Only around 20% of mining-related environmental conflicts have resulted in "justice" from the perspective of social movements (Özkaynak et al., 2021), but in Argentina for instance, almost half of the conflicts have resulted in cancelling or suspending the projects, and social movements have achieved important institutional changes (Walter and Wagner, 2021). Macchione Saes and Bisht (2020) contrast the outcomes of mining-related social conflicts in India and Brazil and highlight their differing results, but also the fact that different local regimes can both result in environmental injustices.

Final consumers have less power to influence firm's behaviour and technological trajectories in this sector since they are very distant. Sectors that produce final consumption goods are increasingly subject to customers' concerns about their production and sourcing policies, with trends of conscious consumerism in areas such as clothing and food. Minerals, however, are only used as intermediate inputs for the products and infrastructure used by final consumers, who are often blissfully unaware of the social and environmental problems in the first stages of the value chains.

4.2 Pressures for change, niches and alternative regimes in mining

One big challenge with the mineral sector is that relevant markets are not sending the "right" signals to induce changes in the directions required. On the one hand, products developed with the minerals (e.g., electric cars) are typically consumed at a great spatial, social and affective 'distance' from the sites of extraction. As a result, consumers often do not see or feel the problems, so they do not use their power to encourage changes. In association with the energy transition, some demand- side pressures are beginning to emerge as manufacturing customers, for instance within the automobile industry, are starting to consider concerns from consumers for traceable minerals that are responsibly extracted. However, these are still very weak and have not translated into concrete actions. To a large extent this is explained by the global nature of the copper industry, with refining and manufacturing concentrated in locations far away from sites of extraction. Global financial markets are also starting to pay attention to forms of extraction. This again apply however, only to global companies that are listed on global stock exchanges, especially those based in London, which has been a focal point for activists to improve business performance on climate and human rights (Saner, 2022).

A second challenge for market forces to operate is that competition between producers, as in other commodity markets, pushes innovative efforts along the value chain typically in the direction of reducing costs (and production risks) not of improving processes. Given this market structure, in effect, there are concerns that, that a possible rise in price of minerals in response to the increase in global demand from the energy transition could have a negative impact on company's movements into more sustainable practices since this could provide relief from pressures to change technological practices that operate through profits, for instance related to energy or water costs. As reported by Saner (2022) company owners recognise this possible negative effect coming from market incentives. 'It will be really bad for making changes to happen if the price of copper rises, since it will just allow businesses to stay in their comfort zone'. Similarly in relation to the cost of inputs: 'If the costs [of energy come] down, we will just carry on as we are'.

Another major challenge comes from the limited impact of national regulations on conditions at the sites of mining when powerful multinationals can simply

move to another country if regulations are seen to overly constrain operators. A limitation that becomes more problematic in countries dependent on mineral extraction, as many low- and middle-income countries are. For eighteen resource rich countries minerals explains more than 50% of total exports, and among these several own important reserves of critical minerals for the transition, e.g., Chile, Peru, and RDC; in 23 African countries minerals explain more than 30% of total exports, for 38 resource rich countries mineral exports explain between 30 and 50% of total exports. This level of dependency together with the capacity of companies to move around introduces serious challenge to the capacity of national governments to regulate the sector.

Likewise, international initiatives that have emerged to address these gaps, including The Extractive Industry Transparency Initiative (EITI), the Responsible Mining Index and the International Council of Mining and Metals, are having limited impact (Banerjee 2017). One significant problem with these standards is that they are multiple and are not harmonised. According to company managers, as reported by Saner (2022) 'There is an "alphabet soup" of standards, metrics and different ratings providers - the joke goes that if you want a better ESG rating, change providers'. Another problem is that they are voluntary and self-reported, not outcome orientated, with little or no consequences for failures: 'They only require [incumbents] to report on the procedures they have in place and not whether they are having an impact'. 'These standards are about setting the floor not the ceiling' (Saner, 2022). As such they do not act as a strong source of pressure to go beyond current operational practices and encourage innovation, given that industry leaders always score highly and have no incentive to make improvements.

New knowledge and technologies are opening opportunities for significant transformation, for instance in association with new IT solutions that could enable maximum control of processes and therefore reduce the use of resources to the minimum, or with the application of biotechnology for extraction processes, that uses bacteria instead of energy and water to extract the minerals. But with market and institutional forces exercising limited pressures for change these and other new technologies that can work to reduce environmental impact are not being introduced to the sector at the necessary scale and pace. This explains, why ambitious project such as the one proposed to produce "green copper" by the state-owned Codelco, which was technologically feasible, was abandoned on the grounds of impossibility to charge higher price required to sustain it.

The industrial organisation of the sector does not contribute to the development and introduction of new technologies to improve environmental performance, with the provision of key sensitive inputs like machineries, chemicals and control systems being dominated by a handful of large multinational companies that have long term contracts with the mining companies, which under limited pressures for change, privilege security over innovation. In the sector of

suppliers, barriers to entry are huge, and competition between providers not very strong, all of which limits seriously the possibilities of path breaking innovations (see Marin et al, 2021).

To a large extent this explains the absence of niche or spaces experimenting with radically different technologies (soft and hard) related to mineral extraction, as they are traditionally defined in the transition literature. It is possible to find purely technological alternatives to specific problems. For example, the use of seawater as an alternative to the use of freshwater in areas of severe water scarcity; biotechnology applications to extract the mineral from low ore-grade sources with lower environmental by-effects (for more details on these, see the case studies by Benavente and Goya, 2012a, 2012b, 2012c). These technologies, however, all have something in common: they do not propose radically different ways to extract the mineral. They only address specific problems, such as excessive use of water. They can be described thus as only path repairing, not path breaking (Marin and Van Zwanenberg, 2023).

An excellent example is the recent development of technologies to desalinate sea water, to replace the use of fresh water in areas of water scarcity. Water is a major cause of concern in Chile, a country with severe water scarcity where mining uses up to 50 % of this resource in certain areas (e.g., Antofagasta). To address this problem several important mines (e.g., La Escondida, Anglo American; Los Pelambres, Antofagasta Minerales; and Spence, BHP) have been experimenting and scaling-up projects to desalinate seawater for copper extraction. This technological approach, which is six to seven times more expensive than the dominant approach based on fresh water, is increasingly considered crucial by large companies for the feasibility of the activity in areas where social pressures have been mounting in relation to water use (Odell 2021). It is being questioned however as it does not fundamentally change how water is used in mining processing or address other water-related socioenvironmental issues such as contamination and tailings safety. It does not change how much water is used, or the way in which water is used in the process. It is being questioned also due to the longer-term implications of harming marine biodiversity and livelihoods, with new social conflicts emerging with fishing communities in the coastal regions where the seawater is drawn from, and where concentrated saltwater residues are disposed.

An alternative is to utilise seawater without desalination. This option, first implemented at scale in Chile in the 1970s, following early adoptions and innovations by domestic companies in the 1920s, is considered less risky for the environment since it does not generate a polluting waste such as brine that can contaminate the sea, but it is more problematic for companies because it can damage existing machinery and therefore requires deeper changes in the whole extraction processes e.g. Tocopilla, Pudahuel, Michilla (Benavente and Goya, 2011; Odell 2021). This is therefore less popular and has received less attention and investments, showing the extent to which incumbents are introducing

changes only when forced and with the aim to meet the minimum requirements to sustain profits.

The desalination as an alternative has been described then as a problem-shifting technology which will result in a new dead-end pathway (van den Bergh et al., 2015; Saner, 2022; Rosenbloom and Meadowcroft, 2022). “It does not reduce freshwater use, and does nothing for reducing mining’s overall water intensity, GHG emissions, water pollution and tailings safety. It is also shifting rather than addressing social problems - with conflicts moving from those located around mining projects to communities in coastal regions” (Saner, 2022). Despite significant investment, this technology does not fundamentally transform processes and cannot deliver long-term sustainable improvements in mining.

There is a real risk then that these one-dimensional improvements are used by the incumbents as a way to “greenwash”. For example, in Chile, there has been discussions about expanding green hydrogen, and the display of a single forklift operating with green hydrogen was showcased as “green mining”.

Are there other forces of change at place?

Despite this strong lock in, and strong barriers to change some positive signs are emerging.

One the one hand, the pressures coming from the landscape with climate change and the imperatives for more sustainable technologies and practices, environmental and social, seem to be increasing, and could increase more with the energy transition (this is why I think is so important to do more research not only to understand but also contribute to this process., link energy transitions with mining problems), and this can affect more mining companies - up to know much less affected than for instance energy companies, that have activities among their stakeholders.

On the other hand, civil society, has not been silent in response to the environmental and social risks posed by these technologies. The mining sector has become intensively monitored by local communities, social movements, and civil society in general. The Environmental Justice Atlas has reported more than 2000 active social and environmental conflicts around the world, a third of which are related to mining. Many of these conflicts end up in closure of the plants, others in delayed projects (Wagner and Walter, 2020; Temper et al., 2018). Existing estimations indicate that disputes with local communities have currently slowed or halted around \$25 billion in mining projects, with costs for companies of around \$20 million per week (Banerjee 2017, <https://insight.kellogg>). According to the Observatorio de la Productividad (2020) in Chile 25 thousand million dollars investments in the sector are delayed or stopped by social conflicts. As shown by Walter and Wagner (2021), social

movements in Argentina have achieved the suspension or cancellation of about half of the projects to which they have opposed.

Literature on social movements has explored different kinds of impacts of socio-environmental conflicts focusing mostly on political, institutional, and cultural changes (Temper et al., 2018; Vela-Almeida and Torres, 2021; Bebbington and Bury, 2009). There is, however, limited research investigating the connections between the activities and impacts of social movements in conflicts and those of actors central to the incumbent mineral system, such as businesses (Hess, 2005; Marin and Goya, 2021; Smith, 2016).

5. Possible future scenarios

First, we can imagine a future where consumption of (and therefore demand for) raw materials decreases radically, through a combination of recycling and changes in the design of products and service provision (see for instance the proposals for dematerialisation in Jackson, 1996). The problem with these hypothetical futures is that they are still too far from the horizon, and resting on their promises can lead us to ignore all the problems that we still face in the short- and medium-term.

A second, less radical, but still system-level possibility is a transition towards truly sustainable mining activities, where strict and science-informed international standards concerning issues such as water management, carbon emissions and relationship with communities are designed and enforced throughout the relevant value chains. One problem with this future is who sets the standards, which would determine if they are really science-based and demanding enough to consider mining to be sustainable. The eventual transitions towards that situation would almost certainly need the development of novel or underdeveloped technological trajectories, which leads to our third hypothetical future. For these two potential transitions, social movements are likely going to have a key role in their promotion, but they alone are not likely to be enough to trigger them. Minerals are a non-renewable resource. By definition, mineral exploitation cannot last forever, and as the traumatic Chilean experience with the development of synthetic saltpetre shows,¹³ demand for minerals can fade completely before their exhaustion if good substitutes are developed. Mining-dependent developing countries should take this risk seriously and plan ahead. To make the material contribution of mining to these economies economically sustainable, part of the rents obtained from mining should be invested in the development of technological capabilities that can produce flows of income once the mineral resource stops doing it. This is directly related to the two previous ideas; a future with low demand for materials would force this situation, and the development of alternative technologies that allow for sustainable mining could result in the development of technological capabilities that are useful beyond mining activities. The difference is that this third potential systemic transformation of the sector

emphasises economic sustainability from the perspective of mining developing economies. The innovation studies literature has considered this issue, but as it has focused on economic sustainability it tends to pay less attention to environmental and social sustainability. Its focus on technology also translates into insufficient attention to important dimensions such as demand, politics and power, and symbolic meanings, all aspects that are properly accounted for in transitions research.

6. The way forward: Transitions studies and extractive industries

Transition frameworks are well-suited to analyse all of the dimensions that should be considered to understand mining and explore possible directions for transitions. At the same time, exploring this system could provide useful insights for transitions practice and theory, as it would confront the framework with a reality that in important dimensions, it differs from most of the systems it has studied to date.

There are at least two broad lines along which theoretical and empirical work could contribute to promoting transitions in mining: exploring and characterising the likely transition pathways, and normative aspects related to the tradeoffs faced by developing economies that are dependent on unsustainable activities.

Regarding the first, as we argued above, there is a strong lock-in in terms of technologies, industrial structure, and political and economic power, and a lack of visible alternatives. We need further research to understand transitions that do not necessarily develop starting from niches, but from global and system-level, coordinated responses to physical and social pressures and the associated windows of opportunity that they present. Incumbents need to be involved or possibly forced by policy to participate. Global coordination (see Fuenfschilling and Binz, 2018) could be necessary, and the different roles of countries with different development levels and of multinational corporations should be explored, as well as possible institutional innovations at a global level. Social movements could be a driving force to trigger the necessary changes by public and private actors. In some cases, such as Argentina, they have had overwhelmingly positive results (see Walter and Wagner, 2021), but that is not always the case (see e.g. Macchione Saes and Bisht, 2020). The telecoupling literature (see Hull and Liu, 2018) can provide insights into the way local social movements may have global implications. Some of the dimensions along which social movements interact with the regime, like advocacy, protests and media campaigns, have received more attention but others, like potential effects of social movements on firms' technological trajectories, or direct effects on policies, have received little attention. The close relationship between mining and the energy transition means that interactions between systems (see Rosenbloom, 2020) and their transition pathways are key for an eventual "deep transition" (Schot and Kanger, 2018) that goes well beyond the energy system.

The transitions literature starts from the basis that radical socio-technical changes are required, as “incremental improvements and technological fixes” are not enough (Köhler et al., 2019). However, in a situation such as that of mining, where the energy transition itself is putting pressure on a conflictive system to keep producing, a slower path towards a new regime, with partial improvements along the way, may be required.

What is a sustainable transition, from the perspective of the citizens and governments of developing countries? We consider that the normative emphasis on sustainability which guides the transitions literature is the right approach, in contrast with most previous schools of thought on development. However, in the short run, in the absence of alternative technological and institutional arrangements that could eventually replace parts of the current regime, there is necessarily a certain tradeoff between material living conditions and environmental sustainability, especially because of the government revenues obtained from mining activities that have no substitute available. Transition studies, for the most part, assume away the problem of economic sustainability (see Marin and van Zwanenberg, 2023). The idea of a “socio-political regime” (Swilling et al., 2016) can help to simultaneously consider sustainability and “developmentalist” perspectives, as the balance between potentially conflicting objectives is determined by political processes. Dealing with this tradeoff will make transitions more policy-relevant for developing economies. New approaches to social dialogue and participation might help address these conflicts and reach socially, environmentally, economically -in sum, politically- feasible alternatives.

There is a further issue with economic sustainability: mining is by definition unsustainable in the long run, and insights and recommendations from innovation studies have not succeeded in helping developing economies to use natural resource-based activities as a lever to develop technological capabilities. A sustainability transitions perspective may also be helpful for countries to develop long-lasting technological capabilities that could outlive mining, in path-creating pathways, as proposed by Marín and van Zwanenberg (2023).

How do all of the issues discussed above and their interactions play out in relation to different potential transition pathways? Above we sketched the possibilities of radical changes in material demand, and of less radical transitions based on standards and certifications, more likely to achieve results in the short and medium term. Both present important challenges where more research could provide valuable insights. For instance, understanding the (global) socio-political regime can help ensure that transition proposals based on standard-setting are effective and not mere greenwashing by incumbents; understanding why Codelco’s plan for higher-priced “green copper” failed; ensuring that actors leading the energy transition properly account for all of its environmental and social costs; understanding how local social movements in developing countries can attain global visibility and collaborate with their peers

in developed economies to promote global changes; or distinguishing whether a technological fix to an environmental problem is effectively a contribution, or only a cosmetic improvement used to reinforce the incumbent regime. How should developing countries deal with the tradeoff between income generation and sustainability objectives?

7. Transitions, minerals, and policy

We have discussed a broad set of issues, as our point is to show the directions along which transitions researchers could contribute to understanding mining, its relationship to the energy transition, and possible directions for transitions. In terms of policy, there are many open directions, here we mention only some we consider especially important.

As argued by Franceschini and Alkemade (2016), there is an important role for policy in stimulating new technologies in industries where the technologies used and developed by dominant incumbents are problematic. Technological progress is path-dependent and has a direction. Although there is apparently a narrow set of technological alternatives for a given set of natural conditions, that set of feasible technologies is the result of technological trajectories shaped by a relatively slack set of regulations -in other words, firms were and are not forced to internalise all environmental externalities. If different regulations had been in place across key mining economies over the last decades, we would probably have others, less environmentally damaging technologies available. As an example, in an Argentinean region where cyanide extraction is forbidden -as a result of the actions of social movements- a different technology will be used so that a mining project is feasible. This technology is not new, but it would not have been considered if the restriction was not in place, because it has a lower mineral recovery rate than the cyanide-based alternative (Murguía, 2020). In Chile, seawater has been used in some situations where freshwater is not available (Benavente and Goya, 2012c). How many existing mining operations could still be economically feasible if they used less polluting “second-best” (in financial terms) technologies? How many cleaner technological trajectories have not been developed, or improved enough, because the required incentives have not been in place? As argued by Fuenfschilling and Binz (2018), “institutional rationalities also materialize in technologies, which enhances their dominance even further”. There is an important role for technological transparency that governments have not attempted to enforce, as well as for promoting the development and improvement of cleaner technologies. This would also contribute to the long-run economic sustainability of mining economies if they develop dynamic technological capabilities which can outlive the mineral resources. The correct approach to these issues should consider not only economic and technological factors, but, as we argued above, also other dimensions. For example, do mining companies already have economic power in a country, or is it a relatively new sector? Does the government have the experience and technical

capabilities required to design and enforce the necessary industrial policies? Which countries are the main potential buyers and how much would they collaborate with these strategies? Innovation studies can contribute, but they should give more emphasis to issues such as directionality and legitimacy (Schlaile et al., 2017). Transition policy could be the overarching policy goal, that with a systemic look helps to align other policy domains (Alkemade et al., 2011).

Following on from the last point, country-level actions are not likely to be enough to trigger a proper transition. Most mining output is exported, so the demand side is “exogenous” to mining countries. Both industrialising economies like China and India and developed economies are important buyers, which mean that a single approach to how buyers could contribute to a transition is not possible. Moreover, minerals are at the beginning of value chains, and final consumers cannot directly affect what happens with mining through consumption decisions. Most key technologies are developed in advanced economies, and the gross of global mining output is produced by a handful of multinational corporations with headquarters in developed countries. Most social opposition to mining activities are led by small, local social movements made up of residents of the directly affected areas, not always connected to global groups that have more resources and much broader ranges of action.¹⁴ All of these factors, and others we discussed above, show why any attempt to redirect mining needs to simultaneously consider the local and the global. How to give global visibility to local social movements? What kind of global institutional innovations may help transform mining?

At the national level, the traditional approaches to local communities are not working, as shown by the dramatic increase in socio-environmental conflicts, which now emerge at virtually all new mining projects. We need institutions that allow the local populaces not only to have a voice but for their opinions to play a part in which activities are developed in their regions and how. Social dialogue processes must change in the direction of procedural justice.

In general, the approach to local policy and institutions depends crucially on the level of development of mining in a country. For economies where mining is already an important activity, it is necessary to transform an existing regime, with all its difficulties. In countries where there is potential for mining but the sector is only nascent, as in Argentina, there is more room for designing appropriate policies from the start, as long as there is knowledge about what these policies are. Nordic countries may soon begin extraction of minerals that are critical to the energy transition but that do date have remained unexploited (Pasi et al., 2021). It will be interesting to see how new mining activities unfold in developed economies in the context of the green transition, and it could open an opportunity to improve environmental and social standards in other countries.

Eventual transition pathways for mining may originate from social movements, different technological trajectories, or global institutional changes to name some. But in all cases, policy should play an important role in opening spaces for them.

Finally, what is sustainability? Who defines social and environmental justice? There is an undeniable tension between the development of activities that produce much-needed jobs and fiscal revenues for developing countries and the social and environmental costs of these activities, which are only faced by a small fraction of their populations. The relative weight put on traditional economic growth arguments tends to be high among policymakers and the general population, the more so the worse their living conditions are. The perceived negative impact of economic degradation on future generations does not outweigh the need to improve living conditions today. To be more policy-relevant for developing economies, transition studies should, while maintaining the normative focus on sustainability, incorporate this tension into their analyses.

8. Summary and conclusions

Mining is fundamental to the economies of many developing countries, but it has a strong negative environmental and social footprint. The increase in mineral demand due to the energy transition will stress the existing tension between economic and sustainability objectives faced by these countries.

The mining system is dominated by large multinational conglomerates, there is an apparent strong technological and political lock-in, and even though social and environmental pressures have been mounting, a transformation of the system seems far given the relevance of the activity for many developing economies and the power of incumbents in this respect. Whether alternative technological directions are feasible--and have been invisible due to path dependence and the existing incentive structures--is an important question to explore. But it is also important to look beyond technology and understand the social and political processes underlying the policy frameworks surrounding mining and possible directions for change.

Considering all of the dimensions of the socio-technical system allows us to have a complete and systemic view of the issues that should be addressed and their relationships. Some recent work in transitions theory seems to be particularly relevant to understand this system, including the ideas of global socio-technical regimes (Fuenfschilling and Binz, 2018) and of deep transitions and interconnections between systems (Schot and Kanger, 2018).

The different frameworks developed in the transition literature could help produce valuable insights for transitions in mining, however, until now, the problems associated with mining have received little attention in the literature. Understanding mining from the perspective of transitions may require

broadening the analyses to think about situations where the lock-in is such that niches do not appear to be relevant, and where incremental fixes in the short and medium run may be required to achieve a transition in the long run. The problems and possible ways out of them should consider the local and the global aspects of the regime, as well as its connections. Interactions with other systems, including but not limited to energy, should also be central to the analysis, in part because of the position of mining in value chains, not directly connected to final consumers. Some dimensions, such as technology and social movements, are probably going to be relevant for any successful transition pathway.

The economic dependence of many developing countries on mining, together with the demand pressures generated by the energy transition produce a strong tension that should not be ignored. In the case of energy systems, there are alternatives to the fossil-based regime towards which countries can move. In the case of mining, there is no alternative, at least in the medium run, that can maintain the required production levels without the social and environmental costs that mining has today. And faced with pressing material needs (housing and infrastructure, health, pensions, sanitation, etc.), environmental and social sustainability are usually treated as a second-order concern, both by policymakers and by the people in these countries.

The focus of transition studies on sustainability, combined with the type of systems and contexts that have been studied, has resulted in invisibilising trade-offs between sustainability and traditional economic growth policy objectives. The implicit assumption is that the sustainability-growth debate is outdated and already resolved, while it is very much alive in many low and middle-income countries where the living conditions of a large share of the population and the income-generating possibilities of mining activities can often tilt the balance in their favour, to the detriment of future generations.

Innovation studies, that can help understand how mining can generate other technological capabilities that could bring material wellbeing beyond mining, have tended to do the opposite: focus too much on technology and growth, and not enough on sustainability. It would be fruitful to increase the interaction between sustainability transitions scholars and those from innovation studies (see Schlaile et al. 2017; Andersen, et al. 2020) and development economics (Marin and Van Zwanenberg, 2023). Bringing together these different views will make all these different research strands to be more policy-relevant.

This paper provided a characterisation of mining's socio-technical regime and briefly described some possible pathways for transitions. It also proposed some directions along which transition studies could help understand mining, its relationship to other systems, and possible ways out of its unsustainable trajectory. Finally, some dimensions of public policy that are especially important to transform mining were discussed.

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Notes

¹ We thank Jose Miguel Benavente, Adrian Smith and Allan Dahl Andersen for their helpful comments and suggestions.

² See for instance the critique in the context of transition management, by Shove and Walker (2007).

³ See for instance Brauers et al., 2020; Leipprand and Flachsland, 2018; Mayer, 2018; Skoczkowski et al., 2020, all focusing on coal.

⁴ Awareness of this relationship is still insufficient, as shown, for example, by the scant references to mining activities in the recent Theme Reports for the United Nations High-level Dialogue on Energy to be held in September 2021

⁵ See the Environmental Justice Atlas at ejatlas.org/commodity.

⁶ However, their lock-in scenario is still related to an existing alternative that fails to replace the regime

⁷ Innovation studies are also underdeveloped in their understanding of resource-based sectors. As shown by Andersen et al., (2018), less than one per cent of articles in innovation studies focus on natural-resource based industries. Some important exceptions, that also consider environmental sustainability aspects, include Katz (2015); Marin et al., (2015); Andersen et al., (2015, 2018); and Marin and van Zwanenberg, 2020).

⁸ For a debate on the shortcomings of innovation studies see the special issue introduced by Kuhlmann (2018), including the discussion paper by Schot and Steinmueller (2018) and the replies by Giuliani (2018) and Fagerberg (2018)

⁹ An exception seems to be when companies are forced to try technological alternatives due to natural constraints. We come back to this in the next section

¹⁰ Feola (2020) discusses how political priorities differ across countries and argues that this is rarely acknowledged in transitions research. On the political tradeoffs associated with transitions, see for example Newell and Mulvaney (2013) in the context of energy

¹¹ In 2008 almost a quarter of global mineral production was through publicly owned firms, half of which was accounted for by China (World Bank, 2011).

¹² The economic viability of a particular mining operation depends on the ore grade (which determines costs) and the mineral price. As prices fall, operations are closed, and smaller scale operations are the first ones that shut down; this affects artisanal operations disproportionately, adding a high degree of job uncertainty to the low salaries and working standards of small scale miners

¹³ By the end of the nineteenth century the Chilean economy was highly dependent on saltpetre. World War I triggered the development of synthetic saltpetre in Germany, which resulted in the complete collapse of the industry.

¹⁴ Sometimes even within countries, different groups are not connected. Coalitions of social movements are much more likely to be successful, see Walter and Wagner (2021).

Factors affecting sustainability transition: An analysis of Indian manufacturing firms

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Abstract

On account of globalisation, the world economy has witnessed unprecedented economic growth in recent decades. At the same time, it also has had several repercussions, such as over- exploitation of resources and increasing emissions, giving rise to a serious concern about environmental sustainability. In today's globalised world, where technologies and policies are increasingly integrated, 'sustainability transition' works as a global system. Therefore, wider participation of actors across the world is necessary to evolve an ecologically-oriented development trajectory. However, the behaviour of actors in such a global system may be governed by various factors. There are two different views regarding the effect of internationalisation on environmental sustainability from a developing country's perspective. The traditional view is that internationalisation may worsen the environmental standards of developing countries by relocating the polluting industries from north to south. On the other hand, it is argued that internalisation may facilitate the transfer of environmental policies and technologies and induce environmental actions among developing countries' firms. This study intends to examine the effect of internationalisation on the sustainability behaviour of Indian manufacturing firms. The effect of two main channels of internationalisation, viz. export and foreign ownership of firms on their environmental spending has been examined. Firm level data has been collected from the CMIE's Prowess database from 2005-06 to 2021-22. The random effect Tobit model has been used. The results indicate a positive relationship between export intensity and the environmental expenditure of firms. It is also found that foreign firms tend to spend more on environmental actions than their local counterparts in India.

Introduction

It is widely argued that on account of globalisation the world economy has witnessed an unprecedented economic growth in the recent decades and at the same time, it has also got several repercussions. The higher economic growth has been associated with growing inequalities between and within countries (Piketty, 2015) along with over-exploitation of resources and increasing emissions giving rise to a serious concern about environmental sustainability (Medows et al.,1972). Since it is undesirable to obstruct the economic growth, the rising economic growth needs to be accompanied by careful measures which could address the associated environmental and social issues. Therefore, the seventeen Sustainable Development Goals (SDGs) agenda has been set up to achieve sustainable development which puts emphasis on how to reconcile the socio-economic needs with the natural environment. Countries world-wide including India¹ are increasingly integrating these SDGs into their development planning and policies.

India has been one of the fastest growing economies in the recent years, the cost of which is that it is also among the largest emitters in the world², and its emission rate is showing an increasing trend. Despite rising growth, India is still struggling with poverty, unemployment and other basic problems. Hence, economic growth is necessary at this stage of India's development. On the other hand, environmental sustainability also remains as a major challenge for India. Industry especially manufacturing sector, which is recognized as engine of economic growth for any economy (Kaldor, 1966), is one of the major contributors to environmental degradation and emission in India and elsewhere in the world. Industrial sector contributes 21 percent of total Greenhouse Gases emission in the world (IPCC,2014). In case of India, 27 percent of CO₂ emission is caused by the industrial sector (TERI,2022). In India, the manufacturing output is predominantly polluting, notwithstanding showing a reduction in the share of polluting industries in the recent years. It has been agreed that at the global level the industrial sector could reduce emission by undertaking several measures e.g., energy efficiency measures, the deployment of sector specific as well as cross-cutting general technologies (IPCC,2014). Moreover, the available evidence tends to suggest that the Indian manufacturing sector is increasingly adopting pollution reducing measures in the recent years. Hence manufacturing sector could be considered as a catalyst and a key component of sustainability transition. The issue therefore is how to evolve a sustainability-oriented development trajectory in a developing country like India via integrating the environmental concerns into the production activities in case of Indian manufacturing sector?

Theoretical background – Sustainability transition: a global system

The ‘Sustainability transition’ approach has received increasing attention as a conceptual framework to deal with the sustainability problem in the recent years. It suggests that, to evolve an ecologically-oriented development trajectory, a broader transformation of an economy towards sustainable modes of production and consumption behaviour is required. The process of such transition requires shift in the ‘socio- technical systems’ (e.g., energy supply, transportation or manufacturing sector etc.) which are made of various actors, institutions, and knowledge and artefacts. The system concept here underlines those different components of the system are greatly interrelated and dependent to each other. Transition in such system requires simultaneous change in technology, social changes such as sustainability-oriented behaviour of various actors, and institutional changes such as regulation, societal pressures etc. (Geels, 2004; Markad et al, 2012). Therefore, the process of sustainability transition is multi- dimensional. In a similar line, Sustainability-Oriented Innovation System (SOIS) framework has been suggested by Pegels and Altermann (2012) to analyse sustainability problem. It emphasizes on the peculiarities of a global Innovation System which is aimed at greening the economy. SOIS is defined as “networks of institutions which create, import, modify and diffuse new technologies that help to reduce environmental impacts and resource intensity to a level commensurate with the earth’s carrying capacity”. It underlines the importance of the global nature of SOIS consisting of multi-level regulations and actors to decouple economic growth from negative impact on environment and excessive resource consumptions via sustainability- oriented innovation. It advocates that technology and regulations are globally integrated.

These theoretical insights have been very helpful to understand the interrelation of various components of the system at macro level or at system level. However, to understand the complexities in the system and promote sustainability transition, a closer look at the micro- level behaviour of particular component of a system is needed. While the role of firm strategies remains crucial in the sustainability transition, it did not receive much attention in the literature (Farla et.al., 2012; Markad 2012). Therefore it is important to understand what kind of firms are contributing toward the sustainability transformation and how to effectively orient their resources, capability and strategies towards environmental sustainability? How are the behaviour of firms towards the sustainability-oriented strategies governed? Understanding the nature of actors and their interplay with other components of the system will untangle the complexities of sustainability transformation.

Firms' contribution to environmental sustainability

Firms may contribute to environmental sustainability in following ways. Firstly, using Preventive strategies which may be process integrated or product integrated innovations, inputs can be used efficiently so that it could conserve the limited natural resources (e.g., using non-renewable energy sources) without restricting the output growth (Cropper,2008). Secondly, the adverse environmental impacts of production that limit the carrying capacity of the earth can be minimized by curative SOS. The curative SOS are additive or end-of pipe innovations that allow emission at the first place, then minimize the negative bi-products of production such as emission, hazardous wastes etc by taking add-on measures using pollution abating technologies viz. by installing scrubbers, waste water treatment plant or managing the supply chain e.g., recycling the waste (Stam et al. 2009, Frondel et.al,2007; Rennings,2000).

However, sustainability problems are complex and unstructured in nature. And the probable solutions are also unclear to the firms as these are not the core activities of many of the firms (Wieczorek et al,2010). Therefore, firms may adopt different alternative strategies which may be in a trial-and-error basis. In the literature SOS has been defined differently in different context and according to availability of data. Sustainability-oriented strategies (SOS) can be defined as any practices adopted by a firm that have a beneficial impact on the natural environment (Horbach, 2008; Kammerer, 2009; Boons et al, 2013 for a detailed review of such definitions). It could be either developed by the firm itself or adopted from external sources, its nature could be technological or organizational, but the additional nature of these strategies should be to improve ecological sustainability (Carrillo-Hermosilla et al.,2010).

These strategies may include organizational innovations i.e. the changes in necessary organisational structure to include sustainability values and beliefs for e.g. promoting participation of all employees in sustainability-oriented practices, routines that aim at protecting the environment, complying to environmental regulation, adoption of assessment mechanisms for environmental performance such as benchmarking and accounting, setting and disclosing environmental performance, providing training to the manpower to orient them towards environmental responsibility and rewarding them for environmental performances and so on. Such practices make the firms aware about the linkage between their production process and natural environment and how to protect environment. These practices are argued to be directly and indirectly beneficial for environmental sustainability (Paraschiv et al, 2012; Ganapathy et al, 2014; Darnal et al., 2010).

For this study we consider the environmental expenditure of firms as a broader measure of SOS. The CMIE Prowess provides information about the variable

'Environment and pollution control related expenses' which follows the definition of Cost Accounting Standard on Pollution Control Cost that defines 'Pollution control' as the control of emissions and effluents into the environment. It constitutes the use of materials, processes, or practices to reduce, minimize, or eliminate the creation of pollutants or wastes. It includes practices that reduce the use of toxic or hazardous materials, energy, water, and/or other resources. This would be used as indicator for SOS in the firms as it includes expenditure on both the preventive as well as end of pipe strategies. We cannot differentiate between different types of SOS due to unavailability of the data.

Motivation of the study

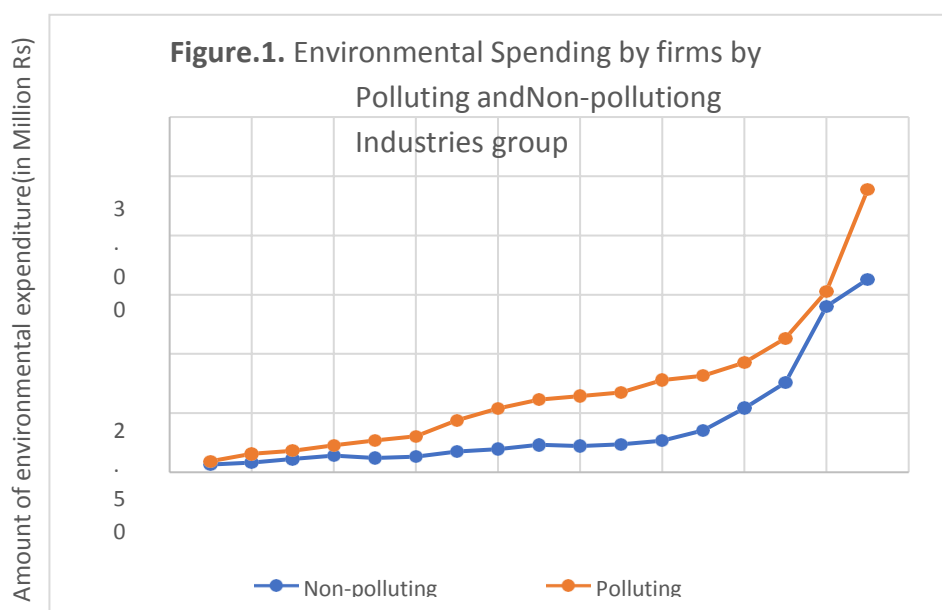
Many firm level studies show that firms are increasingly adopting SOS as it may create win- win situation by providing both environmental and economic benefits (Horbach, 2008; Sideschlag and Yan,2021). In case of Indian manufacturing sector, it is evident from table.1 that the number of firms adopting SOS has been rising in recent years. The total amount of SOS expenditure and its intensity are also showing an increasing trend. Despite the increasing trend, the number of SOS firms and extent of SOS expenditure are almost near to the ground. On an average only 2.88 percentage firms are reporting any positive amount of environmental expenditure. The average of absolute amount of environmental expenditure is only 0.56 million Rupees which becomes 0.03 percent to the total sales of firms on an average. The lower level of participation in SOS is seen not only in the developing country like India, but the developed countries also experience the similar trend (around 5% rate of investment in SOS) (Haller and Murphy,2012; Mcinereny et.al., 2016; Sideschlag and Yan,2021). This becomes the greatest motivation for this study. Because, to accelerate the level of participation in sustainability transition, the drivers of SOS expenditure are of vital concern. Furthermore, figure.1 depicts the comparison of environmental related spending of firms from polluting industries and non- polluting industries group. It shows that firms from polluting industries group are incurring higher expenditure on environment than the firms from non-polluting industries. It may imply that firms from the polluting industries are adopting SOS in order to comply with the domestic regulation. This is because, firms from polluting industries are frequently regulated or expected to experience frequent inspections and regulatory actions by the authority in future in India. To investigate the effect of domestic environmental regulation the polluting industries dummy is included in our main analysis which is explained in next section.

Table.1: Trends of SOS expenditure among Indian manufacturing firms

Year	Total no.of firms	No. of firmsincurring Environmental expenditure	Average amount of Environmental expenditure (in Million RS)	Average environmental expenditure intensity (aspercentage of total sales)
2005	5009	98 (1.96)	0.08	0.01
2006	5280	109 (2.06)	0.11	0.17
2007	5514	125 (2.27)	0.14	0.01
2008	5721	130 (2.27)	0.18	0.01
2009	6068	146 (2.41)	0.18	0.01
2010	6300	159 (2.52)	0.20	0.01
2011	6219	151 (2.43)	0.29	0.01
2012	6114	139 (2.27)	0.34	0.02
2013	6107	148 (2.42)	0.40	0.02
2014	8055	189 (2.35)	0.40	0.01

2015	8967	206 (2.30)	0.42	0.02
2016	9283	249 (2.68)	0.48	0.02
2017	9247	267 (2.89)	0.55	0.02
2018	9354	311 (3.32)	0.71	0.02
2019	9155	356 (3.89)	0.92	0.03
2020	8205	368 (4.49)	1.48	0.03
2021	6039	326 (5.40)	1.98	0.03
Total	120637	3477 (2.88)	0.56	0.03

Source: CMIE PROWESS Database



Studies investigating the determinants of SOS have been started in recent decades but most of them are in the context of developed countries. Since the sustainability transition requires wider participations in SOS from various actors across the world, the contribution of developing countries like India remains crucial. In addition, developing countries are in the early stages of their development so that can it becomes easier for them for adopting sustainability-oriented technologies and strategies into their production process and modify their growth path towards sustainability.

Factors affecting SOS behaviour of firms: hypothesis development

Institutional pressure /Environmental regulation

The most frequently investigated yet inconclusive factor to guide sustainability transition is environmental regulation as recognised in the literature. The conventional conception is that environmental regulation increases the cost and act as constraint to the firms by reducing their profitability, general investment and investment in innovation. Contrasting the conventional ideas, the porter hypothesis (PH) supports the view that environmental regulation alerts the firms about their resource inefficiencies, making information about the issue available, reducing uncertainties, and providing a level-playing field. Firms cannot recognize the economically viable SOS since they are not experienced to the environmental issues. This happens due to lack of information, organizational and co-ordination problems. (Porter and Linde,1995) But environmental regulations may force them to try for innovative SOSs that may provide them economic profit as well. The well-attuned firms see opportunities in environmental regulation by responding in innovative way which they would not have done in business-as-usual situation (Porter and Linde,1995; Jaffe and Palmer,1997).

Following the Porter Hypothesis large number of studies have empirically examined the role of environmental regulation in inducing eco-innovation^{3.3}. Studies found that current environmental regulation as well as anticipated regulation drive the firm to adopt SOS. Moreover, anticipated regulation also indirectly induces SOS by signalling the firms, by creating pressure or providing incentive for the firms who think in future they will be regulated (Khanna et al,2009; Horbach et al, 2013; Doran and Ryan,2011). Kammerer (2009) examined the drivers of environmental innovation among German firms focusing especially on the effect of environmental regulation. The result shows that the influence of environmental regulations varies across different types of innovation such as product and process innovation and different areas of innovation. Taking into account two types of environmental innovations viz. cleaner production innovation and end-of-pipe innovation in case of seven OECD countries, Frondel et.al (2004) found that regulatory pressure and

stringency of environmental policy, induce only the application of end-of-pipe measures whereas cleaner production strategies may be motivated by market forces such as cost savings.

Contrastingly, some studies have found the influence of regulatory factor on environmental innovation is insignificant or negative. In an industry level study in US, Brunnermeier and Cohen (2003) found that the influence of regulatory factor is insignificant to drive SOS. Study by Tsai and Liao (2017) found that environmental regulation is not a significant factor to affect eco-innovation among Taiwan manufacturing firms. It has been argued that the effect of environmental regulation on eco-innovation strategies may differ between developed countries and developing countries as the later may not enforce regulations strictly. Therefore, it becomes pertinent to verify the following question in case of a developing country like India: Does domestic environmental regulation induce higher SOS expenditure among the regulated firms?

Role of internationalisation in sustainability transition

In most of the empirical literature, the effect of domestic environmental regulation or of a specific international policy instrument on SOS have been studied which provides a myopic view of institutions. Institutional pressures can be viewed in a broader way. In addition to environmental regulations which can be identified as coercive institutional factor, normative institutional factor i.e., the awareness of customers and other stakeholders and mimetic institutions that is to learn from industry best practices may affect the sustainability behaviour of firms (Haque, 2018; Zhu et.al, 2012).

In today's globalised world where technologies and policies are increasingly integrated such studies undermine the globalised nature sustainability transition. As argued earlier in a global system of sustainability, multi-level institutions come into effect which together contribute to sustainability. An important channel through which institutions can be diffused across countries is internationalisation.

The literature on macro-level effect of globalisation on environmental sustainability dates back to the pollution haven hypothesis. Copeland and Taylor (1994) define pollution haven in a north-south model where north is an economically developed country and south is a less developed economy. North adopts stringent environmental regulation than the south. In the presence of internationalization, the pollutive industries will move to the south worsening its environmental quality and making it a pollution haven. Following this, several studies analyzed the inter-country and intra-country shifting of location of industries in the context of trade liberalization (Zheng and Shi, 2017). This narrow conception of regional relocation of plants as a result of stringent regulation undermines the detail understanding of firm-level activities. This

approach may fail to explain micro-level contributions towards environmental sustainability. Because, in the recent years SOS are increasingly adopted by the firms voluntarily or induced by several drivers. These SOS may compensate for pollution haven in the developing countries and may contrast the pollution haven hypothesis. Therefore, the debate on pollution haven hypothesis can be modified in the context of increased efforts on SOS by the firms. In this context, this study examines the linkage between internationalization and environmental protection at micro-level by taking a novel approach. Rather than examining whether internalization increase level of pollution by relocating the pollutive industries into the developing country with weaker regulation, we investigate whether presence of internalization lead to increasing efforts towards environmental protection by the firms.

Internationalization may affect the sustainability behaviors of firms via two channels. Firstly, internationalization leads to the diffusion of environmental regulations across borders (Perkins and Neumayer,2012). Export and foreign investment are the two main strategies of internationalization (Vettas,2003). The exporting firms face market access regulation in the stringent regulatory countries in the foreign market. To comply with such 'green barriers' they have to upgrade their environmental standards in production (Hojnik,2017; Zhu et al,2012). Most of the multi-national companies originate from and operate in developed economies which are under stringent environmental regulation for which they have already developed capabilities to comply with such regulations. The exporting firms and MNCs may practice SOS in their destination countries. For instance, The German regulation i.e., ban on an input Azo- dye has compelled the Indian textile and leather industries to incorporate an environmentally friendly strategy into their production process (i.e., substitute of Azo-dye has been developed and substituted with Azo-dye). Moreover, the German regulation was also integrated into the Indian policy (Tewari & Pillai,2005; Chakroborty & Chatterjee,2017). This is because, both exporting firms and MNCs lobby may influence the government with lower regulation to strengthen their environmental regulation to gain competitive advantage in the destination country (Perkins and Neumayer,2012).

The second channel through which internationalization may affect the environmental strategies of firms is international technology transfer and knowledge spill over. The role of international technology transfer and knowledge spill over in addressing the sustainability challenges has attracted attention among the researchers as well as the policymakers across the world (Starmm et.al, 2009; Walz and Delgado,2012). Since the MNCs have already developed SOS to comply with the stringent environmental regulations in the international market, they may transfer their superior sustainability-oriented technologies, knowledge and experiences to the subsidiaries in lower environmental regulation countries. Even the domestic exporting firms (which are not MNCs) are possibly more capable of adopting sustainability-oriented

technologies and practices. This is because they have better knowledge of the best available technologies and practices as they interact with their foreign counterparts who already use such technologies. For instance, a domestic firm exporting intermediate products to a foreign firm may have better understanding of the production process of its counterpart which is a MNC with better SOS (Haller and Murphy, 2012). The exporting firms may also develop the capability via 'learning from exporting'. These firms learn from their foreign market experience, through interaction with technologically superior foreign partners, dealing with demanding foreign customers, observing from best business practices, capable foreign competitors etc. (Hojnik, 2017; Zhu et al, 2012).

Therefore, it can be hypothesized that internationalised firms are more likely to adopt SOS. We examine the effect of two main channels of internationalisation viz. export and foreign ownership on the sustainability-oriented behaviours of firms. The particular hypotheses are:

- a) Export intensity of a firm positively affects its SOS expenditure
- b) The presence of foreign investment positively contributes to SOS expenditure of a firm.

In addition to domestic regulation and internationalisation, we include the following control variables that may determine the SOS behaviour of firms. Market competition may influence the sustainability behaviour of firms. In a less competitive market structure, there is no incentive for the firm to adopt SOS to increase its value. Higher competition in the industry may drive the firm to behave sustainably so that it can increase its value to survive in a competitive market structure (Horbach, 2008; Sideschlag and Yan, 2021). Therefore, it can be hypothesized that competition may induce firms to undertake SOS. In addition, we also control for firm heterogeneity viz. size, age, energy intensity, productivity of firms, innovative capability of firms, type of entity, market share of the firms which may affect the environmental behavior of firms.

Data and empirical strategy

To examine the effect of above-mentioned variables on the SOS expenditure of firms, we have collected all the information from CMIE Prowess database. Time period for this study is from 2005 to 2021. The description of the variables and summary statistics are shown in the Table- 2 and Table-3 respectively.

Table-2. Variable description

Dependent variable	Explanation
Y = SOS Expenditure intensity	Total annual Environmental related expenditure/total annual sales
Independent variables	
Export intensity	Total Export/ sales
Foreign ownership	Categorical variable taking value 1 if belongs to foreign ownership group or its foreign share >10 percent
Domestic environmental Regulation	Categorical variable=1 if firm belongs to red or orange category of industries, 0 otherwise
Size	Log of Sales
Age	2021-year of incorporation of a firm
R &D intensity	Research and Development expenditure /sales
Energy intensity	Power and fuel expenditure/ sales
Ownership structure	Categorical variable=1 if the firm is a public entity and zero for private entity
Productivity of firm	Labour productivity = total sales/no. of employees in the firm
Level of Competition in industry (HHI)	Herfindahl- Hirschman Index of industries at two-digit level

Table.2. Summary statistics

Variables	No.of Observations	Mean	Std. Dev.	Min	Max
SOS Expenditure intensity	120636	0.0003	0.0232	0.0000	8.0000
Domestic environmental Regulation	120637	0.4097	0.4918	0.0000	1.0000
Export intensity	120636	0.0721	0.4956	0.0000	105.5263
Foreign ownership	120637	0.0607	0.2387	0.0000	1.0000
Size	120631	6.4542	2.1611	-2.3026	15.6332
Age	120614	33.355 4	18.686 3	2.0000	159.0000
R &D intensity	15731	0.0187	0.4710	0.0000	57.6000
Energy intensity	109900	0.0730	1.0802	-0.4000	215.0000
Ownership structure	120561	0.6261	0.4838	0.0000	1.0000
Productivity	115451	9.9851	43.467 0	-0.0603	3978.186 0
HHI (Level of Competition in industry)	120637	0.0476	0.0782	0.0088	0.9729

Due to the presence of large number of zero expenditure on SOS, our dependent variable becomes left censored. The ordinary least square method will give biased and inconsistent result in this case. The appropriate model for such situation is a Tobit model. Given the panel data set-up the fixed effect tobit model using maximum likelihood estimation gives biased and inconsistent results. Its marginal effects can be underestimated and slopes may be overestimated. Therefore, random effects model for maximum likelihood estimation is desirable in such case (Shuai and Fan, 2020; Dalei and Joshi, 2020). Moreover, another advantage of random effect tobit regression is that it can include categorical variable in the analysis. Some of the important explanatory variables being categorical in nature, the Random effect tobit model has been chosen. Along with the above-mentioned independent variables, we have included year dummies and industry dummies (at two-digit level) to control for the time effect and industry specific effect. To avoid possible endogeneity

problem, we have taken the lag value of variables viz. export intensity, productivity, energy intensity as there may be two-way causality between these variables and SOS expenditure of firms.

Result and discussion

Table. 3 Random Effect Tobit Regression result: Determinants of SOS Expenditure

	All Manufacturing Firms		Firms from polluting industries only	
Explanatory variables	Coefficient	Std.Error	Coefficient	Std.Error
Domestic Environmental Regulation(polluting industries dummy)	-0.0002	0.0014		
Export intensity_lag	0.0052***	0.0014	0.0045**	0.0022
Foreign ownership	0.0028*	0.0016	0.0049**	0.0023
Size	-0.0006***	0.0003	-0.0020***	0.0004
Age	-0.0001*	0.0000	-0.0001	0.0000
RD_int	0.0027	0.0084	-0.0062	0.0125
Energy intensity_lag	0.0023	0.0046	0.0098	0.0097
Publicentity	0.0024*	0.0013	0.0050***	0.0021
Productivity_lag	0.0000	0.0001	0.0001**	0.0000
HHI	-0.0031	0.0085	-0.0309	0.0223
_cons	-0.0962	0.6084	-0.0866	1.1422
Industry dummy	Included		Included	
Year dummy	Included		Included	
Number of Observations	Number of obs = 14767 Left-censored obs=13976 uncensored obs= 791 right-censored obs=0		Number of obs =6767 Left-censored obs=6309 uncensored obs= 458 right-censored obs=0	

***, **, * imply significance level at 0.01, 0.05, 0.1 respectively

The variable for domestic regulation i.e., the industry level categorical variable for regulated industries (DER) has been insignificant. This implies that firms belonging to regulated industries are not necessarily spending more on SOS. The domestic environmental regulations have failed to induce SOS among the firms from polluting industries in India. Another possible explanation for insignificant effect of domestic regulation may be due to the fact that we include only the industry-level measure of regulation. Even though the industrial classification has been kept in mind of regulatory authority while implementing various environmental laws, the command-and-control type principle has been followed in India. The regulatory authority inspects the polluting activities of firms on case-by-case basis and take necessary actions. Therefore, the firm-level details regarding environmental details would provide a clear picture of the effect of domestic environmental regulation on SOS. This remains as a scope for future study in this area.

However, both the indicators of internationalisation have been significant in both the models. It shows that presence of foreign capital is positively affecting the SOS expenditure intensity of firms. Our result is in line with the empirical study of Zhu et.al, (2012); and Balaguer et al. (2022) which show that direct or indirect involvement of foreign capital induces environmentally friendly behaviour among manufacturing firms in China and Spain respectively.

Among other control variables, size and age are negatively affecting the level of SOS expenditure of firms. The small sized firms are spending more in SOS. The newer firms also tend to spend more on environmental actions. Moreover, the public entities are better oriented towards sustainability than the private entity. This may be due to the fact that the public entities have to face stakeholder pressures from the public. Productivity of firms has been positively significant in the second model. The productive firms are spending more on SOS. This may imply that the productive firms are efficient both in terms their own production process and addressing the environmental concerns.

Conclusion

This study adds to the literature that analyse the determinants of environmental actions by the firms. Different studies have taken different measures of SOS such as environmental innovation, investment in environmentally friendly capital, or pollution abatement expenditure of firms. But we have taken a consolidated measure of SOS that includes any kind of expenditure made by the firms for environmental protection. Hence our measure of SOS is broader than others.

Our results reveal that domestic institutional pressure has not been effectively able to induce SOS engagement among Indian firms. This indicates that although there are multiple environmental acts and rules in place but the enforcement of such regulations has been weak in India. However,

internationalisation has a positive effect on environmental actions in the manufacturing sector. Since export of firms and environmental activities of firms are positively related, it can be argued that international institutional pressure might have been diffused into India via export and induced SOS among firms. In addition, presence of foreign share also positively contributes to SOS expenditure by the firms.

From these results, it can be concluded that encouraging globalisation may contribute to sustainable development in the manufacturing sector especially in the developing countries. Therefore, the typical argument of pollution haven i.e., globalisation may worsen sustainable development especially in developing countries may not hold good at present. In contrast, sustainability transition being global in nature, openness to trade and integration of countries may be helpful for building a sustainable world together.

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Notes

¹ For instance, the twelfth five-year plan of India titled as 'faster, sustainable and more inclusive growth' recognized the need for low carbon strategy to be integrated into growth process and aimed to reduce its emission intensity at 20-25 percent reduction over 2005 base level by 2020. More recently in its Nationally Determined Contributions under the Paris agreement, India has pledged to reduce its emission intensity further by 33-35 percent over 2005 level by 2030.

² It is third largest emitter of CO₂ releasing 2076.8 Million Tonnes of CO₂ by 2016 (Union of concerned scientists, 2018).

³ Insights have been drawn from the empirical literature on eco-innovation as it may be considered as one of the strategies to address environmental issues. The terms such as 'eco-innovation', 'environmental innovation', 'eco strategies', 'green practices', 'sustainable innovation' are interchangeably used in the empirical literature to analyse such environmentally oriented strategies. For instance, Doran and Ryan (2016) broadly measure eco-innovation by indicators such as reduced material use per unit of output, reduced energy use per unit of output, reduced CO₂ 'footprint' (total CO₂ production), replaced materials with less polluting or hazardous substitutes, reduced soil, water, noise, or air pollution, recycled waste, water, or materials, reduced energy use, reduced air, water, soil or noise pollution, improved recycling of product after use

Business models and value networks for industrial energy efficiency in India

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Abstract

Energy efficiency has largely been studied in relation to carbon emissions and energy demand reduction. There is a tendency for spatial blindness in the approaches suggested for energy efficiency improvement in the literature, as the value of energy efficiency can differ in different spatial contexts. In this research, I focus on industrial energy efficiency approaches in the Indian context, where energy efficiency is seen to offer multiple benefits at the firm, industry, region, national, and international level. Within the Indian context, approaches to energy efficiency differ across regions and states, as different sub-national governments and agencies seem to prioritise different measures.

The dynamics within the value network of industrial firms and the barriers to energy efficiency have not been fully understood in the literature. This research aims to address this gap by investigating the business model approaches in India's energy intensive industries. Improvements in energy efficiency have largely been studied at the firm level, using business model approaches to value creation, value delivery and value capture. The study recognises that several barriers to energy efficiency are external to firms, and therefore innovation in energy efficiency requires ecosystem approaches or a study of value networks within which firms function and innovate. Within a value network, organisations or businesses work towards a shared value proposition, and the business models within the network are outcome-based. These value networks might differ from place to place, as different regional contexts influence the drivers of value creation for business models. Such value drivers can include regional policies, regulations, financial mechanisms, support from

local industry association, government institutions and other ecosystem elements of a socio-technical system, defined as co-evolutionary elements.

The study adopts a novel perspective of complex values that goes beyond traditional economic value identification approaches and considers a range of non-economic value drivers, such as social, environmental, and regulatory factors, that can impact the adoption and implementation of business models for industrial energy efficiency. The complex value perspective can offer a more holistic understanding of the business model thinking process in a value network.

This work presents an ongoing investigation in the field of business model innovation for energy efficiency, currently in the literature review phase. To gain insights into the value network dynamics, the research will conduct two case studies focusing on energy-intensive industrial sectors: sugar manufacturing in Uttar Pradesh and textiles manufacturing in Rajasthan. The data collection phase, including in-depth interviews, document analysis, and focus group discussions, is planned for the latter half of this year. These region-specific case studies will contribute valuable knowledge on business model approaches for energy efficiency in different contexts. The region-specific case study approach will be critical to thinking about business model approaches for energy efficiency in different contexts and will be useful in providing constructive inputs to policy makers, regulatory agencies, industries, industry associations, energy service providers, equipment manufacturers and policy researchers. The findings emerging from the fieldwork will be presented at the Globelics conference in October, 2023.

1. Introduction

India ranks third in the world in primary energy consumption, with the industrial sector accounting for 56% of the country's total energy consumption (BEE, 2021). The Bureau of Energy Efficiency's (BEE) National Strategy Plan states that among all consumer segments in India, the industrial sector has the highest energy-saving potential of 60% by 2030. Key industries such as cement, iron & steel, textiles, sugar, and fertilisers rely heavily on coal, oil, and gas as direct inputs. These industries contribute significantly to the country's overall energy consumption. The inefficient use of key equipment and motors, as well as processes in these industries, leads to higher energy consumption and costs (BEE, 2020). For India to transition to a sustainable energy future, industrial businesses must prioritise energy efficiency as a core part of their practices. However, several barriers hinder energy efficiency improvements in these industries.

The business models for industrial energy efficiency in India have not been adequately explored in the literature. The dynamics within the value network of industrial firms and the barriers to energy efficiency have not been fully understood. This research aims to address this gap in the literature by investigating the business model approaches for industrial energy efficiency in India's energy intensive industries.

As the first objective, the research will explore how the dynamics between firms in the value network influence value creation, value delivery and value capture from industrial energy efficiency, using the value networks mapping framework by Grudinski et al. (2015). The study builds on the approach that business models do not just have a company focus, but involve a wider set of stakeholders, necessitating a broader value-network perspective for innovating and transforming the business model (Bocken et al., 2014; Evans et al., 2017). The research would also investigate the strategies adopted by business models to deliver the value proposition and the outcomes of the values captured. I draw from Hall & Roelich (2016)'s concept of complex values of business models, defined as the production of financial, developmental, social and environmental benefits that accrue to different actors, across multiple spaces and times, and through several systems, for the business models to remain viable. The value is captured from a process of negotiation or adjustment between new values and the energy system.

The industrial business models in India, particularly in the energy-intensive industries have been unable to optimally find value in adopting energy efficiency measures (Kumar et al., 2017; PwC & SSEF, 2014; TERI, 2012). The energy efficiency measures are largely limited to big conglomerates and a few PAT (Perform, Achieve and Trade) industries that are mandated by the Ministry of Power to reduce their specific energy consumption. Several private Energy Service Companies (ESCO) business models have been developed over the past two decades, but their sustainability has been a concern, largely due to lack of financing mechanisms and limited confidence among industrial consumers to opt for ESCO services (Kumar et al., 2017). Also, the energy services business models for energy efficiency are limited in their services to energy consultancy, equipment supply contracts and shared savings models. Therefore, as a second objective, I will identify the key barriers faced by business models in improving industrial energy efficiency, and what changes within the firm or the value network can help address the barriers.

Business models co-evolve with other elements in a socio-technical system, including infrastructure, technology, user practices and ecosystem (Foxon, 2011). I draw from the co-evolutionary approaches for studying sustainability transitions, to understand how the value drivers for energy efficiency have evolved along with other elements. The Government of India, has introduced several policy and institutional measures industrial energy efficiency improvement, such as the Perform, Achieve and Trade Scheme. However, little is known about the impact of such schemes on business model approaches. Thus, as a third objective, I will explore how the co-evolutionary factors, external to the value network, support or hinder the evolution of business models for industrial energy efficiency in the two Indian states of UP and Rajasthan, using a multiple case-study approach.

In the next section to follow, I will review the literature on the benefits to energy efficiency in the Indian context, key definitions to study business models and value networks, business model approaches for industrial energy efficiency, policy efforts towards energy efficiency improvements in India, and barriers to industrial energy efficiency.

2. Literature review

2.1 Multiple benefits of industrial energy efficiency: understanding the developing country needs

Different studies have defined energy efficiency benefits in various ways, including non-energy benefits (NEBs) (Rasmussen, 2017), multiple benefits (IEA, 2014), co-benefits (Jakob, 2006), and productivity benefits (Worrell et al., 2003), at individual, sectoral, national, and international levels (Nehler & Rasmussen, 2016a; J. Rasmussen, 2017). Annex 1 presents a broad overview of

literature around different definitions to energy efficiency benefits. Rasmussen (2017) has discussed that NEBs for the industrial sector include reduced costs for maintenance and operations, reduced waste, improved product quality, increased reliability, improved worker safety, and improved productivity (Cooremans, 2011; Pye & McKane, 2000; Worrell et al., 2003). Environmental co-benefits of industrial energy efficiency include reduced air pollution, improved local air quality, reduced corrosion of materials, and related health benefits (Jakob, 2006).

IEA's multiple benefits approach to energy efficiency policy seeks to expand the traditional focus on reduced energy demand and lower greenhouse gas emissions by identifying and measuring impacts across many spheres and stakeholders (IEA, 2014). This approach reflects a paradigm shift towards actions on both the supply and demand sides to achieve economic growth, energy security, competitiveness, and environmental sustainability.

The lack of attention paid to energy efficiency investment opportunities is a major barrier to its uptake, and the multiple benefits approach aims to render more apparent the benefits that energy efficiency can generate for stakeholders (IEA, 2014). The approach can also help to understand the sources and causes of the rebound effect of energy efficiency and manage any trade-offs that might take place (Sorrell, 2004). For instance, in the context of developing countries where growth rates are high and economy is dependent on energy intensive activities, the rebound effect may be desirable at an initial stage for the economy to capitalise on its energy resources and stimulate other efficiencies (IEA, 2014). Goldemberg et al. (1994) also argue that energy requirements for fulfilment of basic human needs and infrastructure development need to be prioritised in the Global South. The infrastructure development would require innovations in the processing of materials from energy-intensive industries. These industries have already matured and saturated in the Global North, causing much damage to the global climate. Thus, to avoid the consequences of increased carbon emissions from increased energy production and use, the innovations in the South need to be less energy-intensive, cost-effective and cleaner technologies (Goldemberg et al., 1994; Reddy, 2002).

However, the price elasticity for energy demand differs across consumer segments. Not all consumers may respond to increase in energy tariffs by reduction in energy use. For such segments, it may be more effective to reduce demand by devising measures to promote the installation of energy-conserving end-use equipment, in which case the resulting efficiency improvements are non-price-induced (Reddy, 2002). This makes a strong case to study how business model innovations can support industrial energy efficiency in India.

2.2 Business models in the value networks for industrial energy efficiency

2.2.1 Defining business models, value chains and value networks

The literature presents various perspectives on the business models. Amit and Zott (2012) describe business models, from an activities-based perspective including the selection of activities ('what'), the activity system structure ('how'), and who performs the activities ('who'). Teece (2010) describes that a business model articulates how the company will convert resources and capabilities into economic value. It is nothing less than the organisational and financial 'architecture' of a business and includes implicit assumptions about customers, their needs, and the behaviour of revenues, costs and competitors (Teece, 2010). More specifically, Osterwalder and Pigneur (2010) describe a business model as a series of elements: the value proposition (product/service offering, customer segments, customer relationships), activities, resources, partners, distribution channels (i.e. value creation and delivery) and cost structure, and revenue model (i.e. value capture). Richardson (2008) based on a wide range of literature, proposes a consolidated view of the components of business models as: the value proposition (i.e. the offer and the target customer segment), the value creation and delivery system, and the value capture system.

Scholars of business management and strategy have discussed through different sectoral examples how firms function within a value chain and value network contexts, and why it is important to think about these concepts. Business models are concerned with how the firm defines its competitive strategy through the design of the product or service it offers to its market, how it charges for it, what it costs to produce, how it differentiates itself from other firms by the value proposition, and how the firm integrates its own value chain with those of other firms in a value network (Rasmussen, 2007) .

Porter (1985) has argued that a value chain of a firm provides the source of its competitive advantage. The value chain displays how total value is created by the firm and consists of value activities and a margin. Every value activity employs purchased inputs, human resources, some form of technology and makes use of information. The value created by the chain is measured by the total product revenue. The margin is this value less costs (Porter, 1985).

Further, Chesbrough and Rosenbloom (2002) state that the firms use complementary assets to supplement their own assets, causing the firm's value chain to intersect with the value chains of the owners of complementary assets and raises the issue of distribution of value between the participants. Chesbrough and Rosenbloom (2002) use the term 'value network' to describe the relationship between the firm and its suppliers and customers. The role of the business model is to position the firm in the value network in such a way that the firm can capture value from its innovation. Porter argues that a source of competitive advantage is optimising or better coordinating the linkages

between the firm's value chain and the supplier or buyer value chains. A business model does not only have a company focus, but involves a wider set of stakeholders, necessitating a broader value-network perspective for innovating and transforming the business model (Bocken et al., 2014; Evans et al., 2017). Further, while reviewing the case of telecommunications network, Li and Whalley (2002) argue that a particular strategy or business model formulated within the context of one value chain may at the same time be inappropriate, or even harmful, in the context of the other value chains of which these nodes are part.

Synonymous to value networks, (Oskam et al., 2021) use the concept of 'innovation ecosystem' that consists of multiple actors that aim to create and capture value from collaborative innovation activities around a joint value proposition. An important element of these sustainability-oriented innovation ecosystems is the development of a business model that integrates environmental and social value with economic viability (Bocken et al., 2014). Parida et al. (2019) adds to the idea and discusses the role of value networks in influencing value delivery of business models. New business models create the need for revised roles and responsibilities in industrial ecosystems. The business ecosystems external to the company become much more important and affect value delivery significantly as relationships become intensified, interdependent, and globally distributed.

2.3 Business model innovation for energy efficiency

Business model innovation is a potential approach for incorporating energy efficiency into mainstream businesses. The decision-making process around investments for energy efficiency is the key to business model innovation. Rasmussen (2014) has discussed a life cycle decision-making model where firms over time will move from a state where no energy-efficiency decisions are made towards a steady state where the firms are said to routinely seek for new energy-efficiency investments to invest in. Neal Elliott & Pye (1998) present a seven-step model for such a decision-making, where the steps include: opportunity identification, technology identification and project design, financial analysis, purchasing and procurement, financing, installation, start-up and training.

Energy Service Companies (ESCOs) and Energy Performance Contracts (EPCs) are two commonly studied business models for energy efficiency. The energy performance contracting is a financial mechanism for completing energy upgrades that allows for comprehensive energy upgrades without tapping into an organization's capital budget (Zhu, 2020). The owner develops a Request for Proposal (RFP) for ESCO selection, and the ESCO conducts an audit and develops an implementation proposal. A common type of contract used by ESCOs are known as 'chauffage', with ESCOs taking over complete responsibility for providing clients with an agreed set of energy services.

Another type of ESCO is a Government-backed super ESCOs, often promote large scale programmes, such as the Energy Efficiency Services Limited (EESL) in India - promoted by the Ministry of Power. The pay-as-you-save (PAYS) ESCO model involves getting efficient energy using devices or equipment to users. Users continue to pay the agreed-upon electricity bill for a certain period of time, after which the device/equipment ownership is transferred to the users (Zhu, 2020).

Some international examples of energy efficiency business model innovation within the value networks include Energy Symbiosis Network and Learning Energy Efficiency Networks (LEEN) (Koewener et al., 2014; Krishnan, 2022). In an energy symbiosis network, the industrial units in a cluster exchange steam, compressed air, and waste heat, and can also share centralized assets such as a renewable energy microgrid (Krishnan, 2022). Waste heat at high temperatures (above 500°C) from refractories, die casting, etc. can reduce or meet the heat demand within the sector as well as in low- and medium-temperature processes outside the sector. The LEEN networks were originally developed in Switzerland in 1987, and later adapted to the German context. The main idea is to share experiences among companies in order to reduce transaction costs, while simultaneously using social mechanisms to encourage industrial energy efficiency through company management (Koewener et al., 2014). They serve to increase the priority of energy efficiency aspects within companies, while alleviating high transaction costs and assisting company decision-making. Often, the benefits of LEEN can be fully realized by industry itself, and the processes can also be financed by the companies themselves to the greatest possible extent.

However, an understanding of business models for energy efficiency in the literature and the options available for innovation for energy efficiency seem limited at present. While there is an extensive literature on energy efficiency measures for different industrial sectors (Bhaskar et al., 2013; Chauhan et al., 2011; Nehler & Rasmussen, 2016b; SSEF & CII, 2013; TERI, 2012), there is no comprehensive view of how firms should approach embedding energy efficiency as a value proposition within the value networks.

2.4 India's evolving efforts to support industrial energy efficiency

2.4.1 India's commitment to climate change mitigation

During the COP-26 in 2021, India made the commitments to reduce its total projected carbon emissions by one billion tonnes by 2030 and reduce the economy's carbon intensity by 45 per cent by 2030 over 2005 levels. In addition, India aims to have 500 GW of non-fossil energy capacity and meet 50% of its energy requirements from renewable energy by 2030. India had already achieved a reduction of its emissions intensity by 21% between 2005 and 2014 (BEE & AEEE, 2021), and is committed to further achieve its targets through

several industrial energy efficiency policy measures (discussed in the following sections), as industry has been a key contributor to India's carbon emissions (BEE, 2021).

2.4.2 Policy measures by the Central government

India was an early mover to have framed its Energy Conservation Act 2001 and established the Bureau of Energy Efficiency (BEE), a statutory body under the same legislation. BEE has proactively formulated approaches for achieving energy efficiency at scale and facilitating the adoption of energy-efficient technologies (Agrawal et al., 2020). In 2008, India launched the National Mission for Enhanced Energy Efficiency, which aimed to strengthen the energy efficiency market through innovative business models. The following year witnessed the establishment of EESL, a public sector ESCO for scaling up utility-scale DSM measures (Sarkar et al., 2016).

Recognising the need to maintain a high growth-rate for increasing the living standards of people and reducing the vulnerability to adverse impacts of climate change, the National Action Plan on Climate Change (NAPCC) was released in June 2008. NAPCC outlined eight national missions representing long- term and integrated strategies for climate change. The National Mission for Enhanced Energy Efficiency (NMEEE) is one of the missions to strengthen the energy efficiency market through innovative business models. Four initiatives were unrolled under NMEEE: Perform Achieve and Trade Scheme (PAT), Market Transformation for Energy Efficiency (MTEE), Energy Efficiency Financing Platform (EEFP), and Framework for Energy Efficient Economic Development (FEEED) (BEE, 2021).

The PAT scheme is a market-based mechanism to enhance the cost effectiveness of energy efficiency improvements in energy-intensive large industries (refer Annex 2) and facilities through certification of energy savings that could be traded. The scheme has completed six cycles and covers 13 sectors and ~1100 designated consumers with an estimated energy savings of around 28 Mtoe till PAT Cycle-VI (Ministry of Power, 2022). Annex 3 provides a summary of energy savings achieved under the first three PAT cycles. Further, to support energy efficiency improvements in Small and Medium Enterprises (SMEs), the BEE also introduced the BEE-SME programme, covering four clusters (Ludhiana, Indore, Varanasi, and Pali) (BEE, 2020, 2021).

Currently, around 90% of installed motors in India are of IE1 or IE0 base, which are typically energy inefficient. To address this, the Department for Promotion of Industry and Internal Trade (DPIIT) has implemented a Quality Control Order that mandates all new motors (imported or domestically produced) to be minimum IE2 compliant in India (U4E, 2020). The EESL recently launched the National Motor Replacement Programme, offering lower prices of IE3 motors as compared to market retail price. Under the ESCO model, the entire investment

for replacement will be made by EESL, along with support for Measurement and Verification (M&V) of motors and technical training for maintenance teams (U4E, 2020).

Also, the recently amended Energy Conservation Act has introduced the setting up of India's own and first-ever carbon credits market, which would encourage energy efficiency investments in industries (Jai & Dutt, 2022).

2.4.3 State level efforts to encourage energy efficiency measures

Several states have introduced the State Action Plans for Climate Change (SAPCC), following the blueprint of the NAPCC, that entail energy efficiency priorities, targets and indicative budgets. However, the SAPCC provisions have not been effectively enforced (Oxford Policy Management, 2017). The State Energy Efficiency Index (SEEI) Report highlights the Indian states' performance on adopting energy efficiency policies and regulations, financial means, institutional capacity, financial mechanisms and the impact of energy efficiency/savings achieved. For the past two years, Karnataka, Rajasthan, Haryana, Punjab, Maharashtra and Kerala have featured as the 'front runner or achiever' states out of India's 36 states and Union Territories (BEE & AEEE, 2021, 2022). The remaining states fall in the 'contender' and 'aspirant' categories.

For industrial energy efficiency, some states have implemented regulations for non-PAT industries and taken proactive measures to support energy efficiency industries through State Nodal Agencies. The State Energy and Climate Index (SECI) Report highlights the measures such as Time of Use/Time of Day tariffs adopted by states such as Kerala, Andhra Pradesh, Madhya Pradesh, West Bengal, and Delhi to encourage energy efficiency for several consumer categories including industries (Pandey et al., 2022). Most states are reported to provide 24-hour electricity supply to the industrial sector as per the SECI Report.

On the whole, the rankings tend to focus on relatively narrow indicators highlighting the policy measures to support energy efficiency in states, and do not convey much around investments or business model innovations adopted in different states.

2.5 Barriers to business models in the value networks for industrial energy efficiency in India

Despite the policy and regulatory measures for energy efficiency improvements, the essential obstacles and supporting factors are only partially addressed for industries. Rasmussen (2014) argues the obstacles to achieving energy efficiency are not homogeneous and depend on various factors such as

company size, structure, energy intensity, management preferences, and transaction costs. The company management often does not focus on energy issues, and employees responsible for energy issues may not have enough time to spend on energy efficiency due to other responsibilities. Investment decisions are often evaluated based on payback time rather than internal rate of return, and energy efficiency is not considered a strategic investment. Further, the unclear value creation opportunities for social and environmental benefits can pose a challenge for designing business models that capture economic value for the firm. More specifically, the energy efficiency gap exists due to market and non-market failures, such as lack of information, principal-agent problems, artificially low energy prices, high-risk level, low real return, and uncertainty (Rasmussen, 2014; Sorrell, 2004) .

Specific to the PAT industries in the Indian context, firms suffer the lack of support systems and energy auditors with process specializations, especially in industries with high diversity in processes such as the textiles sector (PwC & SSEF, 2014). There is a need for capacity building among the institutional structure, including BEE and state nodal agencies, designated consumers (DCs) under PAT, and empanelled auditor firms, with regular meetings or contacts to facilitate achievement of energy efficiency targets. Clarity is needed among DCs regarding notification, annual energy returns, mandatory energy audits, and verification audits, as well as experience exchange workshops to understand energy savings measures adopted by other industries in their sector (PwC & SSEF, 2014).

There is also lacking technological innovation for firms that might want to share assets such as heat pumps or microwave heating systems. Both the technologies require local expertise, which can be achieved through technology transfer and partnerships with other nations (Krishnan, 2022).

As for the ESCO market in India, the industries sector has particularly become challenging owing to complexities associated with M&V, and the requirements for a range of process-specific solutions (Kumar et al., 2017). Lack of standardisation of audits, solutions, contracts, project execution and savings validation are other challenges for ESCOs. For the smaller ESCOs, lack of financing is the biggest challenge, as ESCOs generally finance projects on their own balance sheets to reduce financial risks, but this hinders the implementation of many projects (Kumar et al., 2017).

As observed from the literature, the barriers to industrial energy efficiency can be both internal and external to the firm. However, each of the barriers can be mapped within the value network or the innovation ecosystem of the firms. A systematic approach from a value networks perspective can facilitate a comprehensive understanding of business model innovations and supportive policy measures to address the barriers to industrial energy efficiency.

3. Research Questions

The central research questions for the study are as follows:

RQ1: What are the dynamics within the value network of key industries in India that shape value creation, delivery and capture for industrial energy efficiency? RQ2: How have the factors, external to the business models' value network, co-evolved with the value networks for industrial energy efficiency measures in Indian states?

RQ3: What are the key barriers faced by business models in improving industrial energy efficiency, and what changes can help address the barriers?

4. Analytical framework

The research will draw frameworks and concepts from four studies. These include Grudinschi et al. (2015)'s value network mapping framework, Foxon (2011)'s co-evolutionary framework to study the co-evolution of business models in a socio-technical system, Hall and Roelich (2016)'s complex value business model process, and Chowdhury et al. (2018)'s taxonomy of drivers and barriers to industrial energy efficiency.

The value networks framework by Grudinschi et al., (2015) will serve as the primary framework for this study to map the relationships between different actors in the energy value network of industrial firms. This framework provides a clear method for mapping and enhancing value networks, and offers a means to study how missed value propositions or new values can be created in a network. The mapping process by Grudinschi et al., (2015) involves identifying the perceptions of each participant regarding their own added value as well as the value they receive from other participants in the network. The proposed mapping method involves mapping the value network of the current state of collaboration, then enhancing it to create value for all participants in the collaboration, resulting in the mapping of the potential value network. The mapping process includes identifying current perceptions of added value and perceived benefits of collaboration, identifying challenges in the activity of partnership, identifying the strengths and resources of each participant, and converting these strengths and resources into value attributes to respond to challenges. By using this framework, the study aims to identify the value networks of the selected industries, understand the barriers limiting the value creation, and ways to enhance value creation for all stakeholders involved.

The value networks framework will be complemented with Foxon's (2011) co-evolutionary framework to understand how the co-evolutionary elements in a socio-technical system drive value for energy efficiency for business models. By analysing the interactions between the five co-evolutionary elements of technology, institutions, user practices, business strategies, and ecosystems, the research will examine how these elements bring changes in the value network,

further resulting in changes in value propositions, value created, delivery methods, and value captured by the business models. The co-evolutionary framework provides a systemic understanding of the processes of change, extending beyond the dynamics of an individual firm, and identifying which co-evolutionary elements can support the novel business model innovations for energy efficiency. This approach will help to identify factors that have supported improvements in industrial energy efficiency measures in India, for example, the policy measures, institutions, and financial mechanisms provided by the government under the PAT Scheme. Also, the co-evolutionary framework provides a way to identify and analyse feedback loops, which are important drivers of change in socio-technical systems. Feedback loops can either reinforce or destabilise existing conditions, and understanding these dynamics is critical for identifying leverage points for addressing the barriers to energy efficiency.

In addition to the above, the complex values business model process, as defined by Hall and Roelich (2016) and Hiteva and Foxon (2021), is a framework that will enable the identification and analysis of non-economic values created by a business model. The process is guided by the understanding that values are not fixed but rather dynamic, changing over time and across geographies in response to multiple socio-economic and political economy factors. The complex values business model process involves identifying the range of stakeholders involved in a business model and understanding their values and aspirations. The framework recognises that the creation of non-economic values is crucial for sustainability and the transition towards a low-carbon economy. The identification of these values helps to ensure that business models are designed to not only maximize economic benefits but also to meet societal and environmental goals (Hall & Roelich, 2016; Hiteva & Foxon, 2021). Through this process, it is possible to identify trade-offs and synergies between different values in the value network.

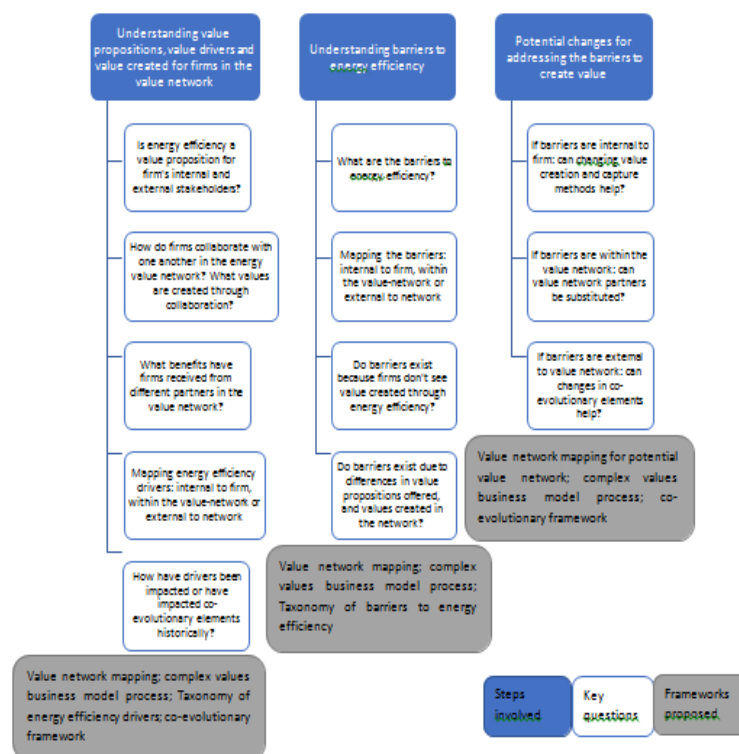
The complex value model recognises that business models consist of mixes of primary and secondary incentives, corresponding to different types of values, and value capture emerges from a process of negotiation between new values and the energy system. Hiteva and Foxon (2021) suggest that this iterative process of value identification and capture is crucial for business model innovation. In the Indian context, the current approach to energy value networks focuses mainly on economic values, lacking a holistic perspective on business model innovation from a complex values viewpoint. Therefore, a complex values approach that identifies the value drivers, potential value propositions, and value capture methods can provide a novel solution for industrial energy efficiency barriers.

Finally, Chowdhury et al. (2018) 's taxonomy of drivers and barriers to energy efficiency provides a multi-scale approach to understanding the factors that impact a firm's energy efficiency at the process, plant, and external

grid/national level (Annex 6). The taxonomy includes drivers and barriers that are both internal and external factors to the organisation. The key barriers in the framework include market related factors such as cost to production disruptions, rising energy prices, and international competition. Other barriers include access to capital, hidden costs, verification of suppliers' performance claims, and difficulties in accessing external skills. Behavioural and organisational factors, such as lack of interest in energy efficiency, lack of time, and divergent interests, can also deter the uptake of energy-saving actions. The taxonomy can help inform whether business models can solve for energy efficiency barriers through changes within the firm, the value network, or would policy support be needed to overcome the barriers. However, with multiple frameworks there is a risk of data overload and complexity, making it difficult to synthesize the data and draw clear conclusions.

Overall, using the four frameworks, the steps for research enquiry and the key questions to be asked will follow the process as shown in Figure 1

Figure 1. Steps for research enquiry, key questions to ask, and frameworks for analysis



5. Research Methodology

5.1 Research philosophy

The research is approached from a pragmatist and social constructivist standpoint. A pragmatist perspective focuses on the practical application of

knowledge and the importance of problem-solving (Saunders et al., 2019). In the case of industrial energy efficiency, this means understanding how firms can reduce their energy use in practical ways that are feasible and effective. A social constructivist standpoint emphasizes the social and cultural context in which knowledge is created and the importance of understanding how people's experiences and beliefs shape their understanding of the world (Boyland, 2019). This is particularly relevant in the context of industrial energy efficiency, as the adoption of new business models is shaped by social, developmental, cultural, and economic values

5.2 Research design

The research will use qualitative methods involving case studies of business models, their value networks and their interactions in a socio-technical system. A qualitative research approach using a case study methodology will enable an in-depth insight into how firms take energy related decisions within a value network and which factors have influenced their decisions over time. To contribute towards the validity of this study and the robustness of the outcomes, a multiple comparative case study design consisting of two cases has been chosen (Eisenhardt, 1989; Eisenhardt & Graebner, 2007).

A case study approach is considered suitable to address the research questions of 'how' and 'why', which is the fundamental criteria for selecting such methods (Aberdeen, 2013). Also, case studies are suitable when the investigator has little control over events, and the focus is on a contemporary phenomenon within a real-life context (Aberdeen, 2013). Additionally, a case study allows studying the context and complexity without isolating particular variables, and therefore are effective ways for developing and testing theories (Eisenhardt, 1989; Flyvbjerg, 2006).

Further, using frameworks for complex values, co-evolutionary theory and energy efficiency barriers, I will be abductively approaching theory development through comparative qualitative case studies. An abductive approach has generalisations to the fore, while seeking to study the details in deviating contexts (Saunders et al., 2019). Also, abduction allows for the constant dialogue between data and theory, and is an iterative process (Kovács & Spens, 2005).

5.2.1 Comparative case studies in the states of UP and Rajasthan

A comparative case study approach is particularly useful to test whether the theory emerging from one context holds true in another context too (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). The comparison of business model case studies in UP and Rajasthan would be useful to study how the differences in the two contexts result in different energy efficiency outcomes.

The industrial sector accounts for 16% and 21% of total electricity consumption in UP and Rajasthan, respectively (PFC, 2022). Both states have several industrial clusters that are home to a large number of small and medium-sized enterprises (SMEs) in the manufacturing sector, which are often energy-intensive. Electricity supply in both states is largely dominated by high loss-making public sector utilities. In FY 21, the aggregate technical and commercial losses of public distribution utilities accounted for 27% and 26% in UP and Rajasthan respectively (PFC, 2022). The above statistics suggest great potential for the two states to proactively adopt measures for industrial energy efficiency as it can allow utilities to rationalise their power procurement costs and better manage peak energy demand (Shah, 2021). However, Rajasthan is home to textiles, cement, and handicrafts industries, whereas food processing, sugar, chemicals and fertilisers, and engineering industries are more prominent in UP (Invest India, 2023; Rajasthan Foundation, 2023; Shah, 2021).

In terms of energy efficiency performance, Rajasthan is among the ‘champion’ states for energy efficiency, and has introduced several measures for industrial energy efficiency (BEE & AEEE, 2021; ET Government, 2021). Rajasthan reported offering financial incentives for energy efficiency in industries, including incentives for conducting energy audits and implementing energy audit recommendations, low-interest loans, and subsidies for the adoption of energy-saving equipment and facilities (BEE & AEEE, 2021). Further, the state has a designated entity to support industries in energy efficiency, such as through technical advisory support or enforcement of energy audits. Rajasthan also deployed dedicated manpower in its nodal agency for energy efficiency, to support PAT industries. The State Nodal Agency in Rajasthan reported undertaking awareness workshops and training programmes for the PAT designated consumers. In addition, Rajasthan has adopted Time of Use tariffs, high open access surcharge and higher tariff cross subsidies, that are critical to disincentivising increase in electricity consumption by the industries (Pandey et al., 2022). The state of Uttar Pradesh, on the other hand has been a laggard on each on these parameters (BEE & AEEE, 2021; Pandey et al., 2022). The comparative case study approach will enable comparing these differences between the two states and their impact on energy efficiency outcomes.

5.2.2 Case study selection: Energy-intensive industries in the two states

Based on challenges pertaining to energy efficiency within energy-intensive industries in the two states and information obtained during scoping visits on industrial sectors undertaking innovative measures for energy efficiency, I plan to study business models and their value networks within the following industrial sectors.

Sugar industry: The sugar industry is one of the largest energy users among industrial sectors in India. The sugar industry has not yet been included under

the PAT sectors by BEE, but has been identified as an energy intensive industry under the Energy Conservation Act. . The high energy consumption in sugar industries is primarily due to running of a large number of old, small capacity sugar mills whose process equipments have not been upgraded. A savings potential of ~20% in electrical energy and 25% in steam consumption is estimated in these industries (TERI, 2012). Also, several of these units have adopted cogeneration using bagasse and methane, for meeting their energy requirements (TERI, 2012). There is an estimated potential to achieve about 14 GW of additional power generation through bagasse-based cogeneration in India's 550 Sugar mills, which has only been achieved upto 50% (MNRE, 2022). A layout of a typical sugar industry in India is provided in Annex 5, which can be a good reference to understanding its value network of suppliers and vendors at each energy decision making stage.

Since, around 40% of India's sugar industries are owned and run by farmer cooperatives (TERI, 2012), this can allow greater possibilities for sugar industries to focus on value creation, which is not just economic in nature. The state of Uttar Pradesh has around 120 sugar mills, the second highest in the country after Maharashtra, of which 20% are owned by the cooperatives (Ministry of Consumer Affairs, 2021). My scoping meetings with sugar manufacturers in UP suggested that certain firms within industry are proactively taking energy efficiency measures.

Textiles industry: Any textile industry consuming greater than 3000 MTOE is considered a DC under PAT scheme, as per the Energy Conservation Act. The wet processing divisions within the textiles industry are highly energy intensive and use high amounts of thermal energy for heat and steam. Electricity is a major input in spinning plants, especially cotton spinning systems. The fuel used by cotton spinning plants is dependent on the geographical location of the plant, as the fuel can be provided for steam used in humidification systems during colder seasons (PwC & SSEF, 2014; SSEF & CII, 2013). Annex 7 provides a layout of operations within a typical textile industry in India.

The diversity within the textiles sector makes it a complex one to study, particularly in terms of Specific Energy Consumption of the mills. There are also variations in lean and busy manufacturing seasons, depending upon market demand, etc. (PwC & SSEF, 2014). Rajasthan is home to large and small textile industries and had 29 DCs from the sector in PAT cycle -II, whereas UP had just 1 such industrial representative (BEE, 2020).

5.2.3 Theoretical sampling

A theoretical sampling strategy will be followed for the case study research (Eisenhardt, 1989) , based on which a textile industry (included under the PAT Scheme) in Rajasthan and a large-scale sugar manufacturing industry in Uttar Pradesh are chosen as the cases.

The case study on the textile firm and its value network provides a valuable opportunity to understand the co-evolutionary elements of institutional and policy support for energy efficiency improvements in the PAT industry. This will enable the exploration of how these elements impact the firm's decision-making processes and the energy value network. Additionally, Rajasthan state has received recognition for its energy efficiency measures, making it an ideal location for the case study to capture the lessons learned and provide recommendations for policy-makers and industry representatives in other states.

The sugar manufacturing industry is not currently included in the PAT industry, but there is potential for it to be included in the future, as per my interactions with the UP state nodal agency officials during the scoping visits. Through the case study of a sugar manufacturing firm in UP, the research will explore the factors that drive firms to proactively pursue energy efficiency measures, despite not being part of the PAT industry. This will provide insight into the value that firms place on energy efficiency measures and how they capture that value.

Overall, the selection of these two case studies will provide a well-rounded perspective on the dynamics within the energy value network and how they interact with varied co-evolutionary elements in a socio-technical system. This shall provide both focus and variation, and enable identifying patterns of decision making between the two industries, but also understand cross-case differences (Eisenhardt & Graebner, 2007, Corbetta, 2003). The selection of case studies and the key rationale supporting the selection is summarise in the following table.

Case studies selection criteria			
Key attributes	Industrial sector	State	Rationale for selection
A PAT firm and its value networks	Textiles	Rajasthan	A PAT firm (large scale) in Rajasthan state (known as the champion state for energy efficiency), will allow studying how co-evolutionary elements related to PAT scheme (policy and institutional support from the state government) have driven energy efficiency measures.

A Non-PAT award-winning firm (for energy efficiency) and its value networks	Sugar	Uttar Pradesh	A study on a firm, proactively pursuing energy efficiency measures, but not included under the PAT scheme, will enable studying how factors internal to the firm or the value network have driven value for energy efficiency. Also, UP has been a laggard in energy efficiency. So, this case study will highlight the additional support measures needed to further improve the firm's energy efficiency performance.

6. Research plan

6.1 Data collection

The study will rely primarily on qualitative data in the form of in-depth semi-structured interviews, document analysis and focus group discussions, to gather rich and comprehensive data on business model approaches to energy efficiency and value chains/networks. The semi-structured interviews will allow for an in-depth exploration of the experiences and perspectives of key stakeholders in the energy value network for industrial energy efficiency, such as business leaders, ESCOs' managers, equipment manufacturers (for boilers, transformers, etc), financiers, energy auditors, central and state government officials, state regulators, leaders of industry associations and energy efficiency experts. Such interviews will provide insights into the drivers, barriers and opportunities for energy efficiency in the industry, that might otherwise be hard to access (Corbetta, 2003). I aim to interview between 25-30 participants (12-15 per industry and state case) or until saturation is reached.

Document analysis will involve a review of vendor contracts and agreements received from industries, business plans, industry reports, policy documents, and regulatory orders. This shall provide valuable insights into the value drivers, market trends and regulatory frameworks, which will let me triangulate the data and develop a more comprehensive understanding of how are energy decisions taken within industries.

I intend to conduct 2 focus group discussions (FGDs) with the local place-based industry associations for sugar and textiles manufacturing in UP and Rajasthan. Based on inputs received from stakeholders during scoping visits, interactions with local place-based industry associations will be more impactful, compared to national or state level industrial associations, as the local bodies engage more closely with industry members. Each FGD shall include 5-7 participants, including the business leaders from the selected industrial cases, their energy managers, energy auditors and other participants from their energy value

networks. The FGDs will be conducted after the interviews have been conducted, to facilitate the emergence of new insights and ideas that may not have been captured through other data collection methods. The group dynamics of focus group discussions can create a safe space for participants to share their opinions and challenge each other's ideas, which can lead to a deeper understanding of the topic. They shall allow for a more interactive exploration of the issues and challenges concerning industrial energy efficiency improvements. By bringing together stakeholders from different backgrounds and perspectives, focus groups can generate a rich and diverse range of opinions and ideas, which can help identify common themes and patterns in the experiences of different stakeholders (Ritchie & Lewis, 2003).

6.2 Data analysis

After the data collection, I will transcribe the data and organise the data into codes. Following Gioia et al. (2013)'s methodology, I will start with a first-order empirical analysis, coding text segments reflecting actions, events, and mechanisms that will contribute to collaborative value creation and capture in the value network, positively or negatively influencing the energy efficiency outcomes. After initial coding, I will go through the data multiple times to identify themes and patterns to create a thematic map of recurring themes that could help answer the questions, with an abductive approach. An abductive research approach will help balance the inductive concept development with consideration of relevant existing theory (Gioia et al., 2013). I will then search for patterns and relationships between the empirical concepts guided by a cross-case replication logic with the aim of finding general empirical practices among the four case studies (Aberdeen, 2013; Eisenhardt & Graebner, 2007). Finally, I will combine the themes found into aggregate dimensions, building a data structure by cycling between emergent concepts and themes, and existing theory (Aberdeen, 2013; Eisenhardt & Graebner, 2007; Gioia et al., 2013).

7. Intended contribution of this research

The business models for industrial energy efficiency in India have not been adequately explored in the literature. The dynamics within the value network of industrial firms and the barriers to energy efficiency have not been fully understood. This research aims to address this gap in the literature by investigating the business model approaches in India's energy intensive industries. Energy efficiency has largely been studied in the literature in energy demand reduction and carbon emissions content, whereby the benefits of energy efficiency vary across spatial settings. This study concentrates on tactics for improving industrial energy efficiency through a study of industrial value networks in India, where the benefits of energy efficiency extend to the enterprise, industry, locality, nation, and the world at large. Also, the strategies

for implementing energy efficiency in India vary among regions and states, with diverse sub-national governments and institutions emphasising distinct measures.

The study adopts a novel perspective of complex values that goes beyond traditional economic value identification approaches and considers a range of non-economic value drivers, such as social, environmental, and regulatory factors, that can impact the adoption and implementation of business models for industrial energy efficiency. The complex value perspective can offer a more holistic understanding of the business model thinking process in a value network. This can help policymakers and industry leaders develop more comprehensive strategies to support the adoption of business models for energy efficiency. Using a value networks approach to studying business models, the study will contribute to understanding how business models in industrial ecosystems lead to new relationships, and create demands for new value propositions and value capture methods.

One of the primary contributions of this study is its focus on energy-intensive industries, which have been challenging to decarbonise due to their high energy consumption and unique operating conditions. By exploring business model approaches that can facilitate industrial energy efficiency in these industries, the study can offer valuable insights to policymakers, industry leaders, and other stakeholders. Furthermore, the study's comparative analysis of co-evolutionary factors in two states is a noteworthy contribution to the literature. By comparing and contrasting the factors that enable or hinder the adoption of business models for industrial energy efficiency, the study can provide a nuanced understanding of how different contexts shape the success or failure of such models.

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9. Annexures

Annexure 1: Non-energy benefits of industrial energy efficiency - A review by Rasmussen (2014, 2017)

Table 1. NEBs related to industrial energy efficiency.

	Mentioned NEBs	Categorisation (if any)
Pye and McKane (2000)	Increased productivity, reduced costs of environmental compliance, reduced production costs (labour, operations and maintenance, raw materials), reduced waste disposal costs, improved product quality (reduced scrap/rework costs, improved customer satisfaction), improved capacity utilisation, improved reliability, improved worker safety, improved efficiency, reduced emissions, extended life of equipment, reduced operating time, reduced ancillary operations, reduced cleaning and maintenance requirements, increased capacity, decreased noise.	
Finman and Laitner (2001) Worrell et al. (2003)	Use of waste fuels, reduced product waste, reduced waste water, reduced hazardous waste, materials reduction, reduced dust emissions, reduced CO, CO ₂ , NO _x , SO _x emissions, reduced need for engineering controls, lowered cooling requirements, increased facility reliability, reduced wear and tear on equipment/machinery, reductions in labour requirements, increased product output/yields, improved equipment performance, shorter process cycle times, improved product quality/purity, increased reliability in production, reduced need for personal protective equipment, improved lighting, reduced noise levels, improved temperature control, improved air quality, decreased liability, improved public image, delaying or reducing capital expenditures, additional space, improved worker morale.	Six categories: (1) Waste (2) Emissions (3) Operations and maintenance (4) Production (5) Working environment (6) Other
Cooremans (2011)	Follows Worrell et al. (2003) but adds reduced legal risks, carbon and energy price risks, disruption of energy supply and commercial risk.	Relates to competitive advantage: (1) Cost (2) Value (3) Risk
IEA (2012)	Health, increased asset values, industrial productivity, safer working conditions, improved quality, reduced capital and operating costs, reduced scrap and energy use, improved competitiveness.	By economic level: (1) Individual (2) Sectoral (3) National (4) International
Lilly and Pearson (1999)	Extended life of equipment, reduced air emissions and related fines, reduced wear and tear, reduced operations and maintenance expenses.	
Mills et al. (2008)	Improved productivity, improved process control, enhanced reliability, reduced operation and maintenance costs.	
Sauter and Volkery (2013)	Reduced operation and maintenance costs, increased motivation, safer working conditions, improved competitiveness, productivity gains, reduced resource use and pollution.	

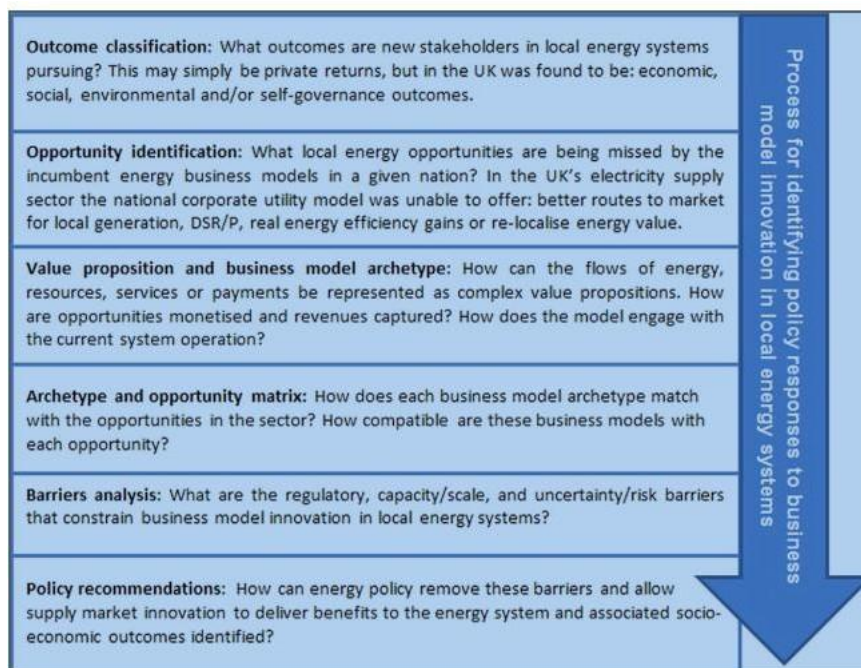
Annexure 3: Energy savings summary of PAT cycles II and III (BEE, 2021)

Sector	Fuel Mix %			
	Coal	Oil	Gas	Electricity
Aluminium	94.0%	4.5%	0.5%	1.0%
Cement	97.0%	1.0%	0.0%	2.0%
Chlor-Alkali	75.0%	2.0%	13.0%	10.0%
Fertilizer	8.0%	0.0%	90.0%	2.0%
Iron and Steel	83.5%	2.0%	1.5%	13.0%
Pulp and Paper	80.0%	5.0%	0.0%	15.0%
Textile	71.8%	0.9%	2.6%	24.7%
Thermal Power Plant	99.5%	0.5%	0.0%	0.0%
Petroleum Refinery	15.9%	24.3%	50.2%	9.6%
Railways	0.0%	69.0%	0.0%	31.0%
DISCOM	0.0%	0.0%	0.0%	100.0%

Annexure 2: PAT industries and their fuel mix (BEE, 2020)

PAT Cycle	Total Energy Savings Achieved		
	Thermal (Mtoe)	Electrical (BU)	Total (Mtoe)
PAT II	10.945	36.466	14.08
PAT III	3.368	1.483	3.496
Total	14.313	37.949	17.58

Annexure 4: Hall and Roelich (2016)'s complex value process

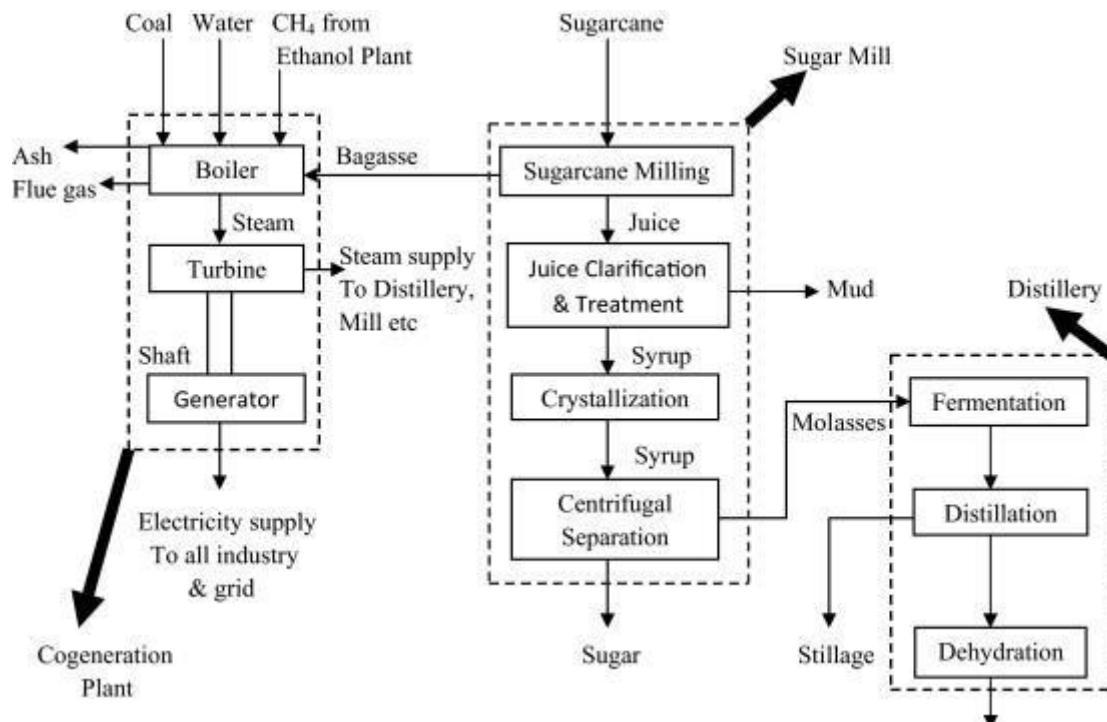


Annexure 5: Barriers to energy efficiency by Chowdhury et al., 2018

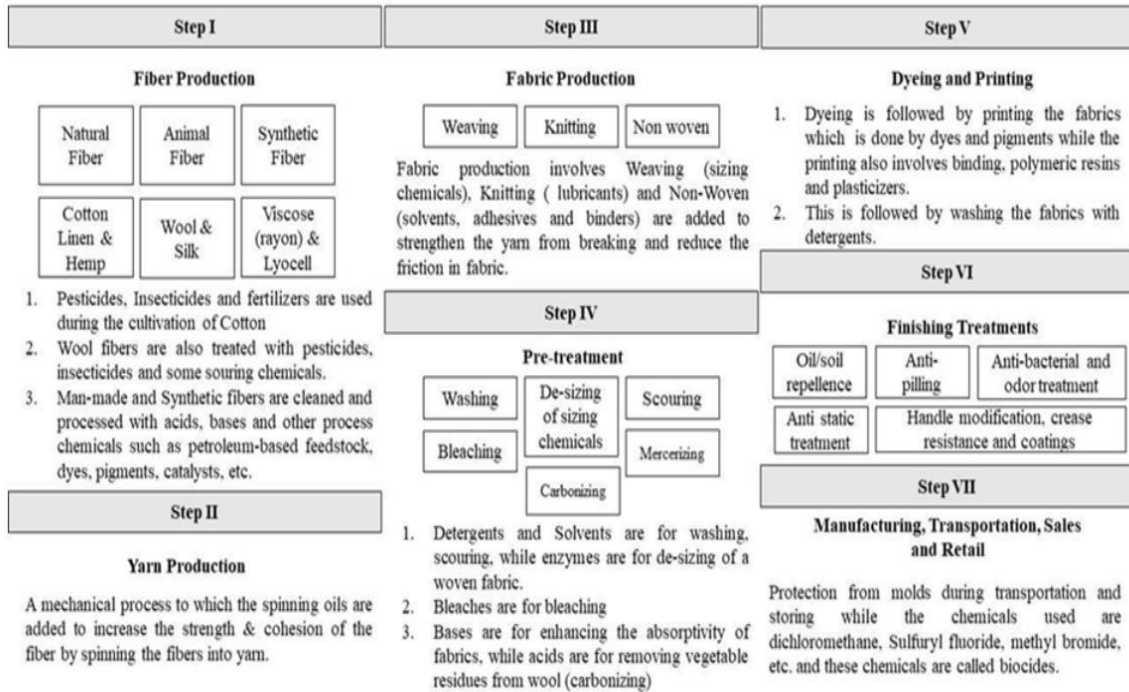
Taxonomy of the barriers to industrial energy efficiency from a disaggregated systems perspective [186,187,192].

Barrier type	Internal Process	Plant	External Grid
<i>Market related factors</i>			
- Costs to production disruptions	x	x	
- Difficulty in gathering external skills	x	x	
- Energy price distortion		x	x
- Hidden costs	x	x	x
- High initial costs/payback	x	x	x
- Lack of access to capital	x	x	x
- Risks to production disruptions	x	x	
- Technical characteristics not adequate	x	x	
- Verification of technology suppliers performance claims	x	x	x
<i>Organisational and behavioural factors</i>			
- Complexity of decision making		x	x
- Divergent interests	x	x	x
- Imperfect evaluation criteria	x	x	x
- Inertia (bounded rationalities)	x	x	x
- Lack of awareness or ignorance	x	x	x
- Lack of time/other priorities		x	x
- Lack of sharing the objectives		x	x
- Lack of interest in energy efficiency		x	x
<i>Policy factors</i>			
- Distortion in fiscal policies			x
- Distortion in energy policies			x
- Lack of proper regulation			x
- Low diffusion of technologies	x	x	
- Low diffusion of information	x	x	
- Scarce communication skills	x	x	

Annexure 6: Layout of a typical sugar industry (Chauhan



Annexure 7: Operations in a typical textile industry (Gunturu et al., 2022)



Maintaining leadership as an incumbent - green windows of opportunity and industrial policy alignment in wind turbine manufacturing in Germany

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Abstract

This research paper analyses the dynamics of the wind turbine industry in Germany, particularly the changes in technology, demand, and institutional support for wind energy. The paper focuses on the challenges faced by original equipment manufacturers (OEMs) due to technology cycles and changes in the composition of demand. The paper also examines how the misalignments of OEMs' business reconfigurations and industrial policy measures to the changes in technology cycles and demand composition have led to the difficulties faced by German turbine manufacturers. The paper centres around two integrated hypotheses: industry consolidations in the wind turbine sector are the result of distinct changes in the technology, demand, and institutional support for wind energy; and misalignments of OEMs' business reconfigurations and industrial policy measures to the above changes in technology cycles and changes in the composition of demand are the reason for the difficulties faced by German turbine manufacturers. Using the manufacturers Siemens-Gamesa, Nordex, and Enercon as case studies, the paper employs and expands the analytical frameworks of green windows of opportunity and structural cycle analyses to show how the industry has developed. The analysis highlights the need for a more comprehensive understanding of sectoral dynamics and alignment of demand and supply-side interventions to ensure local manufacturers benefit from the energy transition. The paper suggests that these competitions are arising during a time when the wind energy sector is undergoing significant transitions, with a shift to new business models centred around service and maintenance segments, new products such as offshore wind turbines, and digital and hybrid solutions.

Introduction

The latest IPCC Synergies Report claims with ‘high confidence’ that there are ‘potential synergies between sustainable development and, for instance, energy efficiency and renewable energy’ (IPCC, 2023, p. 54). Hence, the energy transition and the related economic sectors are also increasingly seen as a contested area of industrial competition and geopolitical importance where the question becomes which companies will develop and produce the technologies and who benefits from the supply chain. In the US, the Inflation Reduction Act and in the EU the Net Zero Industrial Act are efforts aimed at giving manufacturers confidence to expand their production. Similarly, the German government has recently stated its ambition to strengthen the domestic manufacturing of renewable energy technologies such as solar PV and wind (BMW, 2023a, 2023b). These are the latest attempts to match Chinese industrial policy and support Western manufacturers in their competition with their Chinese counterparts, which are an emerging competition not only on costs but increasingly also on the technological frontier.

The onshore and offshore wind turbine manufacturing industries have consolidated significantly in the past decades resulting in changes in the composition of the market and market leaders (Dai et al., 2020). The early leadership of Denmark and the US was first challenged by Germany and Spain in the early 1990s and later by China and India in the early 2000s. Particularly Chinese firms and Chinese industrial policy have been at the forefront of challenging incumbent firms in the wind manufacturing sector. However, there has been no irreversible loss of leadership position and Germany, Denmark and Spain remain key wind power manufacturers alongside Chinese entrants in a market comprised of shared global manufacturing leadership.

These competitions are arising during a time when the wind energy sector is continuing to evolve with continuous improvements in the size and capacity of turbines as well as a shift to new digital and hybrid solutions. The short cycles of turbine technology platforms make it increasingly difficult for OEMs to be profitable. This makes the renewable energy sector a unique case for industrial policy interventions. However, without sufficient alignment of demand and supply side interventions and an understanding of the sectoral dynamics, there is a risk of local manufacturers being unable to benefit from the energy transition. German OEMs have struggled in recent years and industry experts expect further consolidation in the coming years. Thinning profit margins have meant that turbine manufacturers have reported losses which led to layoffs and shifts in production locations to regions with lower labour costs. Despite becoming the biggest selling OEM in the German market, the turbine manufacturer Nordex reported a net loss of €498m in 2022. Siemens Gamesa reported a net loss of €884m in the fourth quarter of 2022, up from €403m during the same period in the previous year. Similarly, Enercon a privately owned OEM has struggled in recent years and received €500m in government

support through the German economic stabilisation fund.

The reasons for these developments are varied. Firstly, German OEMs are under increased pressure to cut costs and prices. This is not only due to increased competition with foreign manufacturers, particularly Chinese OEMs which offer much cheaper turbines in the onshore segment. But also, the competition with other renewable energy sources on the final levelized cost of electricity (LCOE). Particularly solar PV which has seen even steeper LCOE reductions than wind technologies, is attracting vastly bigger manufacturing investments (BNEF, 2023) and is competing with onshore wind as the main alternative to fossil fuels. Secondly, changes from a fixed feed-in tariff to an auction system based on levelized costs of electricity have put further emphasis on costs and changed the composition of wind farm developers. While initially, the German energy transition was to a large degree carried out by smaller energy cooperatives, big players such as utilities or grid operators are entering the market. In the onshore segment, this means the composition of demand seems to follow a similar trajectory to that of the offshore segment where there was a shift to deep-pocketed utilities and oil companies which can fund ever larger projects but also hold more power to drive prices down. For German OEMs, this shift means further competition with US and in particular Chinese manufacturers that have focused much more on economies of scale in their production. Thirdly, Germany's political and institutional landscape continues to significantly impact the uptake and deployment of wind energy technologies.

The paper centres around two integrated hypotheses: Firstly, industry consolidations in the European wind manufacturing sector are the result of technological developments aimed at lowering the LCOE of wind power that are occurring too fast for OEMs to standardize their production. Secondly, it is hypothesised that misalignments of OEMs' business reconfigurations and industrial policy measures to the above changes in technology cycles and changes in demand are the reason for the difficulties faced by German turbine manufacturers.

To analyse how the industry has developed, this paper will use and expand the analytical frameworks of green windows of opportunity and structural cycle analyses. The window of opportunity framework analyses changes to manufacturing production leadership during changes in technologies, demand, or institutional support. Empirical studies on green windows of opportunity have so far largely focused on latecomer countries and the differences in catch-up cycles of different green industries (Binz et al., 2020; Lema et al., 2020). Less attention has been given to industries in advanced economies and how these windows of opportunity can affect incumbent firms. This will further be enhanced with a structural cycle analysis which can help to understand (mis-)alignments of firm strategies and industrial policies. Using the manufacturers Siemens-Gamesa, Nordex, and Enercon as case studies, a mixed-method

analysis will be conducted of German manufacturing firms' responses and organisational reconfigurations in response to changes in technologies, demand, and government policies.

The remainder of the paper is structured as follows. Section 2 briefly discusses relevant differences between onshore and offshore wind and outlines why Germany and German OEMs are proposed as an interesting case study within the European market. Section 3 will present the main theoretical foundations of this study: The window of opportunity literature and the literature on structural cycles. The two theoretical approaches will be combined in what can be called microstructural alignment to technology-push and demand-pull dynamics. Section 4 briefly outlines the research design and methods, while section 5 presents the findings of our analysis. Firstly, the analysis will set out how changes in technology platforms, demand composition, and institutional support frameworks affect German wind turbine manufacturers. Secondly, the analysis will elaborate on three manufacturers as case studies and the extent to which these firms have reconfigured their business model to ensure continued market leadership. Lastly, section 6 will conclude.

Difference between onshore and offshore technologies

Onshore and offshore wind are two fundamentally different technologies, which matured along different cycles and became established markets at different points in time. Additionally, the markets for the two technologies diverge significantly and the expansion and deployment of onshore and offshore wind turbines differ not only geographically but also in terms of their order lead times. While onshore wind has a cycle of 12 to 18 months, in the offshore sector it currently takes between four and five years between the initial order and delivery and instalment of the turbine.

Furthermore, the globalisation of the market and scaling that happened in the onshore segment has not yet happened in offshore to the same extent. The first two expansions of total installed capacity in onshore between 1995 and 2001 and between 2005 and 2010 were mostly driven by scaling up the number of installed turbines. The downturn of new installations in the onshore segment since 2017 has coincided with an increase in the average turbine size indicating developers have installed fewer turbines but with larger individual capacity. This trend has also been observed in the offshore wind segment where there has been a race to bigger turbines and the growth in installed capacity has not yet translated to a growth in the number of turbines.

As will become clear in the analysis, the ever-increasing capacity of turbine capacity has not yet translated to a dominant platform design with large ranges in the demand for different turbine sizes. Given the long lead times of orders, the developments in the onshore and offshore technology platforms and the increasingly shorter technology cycles have important implications for

manufacturers operating in this segment. Initially, the installed capacity in offshore was largely driven by Europe, but China has recently entered the market with installed capacity far exceeding that of Europe. Overall, these differences between onshore and offshore markets pose an interesting juxtaposition to analyse and compare the two markets, their firms and respective government policies against each other.

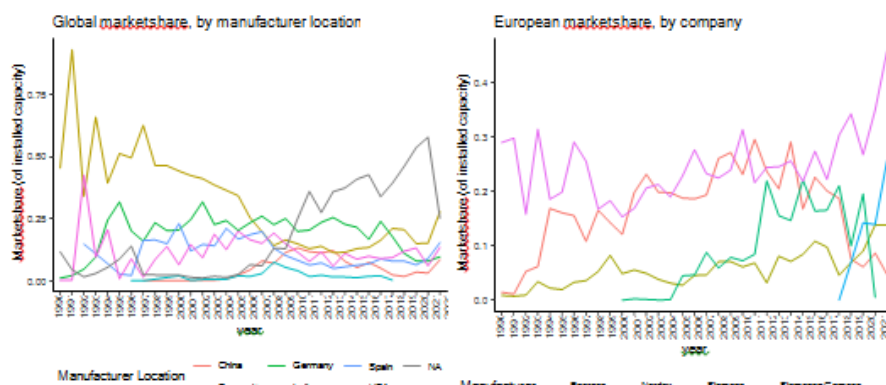
Relevance of Germany as a case study

Germany is often viewed as an international role model for climate action. Over the past twenty years, Germany has positioned itself internationally as a pioneer in energy efficiency, energy security, renewables, and nuclear phaseout. The country's early focus on renewables makes it an interesting case to analyse as German firms have been operating within the wind value chain for a long time and the government has provided long-standing support for the industries. From the start, the support for innovation in renewable technologies in Germany however went much further than seeking to achieve just an increase in the share of renewable electricity in the German energy mix. The 'Energiewende' (energy transition) was intended to ensure Germany's position as a global leader in the development and production manufacturing of renewable technologies and promote the creation of jobs within the industry. The German wind industry has managed to stay at the forefront of the global wind market. Jobs within the German wind industry have continuously risen, reaching 160.000 in 2016. Although the negative effects of a slowing down of new instalments in Germany have meant the number of jobs number has decreased slightly in the last few years, German wind companies remain among the largest in the world.

The German turbine manufacturing industry comprises a handful of large companies which have their headquarters and research and development centres in Germany but operate globally. The largest manufacturer of turbines in Germany is Enercon, with 178 installed onshore wind turbines and an installed capacity of 669 MW (averaging 3,8MW per turbine) in 2021. Nordex, Siemens Gamesa and Vensys (owned by Chinese manufacturer Goldwind) also each installed a combined capacity of 285MW, 86MW, and 32MW in 2021 respectively. In the offshore wind sector, Siemens Gamesa has managed to maintain its global market leadership. This is complemented by a large number of manufacturers of wind turbines and towers as well as servicing firms in Germany (VDMA Working Group Wind Industry, 2020). However, in terms of global market shares German companies have struggled in the past 20 years particularly Enercon having lost significant market shares vis-à-vis international competitors. Only Siemens-Gamesa has managed to increase its market share since the merger, largely due to expansions in the offshore segment.

Figure 1 shows the development of international market leadership in the wind manufacturing sector between 1990 and 2022. The left side of the graph shows how Germany managed to become a major manufacturer of wind turbines during the 1990s and managed to stay in this position relatively consistently until 2018. The recent years also show a potential difficulty for German firms as market leadership decreased. During the same time, there was also a process of consolidation of manufacturing players with the global as well as individual national industries being centred around fewer actors (O'Sullivan, 2020). The right side of the graph shows the European market share for the main European companies, Enercon, Nordex, Siemens/Siemens Gamesa and Vestas.

Figure 1: Global wind manufacturing market share by installed capacity



Source: Own elaborations based on Wind Power database

German manufacturers have diversified along the entire value chain and are increasingly generating large shares of their revenue from the subsequent (post-installation) operation and maintenance of wind turbines. Through the provision of downstream services through full-service agreements which cover the operation, maintenance and repairs of wind turbines, German firms have carved out new business strategies which make up between one-third (Nordex, 2022; Siemens-Gamesa, 2022) and half (Enercon, 2022) of their overall revenue by now. Overall, these dynamics pose Germany as an interesting case to analyse in order to understand how changes in technology platforms, demand composition, and institutional support frameworks affect wind turbine manufacturers and how they adjust to these changes.

Literature Review

Evolution of the German wind turbine manufacturing industry

The development of the German and European wind manufacturing industry has been analysed from several different angles. Much focus has been given to various policies by the German government and how they have affected local manufacturing in the industry. This can further be grouped into “direct”

(demand-side) policies and “indirect (supply-side) policies. The relevance of various support measures aimed at creating a market for renewable energy technologies has been shown by several studies (Bürer and Wüstenhagen, 2009; Darmani et al., 2014; Groba and Breitschopf, 2013; Haas et al., 2011; Jacobs, 2014; Nemet, 2009).

Lütkenhorst and Pegels further review several German support policies for renewable energy technologies and assess the costs and benefits associated (Lütkenhorst and Pegels, 2014; Pegels and Lütkenhorst, 2014). They find that in terms of economic and social benefits, the wind industry has performed better than other renewable technology industries in Germany. Similarly, Lewis and Wiser (2007) analyse early support policies across the main wind manufacturing countries.

While reviewing various direct support policies, Lewis and Wiser find that a sizable domestic market is a prerequisite for a successful local wind manufacturing industry (Ibid, p.19). Similarly, Dechezlepretre and Galachant (2014) find domestic wind deployment policies far more important for the local industry than foreign support policies. Lacal-Arantequi (2019) reviews annual European installed wind capacity to assess the strategies of wind turbine manufacturing companies. Reviewing the recent developments in the German wind manufacturing industry Bach et al. (2020) argue that insufficient provision of space by federal governments, bureaucratic red tape, and political disagreement about the minimum distance between new wind turbines are at fault for the recent struggles of the industry, thus confirming the importance of local demand for German manufacturers. Quitzow et al. (2017) compare global production networks in the wind and solar industries and suggest that for wind manufacturing the development of a local industry likely depends on the presence of a strong home market which implies a consolidation of a number of regional production hubs.

Reichardt and Rogge (2016) review how the German policy mix has influenced corporate innovation activities in the emerging technology of offshore wind in Germany. While they find a general consistency and credibility of the policy mix for corporate innovation activities in offshore wind, they argue that the demand-support through the feed-in tariffs of the EEF and its sufficient level of support and high predictability was most important for German firms. Furthermore, loan programmes, such as the kfW Offshore Wind Energy Loan started in 2011 are argued to be instrumental in supporting the domestic manufacturing industry (Lema et al., 2014; Reichardt and Rogge, 2016). In addition to the German feed-in tariff, Nahm (2021, 2017) argues the German wind manufacturing industry and its supplier network benefitted from several supply-side support measures from the 1950s onwards: Firstly, R&D funding for Industrial Collaborative Research (ICR- Industrielle Gemeinschaftsforschung)—research projects firms in the wind sector and public research institutes. Secondly, local credit unions (Sparkassen), which

provided long-term loans for development projects to further support a demand-pull effect. And lastly, the recruitment of and reliance on high-skill engineers and production workers through Germany's universities and apprenticeship programmes. Interviewing German industry experts, Johnstone et al. (2021, p. 7) find that export promotion and public R&D support were important industrial policy instruments used to promote renewable technologies.

With regards to the development of the wind industry as a whole, Lema et al. (2014) find that as the industry is focusing on bigger projects and bigger turbine sizes, it is also moving away from private equative investment and community-based deployment towards big-business-based deployment (p. 22). This means that the industry consolidation, particularly in the offshore wind segment favours such large players that some industry experts even question whether Vestas' financial power may be too small to compete globally in the long-run (Ibid, p. 22). Schmitz and Lema find similar industrial organisation geared towards economies of scale and the importance of capital and financial power as main determinants for competitiveness in the wind manufacturing industry (Schmitz and Lema, 2015). Wüstenmeyer et al. (2015) show how the offshore segment has decoupled its supply chain from the onshore counterpart and how their respective needs for subsidies increasingly differ. Analysing the turbine manufacturing industry, Hughes and Quitzow (2018) show how major manufacturers are often vertically integrated with in-house developed production lines. They further argue that while demand- side policies are important for national competitiveness, it is important to understand how firms within global production networks influence learning and competition. Looking at industry life cycles, O'Sullivan (2020) maps how the global wind industry has developed and consolidated over time.

Relating to firm strategies, there are only few studies that look at specific firms operating in the wind manufacturing industry and their business strategies over time. Lema and Lema (2016) find that for emerging wind industry manufacturers, R&D partnerships and acquisitions of foreign firms have become important in addition to traditional technology transfer mechanisms such as foreign direct investments and licensing. Awate et al. (2015) compare the M&A strategies of Vestas and Suzlon as examples of how advanced and emerging MNEs internationalise their R&D. Yet, there remains a surprising gap of research studies focusing on firm specific strategies and responses to changes in the industry. In trying to explain China's rise in wind power Haakonsson et al. (2020) attribute recent catch-up by Chinese firms to organizational changes taking place in the incumbent wind turbine lead markets in Europe. Similarly, Dait et al. (2020) investigate the relationship between technological change at the global level and responses by Chinese latecomer firms. However, there are even fewer studies looking particularly at incumbent firms and their responses

to challenges from latecomers or how industrial policy is being used to support these incumbent firms.

Windows of opportunity

To understand developments and trends in the wind turbine manufacturing industry, the concept of green windows of opportunity is useful. The notion of windows of opportunity was first described by Perez and Soete (1988) as a framework to explain the rise of new techno-economic paradigms which open opportunities for the economic leapfrogging of latecomers. Lee and Malerba (2017) have extended the idea of windows of opportunity with the building blocks from the sectoral innovation system literature. The sectoral system comprises knowledge and technologies, demand conditions, actors and networks, and institutions (Malerba, 2006, 2002). The firms of a particular industry can accumulate capabilities and learning in a system that involves knowledge and technologies within the sector, demand conditions in terms of users and consumers, as well as other actors (such as the government, universities or public research centres, suppliers, and financial organisations) and institutions (such as public policies, laws, culture) (Lee and Malerba, 2017). As firms are involved in a dynamic process of competition, cooperation, innovation and imitation, sectoral systems evolve over time through co-evolutionary processes of the different building blocks (Nelson, 1994). These changes often involve the emergence of new modes of organisation and governance, designed to fit changes in the sectoral system. This means that entire country sectors, rather than just individual firms, can evolve in a dynamic process of catching up or falling behind vis-à-vis other countries during long-term cycles. By and large, such structural changes are not predictable in any detail, but the way economic activities are organized and governed can be influenced and supported by government policies (Nelson, 2022).

Lee and Malerba have argued that there are three different windows of opportunity that can be identified: a technological window, a demand window, and an institutional window. However, the dynamics and structural changes following a window of opportunity are not predetermined but depend largely on firms and institutions in both incumbent and latecomer industries (Malerba and Nelson, 2011). Whether countries can utilize a window of opportunity depends on the effective response of firms and other system components. Successful latecomer firms, supported by public policy and institutional actors, usually respond with high levels of learning and absorbing technological capabilities. However, firms and public institutions in incumbent countries also react to changes in technologies and challenges from competitors, which can result in different outcomes.

The standard cycle following a window of opportunity has four variations (Lee and Malerba, 2017): Firstly, an aborted catch-up where efforts by latecomer

firms fail to generate sufficient learning and stagnate without challenging firms in leadership countries. Secondly, a case of persistent leadership where the incumbent invests to cope with new technologies and demand conditions to ensure leadership. Thirdly, a coexistence of old and new leaders. Lastly, a return to old leadership where the incumbent lost their leadership position but manages to return to a position of prominence during a new cycle. This means that although the framework was initially developed for changes in leadership and opportunities for latecomer countries, it can just as well be applied to countries at the technological and industrial frontiers. Indeed, applying the framework to industrial leadership countries and their strategies in dealing with challenges from latecomer countries addresses an important gap in the literature on windows of opportunity. In doing so, the framework follows a Hirschmanian understanding of development as an unbalanced growth process (Hirschman, 1958), where economic 'catch-up' is not an end state but rather a condition for advancement of the frontier or falling behind (Burlamaqui and Kattel, 2016).

More recently, the idea of green windows of opportunity has become more popular in the context of opportunities arising from renewable energy technologies, where they can be described as favourable, but time-bound conditions arising from changes in technologies, markets or institutions (Binz et al., 2020; Dai et al., 2020; Lema et al., 2020). Contrary to traditional energy sectors, renewable sectors such as wind energy centre around public goods. The wind harnessed to generate electricity is non-excludable and non-rivalrous, meaning that each individual's consumption does not have any negative impact on other people's consumption. Fossil fuel-generated electricity that relies on the extraction of limited resources is therefore fundamentally different. As the green economy rests to a larger extent on social objectives, it is argued that the green windows of opportunity also rely to a larger extent on public policy than traditional windows of opportunity (Lema et al., 2020). By acknowledging this, the green windows of opportunity literature address the lack of focus on the role of governments in the traditional windows of opportunity literature and show the importance of synergies of environmental and industrial- or innovation policy (Ibid). Existing studies have attributed the rise of China in several green technologies to successful responses to green windows of opportunity (Dai et al., 2020; Lema et al., 2013; Mathews and Tan, 2015). The literature has focused less on the industry incumbent and how firms respond to such windows of opportunity. However, for incumbents, market challenges and technological challenges are equally relevant as they attempt to try to defend their leadership position.

Structural cycles

Understanding how firms and government policies align or misalign is a useful framing for analysing the dynamics during a (green) window of opportunity. The development and diffusion of new technologies in new-higher value

product segments can create opportunities for value capture. Through technology-push and demand-pull dynamics, organisational reconfigurations, both of individual firms as well as local production systems, will occur (Andreoni et al., 2016). The integration of automation and new ICT technologies with existing production systems has opened new opportunities in higher-value product segments and subsequent firm reconfigurations. Understanding how wind energy technologies have evolved over time and how firms have responded to these changes can help us understand how individual companies, as well as entire regions, can benefit from new emerging windows of opportunity.

For firms, technological transitions and organisational reconfigurations often follow cyclical time-specific patterns. This has been partially researched by the 'product life-cycle' and 'industry life-cycle' literature (Klepper, 1997; Segerstrom et al., 1990). However, approaches such as the product life-cycle leave out important dimensions. Firms can undergo processes of technological transitions through changes in technology platforms. This is important, particularly for local production systems with many smaller firms, where organisational reconfigurations can be triggered by (external) technology transitions. These changes in technology platforms and subsequent organisational reconfigurations of firms' capabilities often follow structural cycles (Andreoni et al., 2016). While a lot of the structural change literature has analysed changes in the sectoral composition, industrial transformation within the same industrial sector has received far less attention. Similarly, the processes in which technological change can lead to organisational reconfiguration and what is required by states to manage this have remained largely under-researched.

The idea of structural cycles is not just an analytical method for understanding transformation processes through technological revolutions, but can also help with the right choice of policies for government to intervene and support these processes (Andreoni et al., 2016). By liaising closely with the private sector, public-private technology intermediaries can play a key role in enabling firms to capture windows of opportunity and retain their competitive advantage. Understanding how governments try to align their policies with the evolving needs of private sector organisations and manage the arising conflicts is key to understanding the success or failure of policies aimed at the energy transition (Andreoni et al., 2016; Andreoni and Chang, 2019). Such alignment of government policies requires governments to take on entrepreneurial characteristics during processes of technological transitions and subsequent organisational reconfigurations.

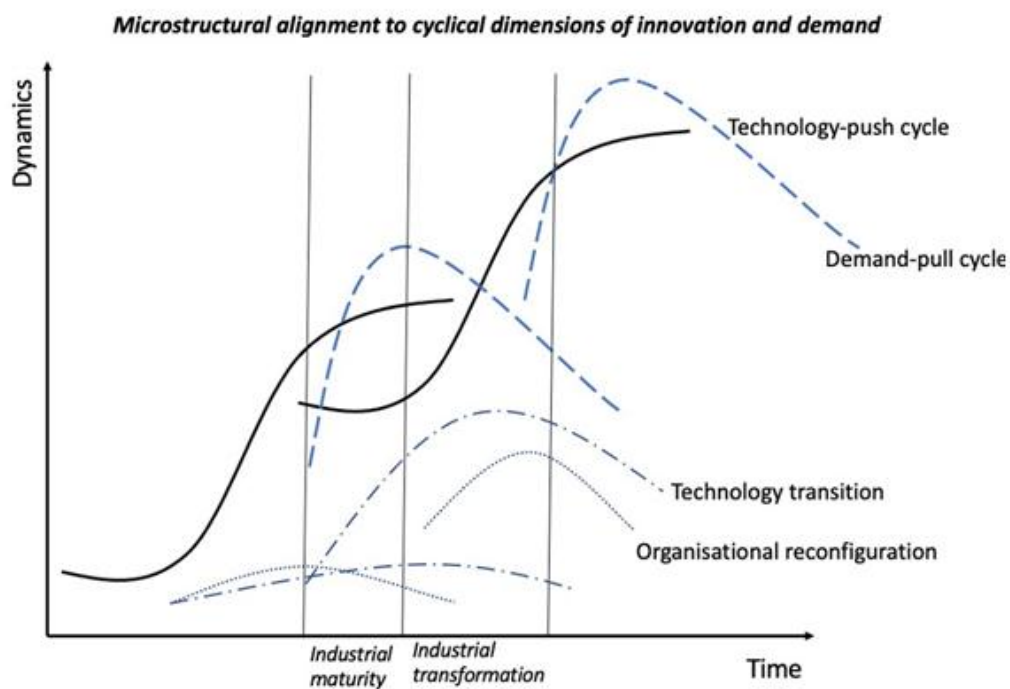
Microstructural alignment

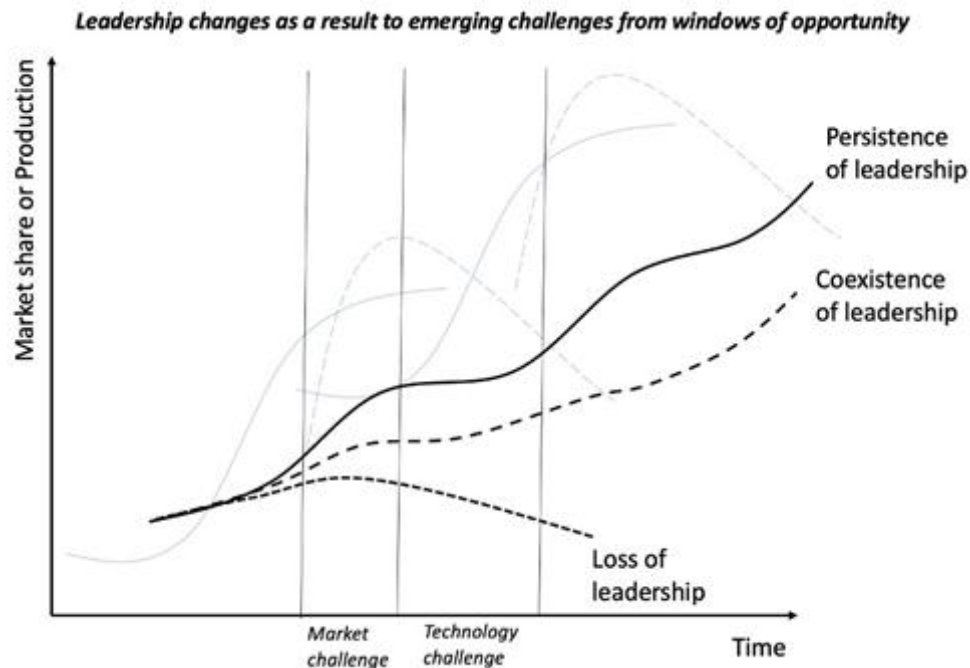
To overcome the respective shortcomings of the window of opportunity and structural cycle frameworks, the paper aims to intergrade the two approaches

and advance theoretically the importance of structural cycle alignment for industrial leadership.

The two parts of Figure 2 use insights from the green windows of opportunity and the structural cycle approaches in an attempted combination of their different angles. The technology-push cycle represents the traditional 'S-curve' visualization of technological change and the move to higher-value segments. The demand-pull cycle is a stylized representation of changing demand conditions related to technological developments. The central hypothesis is a changing temporal importance of technology-push and demand-pull effect where a certain level of technological development has to be present before the demand-pull effect can start having an impact. Similarly, once the technology-push effect starts to plateau, the demand-pull effect may become stronger before eventually also decreasing as a new technology-push cycle emerges and the demand shifts to new products. Underlying these cyclical dynamics of technology-push and demand-pull are the micro-paradigm cycles of technology transition and organisational reconfiguration

Figure 2: Visual presentation of the combination of different theoretical approaches in one framework





Source: own elaborations

Once the technology-push effect starts to plateau, the demand-pull effect may become stronger before eventually also decreasing as a new technology-push cycle emerges and the demand shifts to new products. The bottom part of Figure 2 shows the thereof resulting persistence or change to leadership as the development of market share or production from the perspective of the incumbent. “Persistence of leadership” describes the case in which the sectoral evolution driven by the incumbent and the respective country manages to defend its leadership position. In the case of “Coexistence of leadership” a latecomer country challenges the incumbent and market leadership is from there on shared, hence a downward shift of the curve. If the incumbent fails to fend off the challenge from a latecomer country, leadership is changed, and the incumbent’s market share reduces over time.

Research design

The green windows of opportunity literature so far does not address how productive organisations and public institutions have to adapt to these cyclical demand-pull and technology-push dynamics as well as be aligned to each other and across time. While techno-economic paradigm shifts can help to explain changing patterns of demand and finance, they do not explain how or why industrial production develops along certain trajectories or in specific locations. Similarly, public support for new technologies can often be captured by foreign companies if the domestic manufacturing industries are not capable of adapting to changes in demand and technologies. As this involves complex dynamics of investments and demand, technological change, organisation reconfigurations

and policy support, this will be further analysed in a specific country context. In doing so, the research project aims to understand how exactly demand-push and technology-pull dynamics have played out in the context of Germany and whether or not German firms and public policies were aligned to these changes.

Germany has been chosen for this given its long-standing involvement in the renewable energy sector, with large industrial capabilities and strong policy support. Despite a general resurgence of industrial policy, particularly in the context of the energy transition, there remains a lack of clarity on the sequencing, phasing and alignment of various policy measures. The project will aim to fill these gaps by addressing the hypotheses of the second research question on how structural cycle (mis-)alignment can explain different outcomes to emerging green windows of opportunity spelt out earlier.

To understand how emerging green windows of opportunity opened by cyclical demand-pull or technology-push dynamics as well as institutional changes can be captured (or missed) by the incumbent, the research project will focus on firm and institutional dynamics in the German context and how these co-evolve in the context of changes in demand and technology. For this, a number of data sources will be used: Installed capacity by country and manufacturer are mapped using The WindPower database, while patent data comes from the EPO's Patstat database. Using patent data to measure technological leadership can be misleading given the disparity between quantity and quality.

One way to account for some of this difference is to use triadic patent data which counts patents granted in the US, EU, and Japan assuming that only higher quality inventions get protected in all three major jurisdictions. Information on firm strategies including company mergers and acquisitions have been taken from Orbis as well as individual company reports. Lastly, this is triangulated with data from semi-structured interviews with industry experts, firm representatives, as well as officials from government organisations.

As argued earlier, technology-push and demand-pull dynamics can prompt complex dynamics of technological change, organisation reconfigurations and policy support both at the level of the firm and within local production systems of the sectoral system. These dynamics allow for the formulation of further hypotheses about how the relationship between private firms and public-private technology intermediaries changes over time as firms adapt to technological change and changes in demand. Additionally, public policies can be assessed with regards to the support they offer to firms as they adapt to technological change and opportunities to shift to higher-value product segments. The main analytical challenge is to assess how these technological and organisational changes occur along "time-specific patterns and in specific organisational settings" (Andreoni et al., 2016, p. 887). This includes

understanding how technological change and changing resource-capability dynamics can lead to new value product segments within the same industry as well as organisational reconfigurations in specific settings of a local production system.

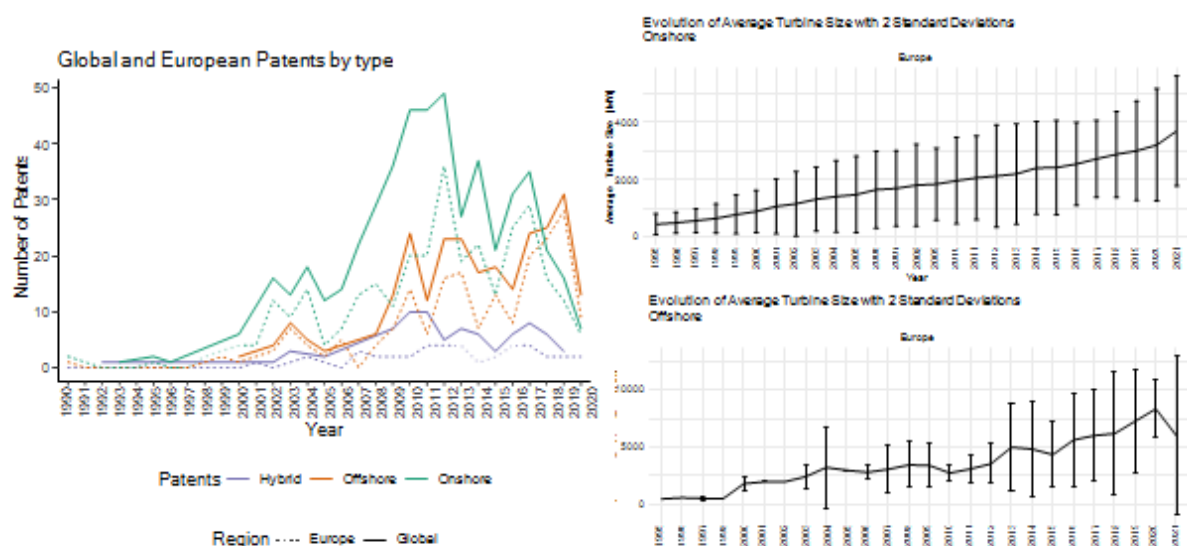
A number of interviews were conducted with industry experts and representatives of the three case study firms as well as representatives from public-private research organisations.

Analysis

Technology-push dynamics and technology-led windows of opportunity

As elaborated above, as technologies change not only do firms respond to this, but the industrial transformation can also be accompanied by technology challenges and potential changes in market leadership (Figure 2). In the wind sector, three distinct cycles changes to the technology frontier can be identified during which technology-led windows of opportunity may have occurred: Starting in the late 1990s with the emergence of onshore wind saw a first innovation activity which resulted in the deployment of small and medium-sized turbines used for onshore wind energy generation. The onshore wind technology first plateaued in the early 2000s before expanding again between 2006 and 2012. The second period also coincided with the emergence of offshore wind as a new high-tech technology domain. This can be characterised as the second main cycle of wind energy technologies.

Figure 3: Technology push dynamics in the wind sector



Source: Own elaborations based on PATSTAT and WindPower Onshore represents patents classified as Y 02E 10/728 Offshore represents patents classified as Y 02E 10/727

For Hybrid, the following search string was used : PCP (Y 02E 10/ 7 [Wind Energy]) AND abstract (“digital” OR “computing” OR “hybrid” OR “energy storage” OR “automated” OR “automatic” OR “smart”). Triadic patents were counted as patents filled in US, EU, and Japan, with information on company location taken from the European Patent Office.

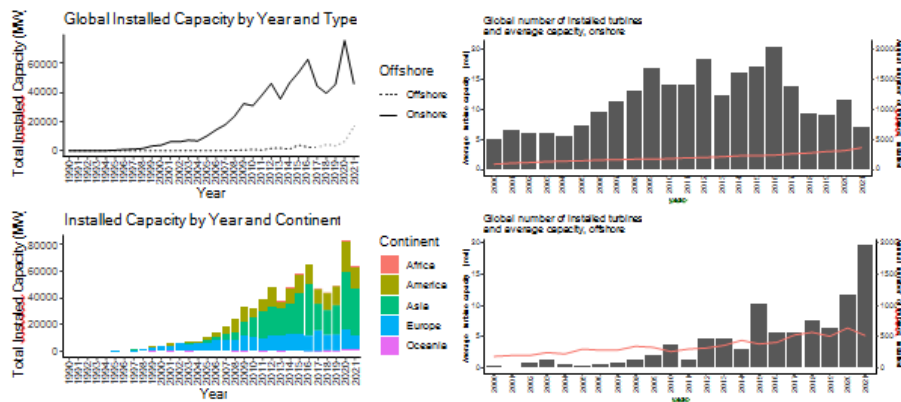
Despite several periods of temporary plateauing, the cycle of offshore technological development is ongoing with European firms seeming to drive the technological frontier. Starting in 2008, with a second cycle in 2017 we can also identify an emergence of new technologies centred around automation and digital/hybrid technologies. Although the emergence of new technologies can be seen as a change to the technological frontier, the technologies co-exist and often complement each other. Additionally, hybrid technologies using smart or automated processes may not always be strictly limited for use in relation to wind turbines and therefore may not necessarily be classified as such.

The right side of Figure 3 shows the averages size of wind turbines installed in Europe together with their range, measured as two standard deviations. It shows that despite onshore wind patents showing a sign of plateauing, the technology keeps evolving with developers continuously demanding bigger turbines. On the one hand, the continuous evolvement of the respective turbine size can pose a problem for manufacturers if this means each turbine class never reaches enough demand before a new class emerges. On the other hand, the large range of installed onshore or offshore wind turbines in Europe indicates there is a lack of clear standardisation of the technology.

Demand-pull dynamics and demand-led windows of opportunity

Similarly, as the technology-push, the demand-pull dynamics went through several cycles in the past three decades. The left panel of Figure 4 shows the expansion of wind turbines across the two technologies as well as across continents. While the initial expansion of onshore wind was mostly driven by European markets, European, and in particular German demand has dropped considerably since 2017 and has remained low since. The second phase starting around 2010 was mostly due to the expansion of new installations in Asia and later the American continents.

Figure 4: Expansion of the onshore and offshore markets and technologies



Source: Own elaborations based on WindPower database

At the same time, around 2016 was also when there was a shift towards offshore wind as a driver of demand. Offshore technologies becoming competitive on price meant a shift away from onshore solutions where the number of installed turbines plateaued in 2016. These shifts both in terms of geographical markets as well as between the onshore and offshore segments demonstrate how demand cycles often lag behind the changes in technological cycles as elaborated in Figure 2. Each closing of the respective technological or demand-led window of opportunity usually brings industry consolidations.

Furthermore, it is worth analysing the composition of demand in Europe. As mentioned earlier, the size of the home has been argued to be a prerequisite for a successful local wind manufacturing industry (Lewis and Wiser, 2007; Quitzow et al., 2017). Figure 5 shows the project characteristics of onshore and offshore wind projects built in each continent, regardless of the manufacturer. They reveal a striking difference between onshore and offshore wind in Europe. In the onshore wind segment, Europe lags far behind in terms of average project capacity and average number of turbines per project. Likely due to limited available space for new projects and the role of smaller actors such as local energy cooperatives, the size of European wind farms in terms of capacity and turbines has remained relatively stable over the last 20 years while projects have become increasingly bigger in other locations. Compared to the annual installed capacity shown in Figure 4, this reveals that while other continents managed to increase the installed capacity by expansions in average project size, Europe fell behind in this regard and subsequently installed capacity stagnated, too.

Figure 5: Composition of demand in the onshore wind sector, by continent



Source: Own elaborations based on the Wind Power database

In the offshore segment, the picture is reversed with European wind farms still being the largest, even exceeding the average capacity and number of turbines of Asian projects. Given that it is generally much more difficult to ship components for offshore turbines and production is much more localised compared to the onshore segment, this gives European manufacturers an opportunity to stay at the forefront of the technology frontier. At the same time, relying overly on expansions in the size of turbines without expanding the number of wind farms can come at the expense of industrial and asset management optimisation where manufacturers struggle to become profitable on one technology platform before a new class of turbines is developed. Additionally, as one industry expert noted, it is Chinese OEMs that are now announcing the largest offshore wind turbines and Europe may face a very similar trajectory to that of onshore wind without the necessary support and alignment of the supply and demand side.

German policy landscape and institutional-led windows of opportunity

To understand institutional-led windows of opportunity in the German wind sector, it is important to outline the demand-side support through the German feed-in tariffs. In 1990 Germany created the world's first renewable energy feed-in tariff to support small operators of renewable energy plants by guaranteeing them priority access to the national electricity grid and paying them a guaranteed feed-in tariff for the next 20 years. Before then, small operators of renewable power plants could only access the grid through a non-binding, voluntary framework implemented by the grid owners themselves, who largely stayed away from wind power. This led to large energy producers essentially obstructing the feeding into the grid by independent competitors (Gründinger,

2017). The support of the *Stromeinspeisegesetz* was limited to power plants with a maximum capacity of 5 MW and remunerated producers of electricity from wind and solar PV sources with a guaranteed 90 per cent of the final price of electricity (which equalled around 8.5ct/kWh in mid-1990). Additionally, it ensured access to the grid as well as compulsory priority access for renewables to the grid. This particularly helped the domestic wind energy industry which increased its cumulative capacity from 71 GWh to 1,500 GWh between 1990 and 1995 (BMW, 2014).

At the same time, public financial actors played a large role in the initial expansion of the German wind industry. Until 2008, Close to half of demand-side investments benefited from low-interest loans supplied by Germany's development bank KfW (Quitow, 2015). Local banks became important providers of capital for a large number of privately owned systems, while equity was still provided mainly by individuals. For the growing number of larger systems, project-based financing was largely provided by regional State-owned banks (*Landesbanken*) as well as the private bank *Commerzbank*, which is also a major investor in wind energy projects (Ibid)

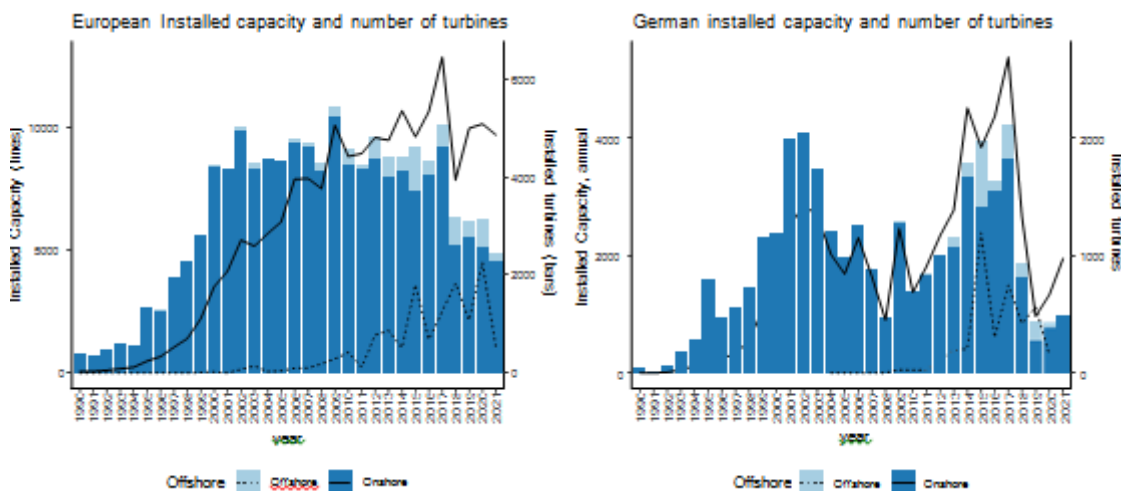
In 2000, the Feed-in Act was replaced by the EEG, which introduced decreasing tariffs over time and at regular intervals to put a downward cost pressure on manufacturers and plant operators. Crucially, the EEG also did not couple the remuneration to electricity prices as the initial *Stromeinspeisegesetz* did but provided guaranteed absolute feed-in tariff payments to ensure investment stability. Furthermore, the payments were not considered public subsidies but rather came from a surcharge on electricity consumers (EEG Umlage). To protect energy-intensive German manufacturers and industrial consumers, the EEG Umlage from the start included various exemptions under the 'special equalization scheme'.

Since the initial passing of the EEG, the law has been changed and amended numerous times by various German governments. Most notably, the EEG of 2012 introduced a market-premium model as a significant change to the original feed-in tariffs. Rather than paying a fixed feed-in tariff which lies above the price of electricity to anyone supplying electricity to the grid, the market premium gives producers of renewable electricity to sell their electricity directly to any end-user. The market- premium regulates the difference between the average prices of renewable energy that are sold on the energy market and the price on energy according to the feed-in tariff at the time. For example, in late 2019 the price for wind energy according to the EEG was 6.2ct/kWh. If the average price for electricity on the energy exchange market is below this, the EEG surcharge will cover the difference. As the market premium is calculated as the difference between the EEG and the average price of electricity, producers who feed their electricity into the grid during peak demand hours when the prices is higher can therefore make a bigger profit. The aim was to incentivise market-oriented behaviour of owners of renewable power plants to

feed electricity into the grid at times when demand was high. Since 2012, the total remuneration paid through the market-premium has surpassed the total value of feed-in tariffs. This is particularly due to the rise of market-premium paid to operators of wind turbines. In comparison, the relative importance of the market-premium for operators of solar panels remains low.

Until 2016, the German government decided the value of the Feed-in-Tariff and hence also the market-premium if electricity is sold directly on the spot market. With the change to the EEG in 2017, the value of the Feed-in-Tariff is being decided through an auction system. The level of funding awarded to wind turbines and large roof-top PV installations (both with an output exceeding 750 kW) is determined by competitive auctions. Investors can submit their bids during the auction rounds, which are announced by the Bundesnetzagentur. The lowest bids win the auction until a specified capacity under auction is met, although a ceiling price is specified by the Bundesnetzagentur in advance. Successful projects will receive the funding rate with which they won for a period of 20 years. Due to inadequacy in the auction system, almost only speculative projects received the potential funding leaving the German wind sector with faced uncertainty of demand. This has also led to a change to bigger projects benefiting from the auction system, with local energy cooperatives missing out and resulting in demand reductions (Herbes et al., 2017). Since the introduction of the auction system, there was a notable decrease in new installations of wind turbines as can be seen in Figure 6. An interviewee claimed that the decrease of demand in Germany in both onshore and offshore wind was almost entirely due to the change to an auction system as well as changes to the approval process.

Figure 6: Demand-pull dynamics in the European and German wind sector



Source: Own calculations based on WindPower database

For onshore wind auctions, there were several rounds in 2018 and 2019 that were undersubscribed. Interviewees suggested this was largely due to regulatory changes and local opposition to wind projects that have slowed the permitting process, making it harder for projects to qualify for auctions. For offshore wind auctions, the first competitive auction in 2017 was notably oversubscribed, with winning bids reaching zero subsidy levels. In 2022, the German government established two different types of auctions, one of which involves negative bidding with no caps on the amounts developers bid. In zero-bid auctions, wind farms earn the market price of electricity, but this leads to higher finance costs due to unstable revenues. Negative bidding takes it a step further by imposing additional costs on wind farms, which are then passed on. Negative bidding in the offshore market in Germany is likely going to increase the pressure on OEMs already operating under tight profit margins. In summary, the changes in both onshore and offshore remuneration can be seen as a closing of institutional windows of opportunity and as a move towards a market-based approach.

Firm responses and industrial policy alignment

As argued in the section above, German wind turbine manufacturers are facing continuous downward cost demands and competitive pressure from abroad, during a time in which the domestic market has contracted since 2018. At the same time, there has been a trend of firm mergers and consolidation in the industry. According to the Global Wind Energy Council, of the once over 100 global manufacturers of wind turbines, only 33 remained in 2019, with the largest six manufacturers accounting for 72 per cent of market share (GWEC, 2020). Hence, the competitive environment of the wind manufacturing industry seems to favour large companies that shift from being solely manufacturers of turnkey solutions to more holistic systems and solution providers. While this hints at synergy effects as the main reasons for mergers and acquisitions by German wind manufacturers, the development of the technological frontier and new product segments suggest firms could try to acquire new knowledge and capabilities through firm takeovers.

This section will analyse the extent to which OEMs are adapting and reconfiguring their organisational settings in response to the different windows of opportunity analysed above. For example, the increasing turbine size has ramifications for deployment because only a handful of firms have the experience, equipment and solutions for the manufacturing, transportation and installation of modern wind turbines (Lema et al., 2014). This has also meant that manufacturers are increasingly looking at new business opportunities in the service and maintenance segment spurring organisational restructurings. Similarly, manufacturers may respond to the continuous importance of low cost solutions with increasingly larger and more efficient machines and designs based on modularisation and standardisation.

Enercon

Enercon has driven the development of the gearless drive design and has also been at the forefront of rotor blade engineering, control systems and grid connection optimisation technologies. Compared to most other turbine manufacturers, Enercon is entirely privately owned which according to interviews conducted has shielded the firms from some of the industry consolidation. Notably, Enercon is not active in the offshore segment and has so far focused entirely on onshore wind. Enercon's business model relies on a large degree of vertical integration with almost all components produced in-house. They have also gone the furthest in terms of offering a full-package approach where Enercon often operates its own wind parks, undertakes the installation of turbines, organises the logistics, conducts service, operation and maintenance, has its own insurance and thus sells the entire wind package (Lema et al., 2014). Enercon's annual report of 2018 directly states this apart from its core business of wind turbine manufacturing, value-added is increasingly derived from service and energy logistics segments as well as integrated hybrid system solutions (Enercon, 2019).

While the company's revenue came almost entirely from wind turbine components and assembly in the 2010s, this has slowly shifted towards the growing importance of revenues from the service segment. In 2021, the service segment, with 53% of total revenue, accounted for the first time for more revenue than the manufacture of wind turbines. Although this shift can in part be explained by decreasing nominal value of the manufacturing-derived revenue, the company's service segment increased by an impressive 16-fold since 2007. Offering O&M services is becoming particularly attractive for manufacturing firms during times when the expansion of the wind market has stalled, and the service revenues can provide more stable incomes. Enercon's full-service packages require customers to sign a partner agreement, which 90% of its customers in Germany have done where the main market lies.

However, it is important to note that this trend that sales for new turbines went down drastically for Enercon since 2017. Enercon's geographical focus is almost entirely in Europe with a strong focus on Germany, while the subsidiary Wobben Windpower is responsible for the Latin American market. A patent infringement issue in the US has meant that Enercon is not operating at all in the US market. Similarly, a patent litigation by a former joint venture partner in India has meant that Enercon has left the Indian market in 2011. However, the company has recently begun to try to re-enter the market.

As one interviewee noted, one of Enercon's core strengths is their close relationship with smaller-scale customers and understanding of local regulations and requirements. Given the recent shift of the German feed-in tariff towards an auction system, local smaller scale energy cooperatives have become largely unprofitable and their demand has subsequently reduced

significantly (Herbes et al., 2017). Additionally, Enercon's annual reports also change a changing focus away from smaller turbines to bigger projects from 2016 onwards. In 2013, Enercon reported that customers of individual turbines or smaller wind parks were an important pillar of the company and believed to be the driver of the wind energy market. In a sign of organisation reconfiguration in response to changes in the composition of demand, the annual report for 2018 states that "the increasing size of contracts is in accordance with the trend of larger public tenders and related installation challenges" (Enercon, 2019,p. 22). The same trend can be seen in the number of turbines of different platforms where the weight shifted slowly from a 2MW platform to 3MW platform in recent years as well as the emergence of more turbines in their 5MW class. Yet, despite small increases in the average turbine and project size, Enercon still lies far below the industry average and particularly compared to Siemens-Gamesa (Figure 7). Indeed, to keep up with technological developments, the company underwent organisation restructuring and procedural reorientation from 2012 onwards by concentrating research and development in the designated subsidiary Wobben Research and Development (WRD). The subsidiary works in close cooperation with other companies, universities, and research institutes to develop new technologies. 2021 saw the first deployment of the E-nacelle with integrated electrical engineering in the E-160 EP5 E3 turbine (Enercon, 2022). Other technological developments by WRD include the 2014 established designated innovation centre including a test hangar at the company's location in Aurich. Enercon has further instructed a management consultancy with an internal reconfiguration of the organisational structure under the project "Turnaround 2022". The project aims to gather partner companies in the manufacturing as well as service segment under the parent company UEE holding (Enercon, 2021).

Table 1: Main Mergers, Acquisitions and Joint Ventures by Enercon, Nordex, and Siemens Gamesa

Acquiror name	Target name	Target country code	Deal type	Industry	Date
ENERCON	Induction Generatorenfertigung GmbH	DE	N.A.	Mechanical Engineering	2021
	Mechanic Anlagenbau GmbH	DE	N.A.	Industrial Equipment Supplier	2021
	Rothenseer Generatorenfertigung	DE	N.A.	Mechanical Engineering	2021

	GmbH				
	Windgeneratorenfertigung Magdeburg GmbH Erstkonsolidierung	DE	N.A.	Industrial Equipment Supplier	2021
	Composite Material Supply GmbH	DE	N.A.	Logistics	2021
	LAGERWEY GROUP BV	NL	Acquisition 100%	Windturbine manufacturer	2019
	Energieanlagenmontage GmbH	DE	N.A.	Equipment installer	2017
	ZEIT Zentrum für den ertragsorientierten Einsatz von IT GmbH	DE	N.A.	IT Consultant	2017
	Gusszentrum Ostfriesland GZO	DE	N.A.	Component manufacturer	2010
	KOCKUMS INDUSTRIER'S WIND POWER PYLONS UNIT	SE	Acquisition 100%	Pyolon manufacturer	2002
	WEC Turmbau GmbH	DE	Joint Venture	Tower manufacturer	2000
	SKET MASCHINEN UND ANLAGENBAU	DE	Acquisition 100%	Machine manufacturer	1998
NORDEX	TPI Composites	US	Strategic Partnership	Rotor blade process technology	2021
	SSP TECHNOLOGY A/S	DK	Acquisition 100%	Machine manufacturer	2019
	ACCIONA WINDPOWER SL	ES	Acquisition 100%	Windturbine manufacturer	2016
	Südwind	DE	Acquisition 100%	Windturbine manufacturer	2001
SIEMENS - GAMESA	TetraSpar Demonstration Project with Stiesdal	DE	Joint Venture	Offshore technologies	2021
	Digital Ventures Lab, in partnership with IBM	DE	Joint Venture	Machine learning	2021
	RIA BLADES SA	PT	Acquisition 100%	Blade manufacturer	2020
	SENVION HOLDING GMBH'S CERTAIN	DE	Acquisition 100%	Onshore Service	2020

	EUROPEAN SERVICES AND ONSHORE ASSETS			Business	
	Microsoft	US	Strategic Partnership	Digital solutions	
	Azure AI		Joint Venture	Artificial Intelligence	2019
	NEM Solutions		Strategic Partnership	Remote diagnostics sensors	2018
	Gamesa	ES	Merger	Synergies and market access	2017

Source: Orbis and company reports

In addition to Enercon's expansion in downstream activities, Enercon has acquired a number of manufacturing companies in recent years. This started most notably with the first partial stake and later full acquisition in 2018 of the Dutch manufacturer Lagerwey. The strategic involvement in Lagerwey was motivated by expected synergies in production and extending Enercon's product portfolio. From a technological perspective, the acquisition brought the integration of a Lagerwey's permanent magnet solutions into Enercon's products. Other recent consolidations ("Erstkonsolidierung") include several mechanical engineering and industrial manufacturing companies. Although the annual statements do not provide information on the type of consolidation (acquisition, merger, or joint venture) it can be hypothesised that these acquisitions were motivated by bringing new knowledge and expertise to Enercon's production processes and product portfolio. Overall, Enercon's expansion strategy appears to be centred mostly around vertical integration and close relationships with smaller developers and operators.

Siemens Games

The origin of Siemens' activity in the wind manufacturing sector goes back to the acquisition of the Danish manufacturer Bonus in 2004. In 2016, Siemens Wind Power merged with the Spanish company Gamesa, with Siemens shareholders holding a 59 per cent stake in the combined company and Siemens agreeing to pay €1 billion for its stake in Gamesa. While its headquarters are located in Spain, the company still has a strong regional presence in Germany with a factory and two R&D centres in the north of Germany. At the same time, Siemens-Gamesa continues strong ties to Denmark with much of the offshore manufacturing taking place there. In December 2022, Siemens Energy placed a standing purchase order to the remaining shares of Siemens Gamesa, as a result, Siemens Energy's stake in Siemens Gamesa has increased to 93%. Siemens-Gamesa's first combined annual reports state a clear ambition for global leadership, centred around scale, business and geographic

diversification, technological leadership and post-merger synergies (Siemens-Gamesa, 2018).

Siemens-Gamesa has been leading in offshore wind solutions as the world's leading manufacturer of offshore turbines. It is the only major German manufacturer that produces in the offshore segment with a strong geographical focus on Europe. In 2021, Siemens Gamesa signed orders with €12,185 million, where onshore contributed €4,708 million, offshore contributed €4,068 million, and the service division accounting for €3,409 million. Overall the share of the service division in the entire order backlog accounts for 30,5 per cent and experiences the highest year-on-year growth out of the three main divisions over the last 12 months (Siemens-Gamesa, 2022).

Compared to Enercon and Nordex, Siemens-Gamesa has a much more global market focus. Particularly in the onshore segment, Siemens-Gamesa's geographical distribution is more fragmented. This means the company is less reliable on individual markets and less exposed to changes in demand or the regulatory environment in wind turbine installations. The company also seems to have a clear strategy of focusing on larger projects and larger wind turbines with average project size not only exceeding that of Enercon and Nordex but also the global average (see Figure 7).

In October 2019, Siemens Gamesa further agreed to acquire its rival Senvion GmbH and Senvion Industria, covering Senvion's European onshore wind turbine service business and intellectual property (IP), as well as a wind turbine blade manufacturing facility. The acquisition was motivated by reducing dependency on suppliers sourcing from Asia, as well as improving market position access in key European markets such as Germany, France, and Italy (Siemens-Gamesa, 2020a).

Already in 2011, Siemens Wind Power started testing wind turbines with direct drive technologies. Since then, the company has firmly established itself as a major player in the technology with over 1000 turbines using direct drive technologies installed in all major offshore markets (Siemens-Gamesa, 2020b). In recent years, Siemens-Gamesa has entered several strategic partnerships or joint ventures with companies specialized in artificial intelligence and digital solutions. This included strategic partnerships with NEM solutions and Microsoft on remote diagnostics sensors and digital solutions, as well as joint ventures with Azure AI and IBM, to acquire capabilities in machine learning and artificial intelligence to speed up manufacturing processes (Siemens-Gamesa, 2022). Similarly, in 2019 Siemens Gamesa bolstered its team with the objective of leading a digital transformation in the sector. A new team of over 150 people covering a Digital Ventures Lab was established to search for new developments, as well as several global remote diagnostic centres which convert Big Data into value for customers. Siemens-Gamesa was further the

first manufacturer to install remote diagnostics sensors on wind turbine generators (Siemens-Gamesa, 2019).

Nordex

As another of Europe's largest wind turbine manufacturers, Nordex focuses on turbines in the 3 to 5MW+ class using gearbox-driven turbines and offers individual solutions both for markets with limited space and for regions with limited grid capacities. Emphasizing the importance of flexible platform solutions, turbines can also be operated flexibly in terms of capacity factor, rating, service life and noise requirements, and therefore can also be optimized for specific contexts. Founded in Denmark, the company now has its headquarters in the north of Germany with production sides also in China and Mexico. Their production process consists of nacelle and hub assembly as well as the production of some of the rotor blades, while most turbine components such as gearboxes, converters and generators are purchased via suppliers. While in 2021, Nordex sales amounted to €4,986 million, the service segment only accounted for €0,468 million (Nordex, 2021).

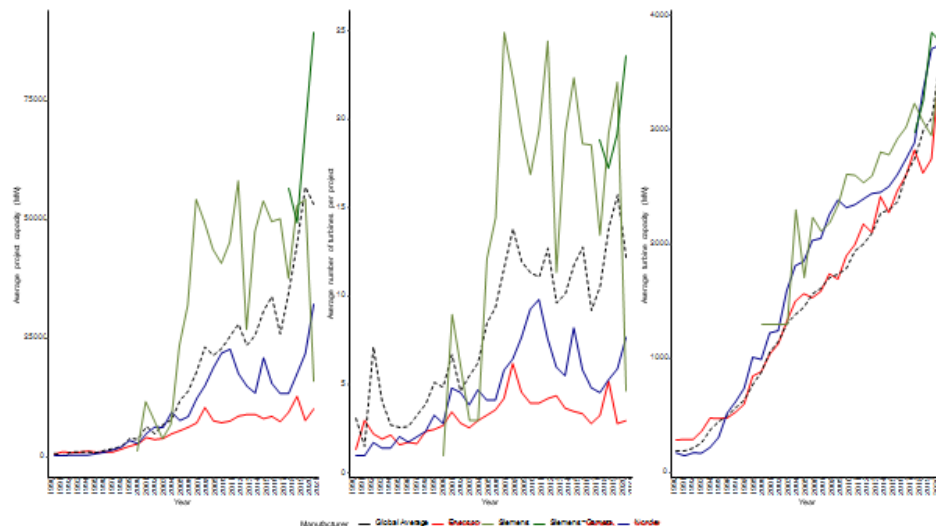
A network of service units in all of the company's key markets ensures Nordex's provision of comprehensive support for wind turbines over their entire lifespan. In the selected markets, mainly outside of Europe, the company also operates as a project developer for wind farms. Since its foundation in 1985, the company has installed turbines with a combined nominal output of almost 39 GW in over 40 countries. The Group's own service organisation supports 9765 wind turbines worldwide with a total nominal output of more than 27GW on the basis of typically long-term maintenance agreements.

In 2016, Nordex acquired the Spanish wind turbine manufacturer Acciona Windpower (AWP), with AWP's parent company Acciona S.A. becoming a majority shareholder with a 29.9% stake. The merger was motivated by strong complementary technologies and markets, with Nordex's focus on Europe and AWP's established position in North and South America, as well as larger projects without land constraints (Acciona, 2016). Based on the data from Error! Reference source not found. this strategy seems to have worked out with the company having a presence in both Europe and the Americas.

The acquisition of Acciona brought expertise in concrete towers, with the intention to complement Nordex's existing expertise in blade manufacturing. In 2017, Nordex further announced the acquisition of SSP Technology A/S, a Danish company which develops and manufactures rotor blade moulds and holds numerous patents for production processes. As of early 2023, Acciona S.A. held 40.97% of the company's equity. Nordex has recently called for a further €347m debt for equity swap to strengthen Nordex's capital structure and

improve financial performance, which would increase Acconia's share in the company by 13.8%.

Figure 7: Onshore wind energy project characteristics for main German manufacturers and global average



Source: Own based on The WindPower database.

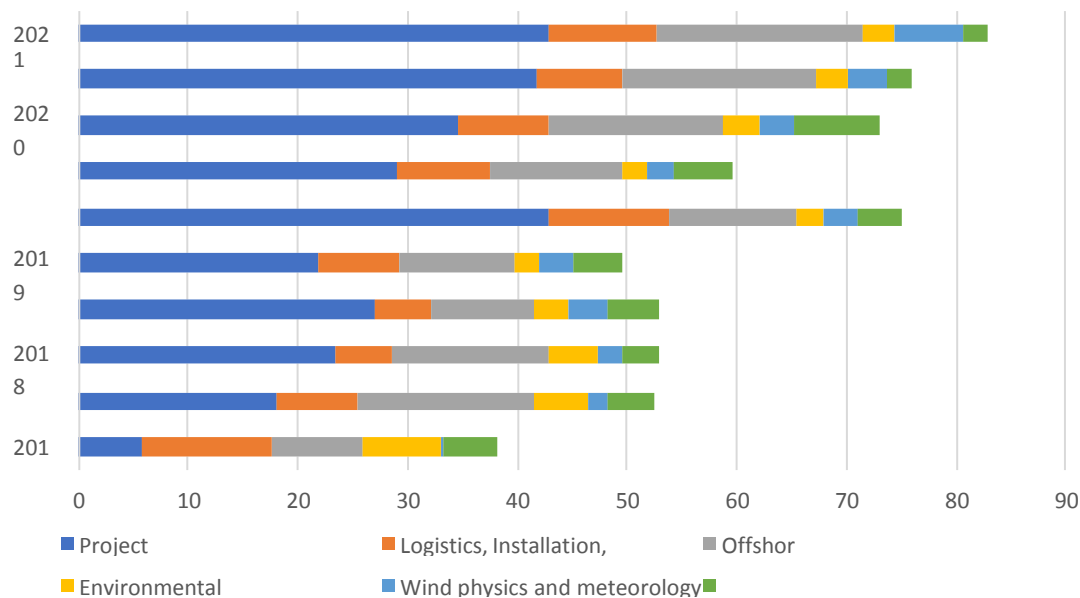
Comparing the data on onshore project size (Figure 7) suggests that Nordex seems to fall between to distinct trends of the industry. Whereas Siemens-Gamesa is focused on much bigger projects (based on average project capacity and average number of turbines per project), Enercon appears to have much smaller projects below the industry average. At the same time, Enercon has been leading the shift to an increased focus on revenue from the company's service segment. Nordex does not seem to have such transitions, yet. At the same time, however, this also shows the importance of the composition of demand and the effect of domestic policies. Enercon, the company with the largest exposure to the European market is also the company with the smallest average windfarms, mirroring the European developments shown in Figure 5.

Industrial Policy Alignment

Although Germany does not have any local content requirements for wind turbines, supply-side policies and access to funding for research and development create strong incentives for wind firms to operate in Germany (O'Sullivan, 2020, p. 1084). In addition to the demand-side focused EEG, German has long-standing support for energy research and supply-side support for research and development through the Energy Research Programme (ERP). Currently, in its 7th edition, the initiative aims to support further cuts in the cost of wind energy and to enhance the reliability and

lifetime of wind turbine installations (BMWK, 2022, p. 34). Figure 8 gives an overview of the different programmes supported through the ERP with an increasing focus on project development since 2012.

Figure 8: German government support to research and development in the field of wind energy, in million €



Source: Based on 7 th Energy Research Programme of the Federal Government (BMWK, 2022)

The EnArgus platform provides data on individual projects supported through the ERP. The data includes information on 3042 projects within the wind turbine segment supported since 1972¹. During the 1990, 957 of 1273 projects supported individual wind park for the “testing of wind turbines within the scope of the measure ‘100 or ‘250 MW Wind”. Between 2000 and 2009 there were none of such projects and the overall number of projects supported also went down drastically to 234. Projects supported during this time were largely prototype and demonstration projects with several of the largest grants awarded to manufacturers such as Siemens, Adwen, and Senvion.

During the last 10 years (2013-2022) the number of wind energy related projects supported increased to 995 again. Looking at the largest projects reveals that most large grants support public-private technology intermediaries and research institutes such as the Fraunhofer Institute for Windenergysystems (IWES), and the German Aerospace Centre (DLR) as well as several universities. Projects included various test centres for wind turbines and blades, demonstration projects, as well as monitoring and evaluation systems.

However, at the same time individual companies are supported and, for example, in 2021 Siemens-Gamesa received €15 million for foundational research on decentralised offshore solutions for wind-to-hydrogen.

Conclusion

In conclusion, the wind turbine manufacturing industry has undergone a significant transformation in recent decades due to the interplay of various factors such as technological advancements, market dynamics, and policy landscapes. Distinct cycles of technological developments, changing demand and institutional support have had a large effect on the European and German wind manufacturing industry. The German market saw a sharp drop in annual installed turbines in 2017 due to changes in the auction system and approval processes, resulting in a falling behind of German demand vis-à-vis global demand. Changes to the auction system which puts heavy emphasis on the final cost of electricity and the lack of sufficient demand means German manufacturers are locked in a race to build ever bigger turbines over increasingly shorter cycles which have resulted in reduced profit margins. In turn, this is threatening the needed upscaling in production capabilities to meet the expected increase in demand for both onshore and offshore turbines in the coming years. Carefully constructed industrial policy will be needed to overcome this misalignment of technological change and demand to ensure continued manufacturing of wind turbines in Germany and Europe. Further interviews planned as part of this research will seek to uncover how industrial policy will have to change if the German wind manufacturing industry is to survive.

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Notes

¹ As the search for “wind turbines” also returns projects supporting “gas turbines” this number is slightly higher. These projects were excluded manually for the analysis.

Organic farming efficiency: the precursor of green economy and sustainable food systems through agroecology in Central Uganda

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Abstract

Organic farming is viewed nowadays as an opportunity for creating new agri-food systems for enhancing producers' revenue, providing essential inputs for agrobiodiversity protection, and mitigating climate change impacts. This study aims to determine the level of technical efficiency in organic farming and its determinants through agroecological approaches for green economy and sustainable food systems. The study was carried out in Central Uganda mainly in 5 districts: Wakiso, Masaka, Bukomansimbi, Ssembabule, and Kyotera. Primary data were collected from 310 organic farmers selected through multiple-stage stratified sampling by proportional random sampling in the 8 counties. The analysis data focused on agroecology performance evaluation tools and applied stochastic frontier analysis and Tobit regression analysis using the computer software STATA. The stochastic Cobb-Douglas production function was used to estimate the frontier production and efficiency levels. The findings revealed that the maximum likelihood estimates of technical efficiency highlighted the diversity, synergies, recycling, and resilience in organic farming as being positive and significant at the 1% level in determining technical efficiency. Results showed that

farmers' respondents were inefficient with an average technical efficiency of 48.40%. Tobit regression analysis showed that the animal's diversity, tree integration (agroforestry, silvopastoralism, agrosilvopastoralism), recycling of biomass and nutrients, rainwater harvesting and saving, and the stability of income/production, and capacity to recover from perturbations were positive and significant in contributing to organic farming technical efficiency. For each country, the transition to a green economy should be based on a country-specific model like improving organic production efficiency through agroecological approaches, which is green growth that should be monitored to assess policy effectiveness in the agriculture sector and development progress.

Key Words: organic farming, agroecological approaches, technical efficiency, green economy, sustainable food systems.

Introduction

Based on environmental protection and providing healthy and safe foods to the population, organic farming is considered an opportunity to create new agri-food systems for sustainable agricultural production and green economy. Organic farming is a holistic production management system and constitutes an inter-disciplinary science, capable of addressing the challenges of food insecurity, climate change impacts, and poverty, and promoting environmentally friendly, socially acceptable, and economically sound production of food and fibers. Nowadays "green" economy acts as the engine of sustainable development without prejudice to the nature, it allows to maintain ecological wellbeing of the population, increases production efficiency due to preservation and increase in the natural capital, reduction of toxic and carbon emissions, expansion of the biodiversity as well as the growth in incomes and employment of the population (Akhmetshina et al, 2018). The green economy is essential for promoting inclusive environmental sustainability and global climate adaptation into our domestic and global economic structures while ensuring a good prospect for people and the environment (Guo et al., 2021). Organic agriculture has been recognized as one of the practices that can improve the health and sustainability of agroecosystems (Giovannucci & Ponte, 2005; Pretty, 2008). As a holistic practice, organic agriculture pays attention to the 'logical association and/or synchronization' of systemic elements (Scofield, 1986), such as water, soils, crops, and livestock. The aim of organic agriculture is to create viable socially, environmentally, and economically integrated agroecosystems (Lampkin, 1994).

Agricultural development in sub-Saharan Africa is of central importance, as levels of food insecurity and rural poverty remain high in many countries and food production systems face multiple and interconnected challenges such as declining soil fertility, climate change, and high pressure on land (Kaplan et al., 2013). Many countries still face high rates of food insecurity and rural poverty (IFAD, 2016) and agriculture is widely recognized as key for addressing both (Diao et al., 2010). In Uganda, the FAO found that sustainable agriculture intensification is of particular concern 83% of the population live in rural areas, employs 72% of the labour force and contributes 25% to the overall gross domestic product (FAO, 2016). Agricultural intensification refers to an increase in agricultural production per unit of inputs such as labor, land, time, fertilizer, seed, feed, or cash (FAO, 2004). Agricultural intensification entailed the green revolution. Globally, the green revolution, while enhancing crop production, proved to be unsustainable as it damaged the environment, caused dramatic loss of biodiversity and associated traditional knowledge, favored wealthier farmers, and left many poor farmers deeper in debt (Rosset, 2006).

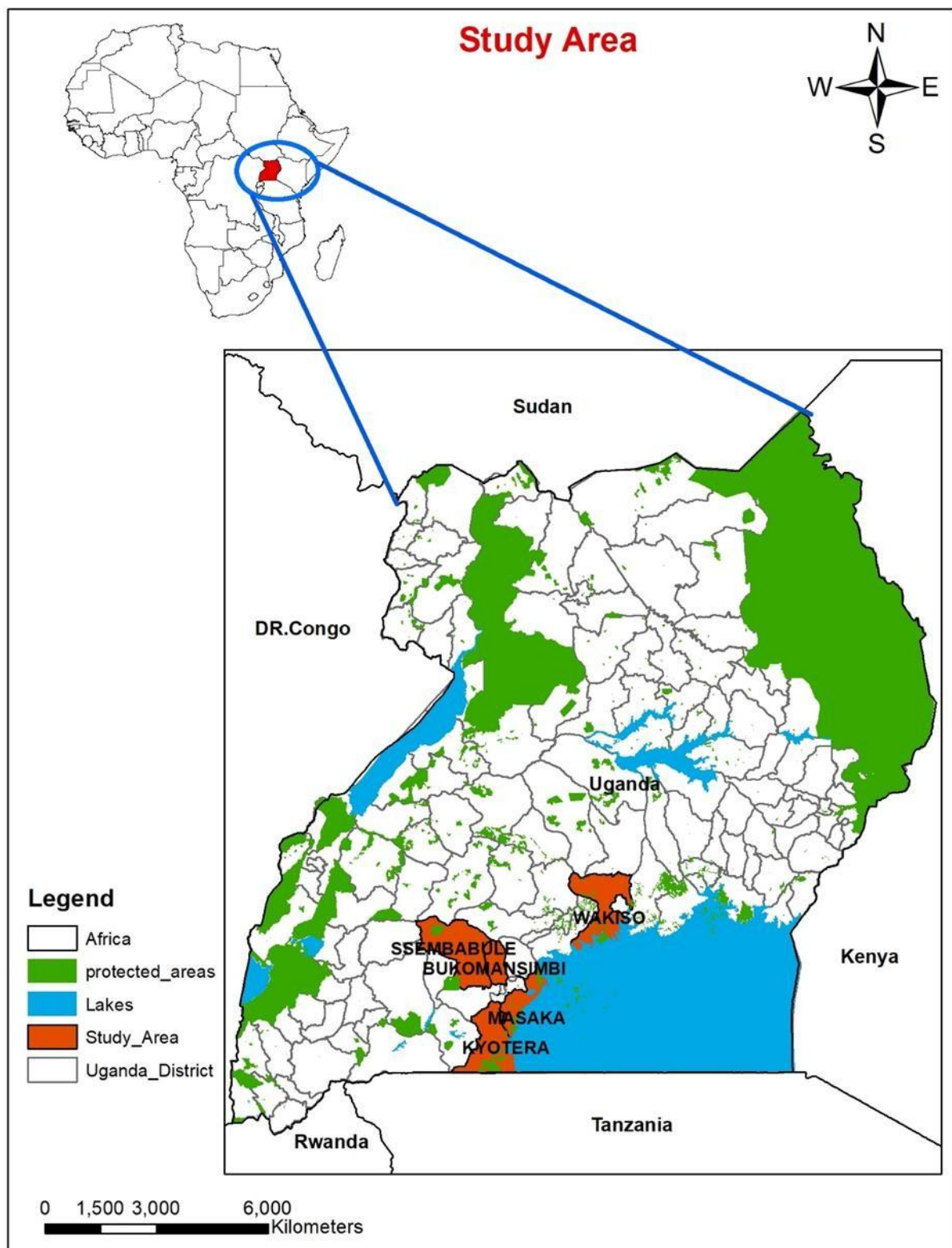
However, organic agriculture can increase agricultural productivity and raise incomes with low- cost, locally available and appropriate technologies, and can be more conducive to food security in Africa than most conventional production systems (Robert, 2017). Nonetheless, approximately 600 million people fall ill through the consumption of contaminated unsafe food each year, with considerable differences among sub-regions; and with the highest burden observed in Africa (WHO, 2020). Organic farming excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, livestock feed additives, and genetically modified organisms while optimizing the health and productivity of plants, animals and people. In Uganda, 139 191 agricultural producers involved in organic production with 16 376 ha harnessed for organic production (IFOAM, 2022). Agroecology goes beyond organic agriculture through innovations and practices that diversify farms and farming landscapes, increase biodiversity, nurture soil health, enhance recycling, promote ecosystem services and stimulate interactions between different species, such that the farm can provide its own organic matter, pest regulation and weed control, without resort to external inputs. Agroecological practices include mulching, crop, livestock integration, agroforestry, composting, and intercropping (Wezel and Silva, 2017). Agroecological farming is considered sustainable agriculture which focuses on ecological production for agrobiodiversity protection and food sovereignty through using multiple and diverse crops or animals, relying on biological processes for building soil fertility and controlling pests and diseases, etc. This research article aims to analyze organic production efficiency through agroecological approaches for a green economy and sustainable food systems. Agroecological approaches explicitly aim at transforming food and agriculture systems, addressing the root causes of problems and providing holistic and long-term solutions (FAO, 2018a) that consider the complexity of farming systems within their social, economic and ecological contexts (Petersen and

Arbenz, 2018). Agroecological approaches aim at building resilient and sustainable local food systems, strongly linked and adapted to their territories and ecosystems (Varghese and Hansen- Kuhn, 2013; Nyéléni, 2015; Anderson et al., 2015). Thus, increasing organic production efficiency through agroecological approaches is the foundation of the green economy through green growth. Green growth is qualitative growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental damages and resilient in that it explains natural hazards (World Bank, 2012). The study therefore examines the level of technical efficiency of organic farmers through agroecological approaches in Central Uganda and identify characteristics that influence technical efficiency. At the practical level, measuring technical efficiency and identifying factors that influence organic farming provides meaningful information to all stakeholders in the formulation of strategies that are likely to improve organic farming technical efficiency through agroecology. At the theoretical level, the study aims at contributing to existing literature and understanding of organic farming technical performance in rural areas of developing countries.

Materials and methods

Setting and study area

This study was conducted in Central Uganda mainly in five districts: Wakiso, Masaka, Bukomansimbi, Ssembabule, and Kyotera (figure 1). These districts belonged to Mukono Zonal Agricultural Research and Development Institute (ZARDI). In Uganda, we registered 10 agroecological zones called ZARDI. The ZARDI has the same climate, land use and cropping patterns, which was relevant in designing and developing the sampling strategy (UBOS, 2020). The ZARDI Mukono is the second in Uganda with 1,382,610 Agricultural Households (UBOS, 2022). Wakiso is the most densely populated district in Uganda, with 3,519,300 inhabitants (UBOS, 2020). The ZARDI Mukono is categorized by tropical climate with bimodal rainfall patterns (Two rainy seasons, main season March to May with peak in April and secondary season October to December with a peak in November) with mean annual rainfall of 1614 mm. Mean temperature ranges from 18.14°C to 26.53°C however, the years 2015 to 2020 registered annual average minimum 18.5°C and maximum 28.1°C (Majaliwa et al., 2015; UBOS, 2020).



Data collection

This paper reports on research from a study in Central Uganda that examines organic farming and the implementation of agroecological approaches. The

organic farms that were part of the sample population were involved in a range of self-described agroecological practices such as diversity, resilience, recycling, and synergies. We adopted both descriptive and exploratory designs and the research approach was both qualitative and quantitative in nature. The study population consisted of organic farmers from rain-fed production systems. The multiple-stage stratified sampling procedure was used to identify the farmers and a final sample of 310 organic farmers was selected. In the first stage, two institutions (Agency For Integrated Rural Development (AFIRD) and St. Jude Family Project) were purposively selected as an organization committed to organic agriculture at least 20 years ago, recognized by one Uganda national organic organization. Both institutions trained the farmers in organic practices following the agroecological approaches. Second, we asked the institutions to provide us with a list of county beneficiaries of the organic practices training. From the lists, we randomly selected 4 counties per institution. Therefore, a total of 8 counties were selected. Third, we acquired the lists of the organic farmers in all the selected county and applied a proportional random sampling (average 50 organic farmers per county in Wakiso district for AFIRD institution and average 27 organic farmers per county for St. Jude Family Project in Masaka district and peri-Masaka district) procedure to select individual farmers to be interviewed. A total of 310 organic farmers were interviewed in the 8 counties (table 1). The visit to the farm is essential for gathering fieldwork material that is generated through qualitative interpretive methods like interviews and participant observation. The survey was carried out in December 2022 to January 2023. The institutions that hosted this research were:

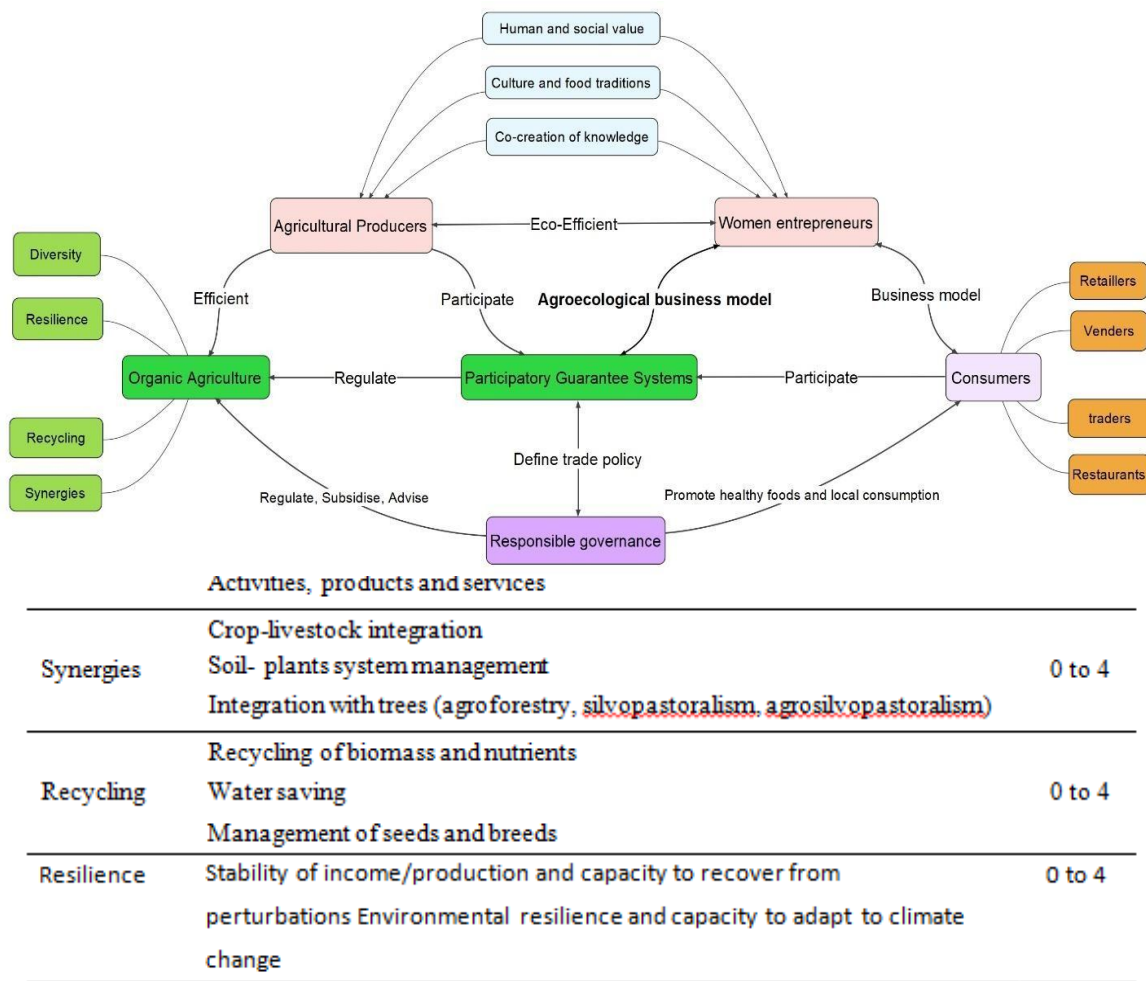
- ❖ AFIRD was founded in 1997 by a group of professionals who realized the need for an integrated approach to rural development and brought their experiences together to develop the country. It was registered as an NGO in 1998 under registration No: S-5914/2404 and Certificate No: 2222. They training farmers in organic sustainable practices through farm planning, soil and water conservation, integration of animals into the farming system, and vegetable growing using indigenous seeds. It is authorized to operate in all parts of Uganda with web site <https://www.afirduganda.org/>
- ❖ St. Jude Family Project is non-governmental organization registered in Uganda No.S.5914/2000 and was founded by Josephine Kizza and her Late husband John Kizza St.Jude Family Project now trains and supports local farmers in agroecology and organic farming, using integrated systems to prevent waste and mitigate the effects of climate change. They work with women farmers' groups, youth, schools, and in the local community. It is located in Masaka with web site <https://stjudefamilyprojects.org/>

Table 1: number of organic farmers interviewed

Institution	District	County	Number of organic farmers	Total	Percentage
Agency For Integrated Rural Development	Wakiso	Busiro	50	200	64.52
		Nansana	50		
		Municipality			
		Kyadondo	50		
		Kira Municipality	50		
St. Jude Family Project	Bukomansimbi	Bukomansimbi	30	110	35.48
	Ssembabule	Mawogola	27		
	Kyotera	Kyotera	27		
	asaka	Bukoto	26		
Total				310	100

Data analysis

The analysis of organic farming through agroecological approaches was based on the Tool for Agroecology Performance Evaluation (TAPE) developed by FAO (Mottet et al., 2020). The method implemented is determining the score for the agroecological indicators. For each indicator, appropriate attribution of the scores was based on interviews and organic farm observation. The scores of each indicator for diversity, synergies, recycling, and resilience range from 0 to 4, depending on how organic farming is. In terms of scale, the score is to provide an indicator that gives the percentage of organic farms by a range. The agroecology principles (diversity, synergies, recycling, and resilience) to assess organic farming relied on the conceptual framework to assess organic farming for agroecology and sustainable food systems designed by Dagoudo et al., (2023) (figure 2). Descriptive analysis such as mean, standard deviation, minimum, maximum, percentage and frequency counts were used to summarize socio-economic and demographic characteristics of the organic farmers, input and output variables, and frequency distribution of technical efficiency levels. Econometric techniques such as stochastic frontier analysis technique and Tobit regression were applied to analyze technical efficiency (TE) among the selected organic farming and the effect of agroecological principles factors (table 2) on TE.



Total organic output Cost estimation

Variant-based cost estimation methods use similarities among components to retrieve relative cost information in terms of design variables (Brinke et al., 1999, Poli 2002). Organic farming is system production that encompasses agriculture production (crop, vegetable, fruit, spices, herbs), animal production, no timber production (fruits, herbs), and animal co-production (manure, eggs, milk). The estimation of organic output cost is based on all output in organic farming.

The total organic output cost (Cop) is estimated as:

$$Cop = Ccp + Cap + Cntp + Ccop \quad (1)$$

Where Ccp is the cost of organic crops, Cap is the cost of organic animals, $Cntp$ is the cost of no timber products (fruits, herbs), and $Ccop$ is the cost of co-products (manure, eggs, milk).

The cost C_i is estimated as:

$$C_i = Q_i P_i \quad (2)$$

Where C_i is the cost of product i^{th} , Q_i is the quantity of product i^{th} , and P_i is the price of product i^{th}

Analytical framework

Traditionally, economic efficiency mainly considers the output ratio of labor and capital input (Walker et al., 2020), while green economic efficiency further addresses energy constraints and non-expected output (Amigues and Moreaux, 2019). The economic theory gives a distinction between two forms of efficiency, allocative and technical efficiency, and a farm that meets both is said to be economically efficient (Ndirangu et al., 2018). Frontier measures of efficiency imply that efficient farms operate along the production frontier. In addition, the amount by which a farm deviates from its frontier production is regarded as a measure of inefficiency (Chepng'etich et al., 2015). Tabe and Molua (2017) noted that research has categorized measures of efficiency into non-parametric and parametric approaches. The most common nonparametric approach is the data envelopment analysis (DEA) which does not separate deviations in output into inefficiency and random errors. Further, it does not allow hypothesis testing for the fitness of the model (Parman and Featherstone, 2019). The stochastic frontier production is the frequently used parametric approach. This approach entails the description of the technology which may be restrictive in most cases (Ajibefun, 2008). Further, the stochastic frontier model attributes deviations from the frontier function into inefficiencies and random errors thus accurate and less sensitive to measurement errors in data (Ndirangu et al., 2018). In addition, it allows testing of hypothesis regarding the goodness of fit for the model. This model estimates the production function by fitting observed data and minimizing measures of their distance from the expected frontier (Abdul and Isgin, 2016). The stochastic production frontier was initially proposed by Aigner et al. (1977). The model is generally expressed as:

$$Y_i = (X_i, \beta) + V_i - U_i \quad (3)$$

Where Y_i denote output of i^{th} organic production unit, X_i is input of agroecology production, V_i is the error component that accounts for the measurement error in the output variable due to the agroecology principles, combined effect of the unobserved input on production, errors in the observation and measuring of data U_i is the error component that accounts for the existence of inefficiency in production, and β s are the unknown parameters to be estimated, which represents elasticities of inputs.

The estimated technical efficiency of i^{th} farmer is determined as the ratio of the observed output for the i^{th} farm relative to the potential output. This can be illustrated as shown in Equation 4.

$$TE_{it} = \frac{Y}{Y^*} = \frac{\exp(X_i\beta + V_i - U_i)}{\exp(X_i\beta + V_i)} = \exp(-U_i) \quad (4)$$

Where, Y is the observed output and Y^* is the potential or frontier output.

Model specification for technical efficiency

The current study applied stochastic frontier model to determine technical efficiency within the framework of Cobb-Douglas production function. Following the specification of the stochastic Cobb-Douglas production model, the data was fitted as below:

$$\ln Y_i = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + V_i - U_i \quad (5)$$

Where, $\ln$ = logarithm to base e , β_0 = constant which represents the intercept of production function, β_1 to β_5 = unknown parameter that were established which are also the output elasticities of score of diversity, synergies, recycling and resilience respectively. Y_i = cost of organic production, V_i = two-sided random error representing stochastic effect beyond farmer's control, measurement errors and other statistical noise and U_i = a non-negative random variable representing technical inefficiency of organic farmer, and X_1 , X_2 , X_3 , X_4 , and X_5 are the amount of farm size, the score diversity, synergies, recycling and resilience respectively.

Following Coelli et al. (2005) and Bi (2004), the model given in the Equation 5 was estimated using the maximum likelihood estimates (MLE). MLE provides the rationale estimates for unknown parameter (β), gamma (γ) and sigma squared (σ^2).

Model specification for the effect of agroecology principles on technical efficiency

The relationship between agroecology principles on technical efficiency was analyzed using tobit regression model since technical efficiency has limited to a minimum of 0 to a maximum of 1, Tobit model was applied as indicated in Equation 6.

$$TE_i = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \dots + \delta_{11} Z_{12} + \omega \quad (6)$$

Where, TE_i = technical efficiency, δ_0 is the intercept of the function while $\delta_1 \dots \delta_{11}$ are unknown scalar parameters to be estimated.

Z₁ =Diversity Crops
 Z₂ =Diversity Animals
 Z₃ =Diversity Activities, products and services
 Z₄ =Crop-livestock integration
 Z₅ =Soil- plants system management
 Z₆ =Integration with trees: agroforestry, silvopastoralism, agrosilvopastoralism
 Z₇ =Recycling of biomass and nutrients
 Z₈ =Water harvesting/saving
 Z₉ =Management of seeds and breeds
 Z₁₀=Stability of income/production and capacity to recover from perturbations
 Z₁₁=Environmental resilience and capacity to adapt to climate change

Results and discussion

Sample description

Table 1 depicts descriptive results of demographic and socio-economic characteristics of selected organic farmers. The study indicated that 29.03% of the respondents were male while 70.97% were female indicating that the organic farming crop is important for both genders. The study indicated that the majority of the farmers had formal education where 38.710% of the respondents had primary education and 29.03% had tertiary secondary. This high percentage of farmers with formal education implies that the majority of farmers were capable of increasing organic farming productivity through the quick understanding of training given on agroecology management such as best practices and innovations. The average size of the family in the area of study was 6 people with a minimum of 1 and a maximum of 20 persons implying the availability of labor among organic farmers. Organic farming was practiced by both young and old people, with the average age of the respondents being 53 years old and ranging from 20 to 90 years old. Between 1 and 9 males were active in organic farming, and between 1 and 14 females were active in organic farming in the respondents' households.

Table 3: Descriptive analysis of organic farmers

Variable	Frequency	Percentage
Female	220	70.97
Male	90	29.03
Primary	120	38.71
Secondary	90	29.03
University	32	10.32
Vocational	36	11.61
None	32	10.32
Married	202	65.16
Widow	59	19.03



Figure 6: organic fruits



Figure 7: organic spices

Descriptive statistics for agroecology variables

The summary statistics for the variables used in the estimation of production function and technical efficiency are presented in Table 2. The production function and technical efficiency for this study were estimated using four types of inputs which are the score of diversity, synergies, recycling, and resilience. The findings in Table 2 show that the scoring is used for the assessment of agroecology principles that are presented by indicator. The scores of each indicator for this element range from 0 to 4. The results show that the indicator for the recycling of biomass and nutrients (2.82 ± 0.951) has a high score following the management of seeds and breeds (2.57 ± 0.877), and diversity crop (2.49 ± 0.819) (table 3). The diversity Activities, products and services (1.12 ± 0.78) and diversity of animals (1.55 ± 0.777) still challenge for organic farmers in Central Uganda. Organic production is characterized by small size holdings with a mean size of 0.04ha, the average holding size was 0.79 ha (± 0.67).

Table 4: Descriptive statistics for the model variables

Variable	N	Mean	Std. Deviation	Min	Max
Area size of organic production (ha)		0.79	0.67	0.04	4.86
Diversity Crops	310	2.49	0.819	0	4
Diversity Animals	310	1.55	0.777	0	4
Diversity Activities, products and services	310	1.12	0.78	0	4
Crop-livestock integration	310	1.77	0.842	0	4
Soil- plants system management	310	2.15	0.679	0	4
Integration with trees: agroforestry, silvopastoralism, agrosilvopastoralism	310	1.7	0.67	0	4
Recycling of biomass and nutrients	310	2.82	0.951	0	4
Water harvesting/saving	310	1.61	1.282	0	4
Management of seeds and breeds	310	2.57	0.877	0	4
Stability of income/production and capacity to recover from perturbations	310	2	0.887	0	4
Environmental resilience and capacity to adapt to climate change (Resen)	310	1.94	0.836	0	4

Estimation of parameters of the frontier production function

Table 3 shows the findings of the stochastic frontier analysis. The parameters of area size, water- harvesting/saving, stability-income, and capacity to recovery were found to be positively significant at 1% level with the estimated β -coefficients of 0.368, 0.313, and 0.602 respectively. The results imply that 1% increase in area size used increases organic farming output by 0.368% and 1% increase in water-harvesting/saving use increases organic farming output by 0.313%. Integrated water management provides large co-benefits for adaptation (Dillon and Arshad, 2016) by improving the resilience of food crop production systems to future climate change (Porter et al. 2014). Moreover, an increase of improved stability-income and capacity to recovery by 1% would increase output by 0.602%. Increasing food productivity through practices such as sustainable intensification improves farm incomes and allows households to build assets for use in times of stress, thereby improving resilience (Campbell et al. 2014). Animals diversity had positive coefficients that were significant at 1% level. Thus, increasing animal diversity by 1% would increase organic farming output by 0.450%. Crop and animal diversification are considered the most promising adaptation measures (Porter et al. 2014; Rojas-Downing et al. 2017). In addition, integration with trees as agroforestry, silvopastoralism, agrosilvopastoralism had a positive and significant coefficient at 10% level showing that a 1% increase in integration with trees organic farming increased organic farming output by 0.2823%. Agroforestry sequesters carbon in vegetation and soils. The use of leguminous trees can enhance biological nitrogen fixation and resilience to climate change. Soil improvement and the provision of perennial vegetation can help to address desertification and land degradation. Agroforestry can increase agricultural productivity, with benefits for food security. Additionally, agroforestry can enable payments to farmers for ecosystem services and reduce vulnerability to climate shocks (Antwi-Agyei et al. 2014; Benjamin et al. 2018; Guo et al. 2018; den Herder et al. 2017; Mbow et al. 2014a; Mosquera- Losada et al. 2018; Mutuo et al. 2005; Nair and Nair 2014; Ram et al. 2017; Rosenstock et al. 2014; Sain et al. 2017; Santiago-Freijanes et al. 2018; Sida et al. 2018; Vignola et al. 2015; Yirdaw et al. 2017). On the other hand, the parameters of crop diversity and recycling of biomass and nutrients were negatively significant at 5% level with the estimated β -coefficients of 0.3388 and 0.3397 respectively. The results imply that 1% increase in crop diversity reduces organic farming output by 0.3388% and 1% increase in the recycling of biomass and nutrients use increases organic farming output by 0.3397%. There are various types of biomass sources such as agricultural products and their processing residues, wood and the wastes resulting from logging, animal dung, and residues from food processing. Recycling biomass and nutrients and reuse as manure for organic production enter the logic of the circular economy. According to Kirchherr et al. (2017), “a circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in

production/ distribution and consumption processes, thus operating at the micro-level (products, companies, consumers). The circular economy in organic farming (at the micro-level) is the base of the green economy through green investment. The recycling of biomass and nutrients affects positively organic farming output but the technologies used are still in majority traditional. More diversity of crops in small area production reduces the organic farming outputs such as yield, animal grazing, and herbs...

The findings in Table 3 indicate that the value of lambda (λ) is 2.1345 indicating that in total deviation 2.1345% difference between observed and organic farming is due to the inefficiency among the sampled respondents.

The value of the gamma parameter (γ) shows that 82% of the deviations in tomato production resulted from technical inefficiencies. The results yielded a sigma squared (σ^2) value of 1.319 that was significant at 1% level, which is significantly greater than zero, indicating the appropriateness of the model. The log likelihood statistic also shows the appropriateness of the model given it is significant at 1% level and the large absolute value of Log Likelihood ratio of -359.4239.

Table 5. Stochastic frontier production function results.

Variable	β -Coef.	Std. Err.	Z-Value	P> z
lnArea_size	0.3677***	0.0557	6.61	0.000
lnDiversity_crops	-0.3388**	0.1463	-2.32	0.021
lnDiversity_animals	0.4504**	0.1533	2.94	0.003
lnDiversity_ Activities-products	0.3774	0.1601	2.36	0.018
lnSynergies_ Crop-livestock- integration	-0.1309	0.1608	-0.81	0.416
lnSynergies_ Soil- plants-system	0.2454	0.1630	1.5100	0.132
lnSynergies_ Integration_trees	0.2823*	0.1523	1.8500	0.064
lnRecycling_ biomass -nutrients	0.3397**	0.1633	-2.0800	0.038
lnRecycling_ Water- harvesting/saving	0.3125***	0.1069	2.9200	0.003
lnRecycling_ Management - seeds-breeds	-0.0299	0.1530	-0.2000	0.845
lnResilience_ Stability-income/ capacity	0.6021***	0.1165	5.1700	0.000
lnResilience_ Environmental/ capacity	-0.0918	0.1712	-0.5400	0.592
Constant	15.8237***	0.2072	76.3600	0.000
Vsigma	-1.4380***	0.2574	-5.5900	0.000

Usigma	0.0785	0.2080	0.3800	0.706
Diagnostic test				
Sigma v	0.4872	0.0627		0.000
Sigma u	1.0400	0.1082		0.000
Sigma2 (σ^2)	1.3191	0.1842		0.000
Lambda (λ)	2.1345	0.1603		
Gamma (γ)	0.8200			
Log likelihood	-359.4239			
Prob > chi2	0.000			

*** Significance at 1%, **Significance at 5%, *Significance at 10%

Technical efficiency in organic farming

The results of the frequency estimates and mean of the technical efficiency are shown in Table 6. The mean technical efficiency for the sample was 51.60%. This shows that there exists an opportunity to improve technical efficiency by more than 48.40% of all restrictions that make organic farming in Central Uganda inefficient are improved. The findings indicated that the majority of respondents (49.68%) recorded technical efficiency ranging from 50% to 75%. The results also noted that 42.21% of the organic farmers had efficiency scores below 0.5. This implies that by increasing technical efficiency, 42.21% of the sampled farmers could increase organic farming output by more than 50%.

Table 6. Frequency distribution of technical efficiency estimates.

Technical efficiency range		Frequency	Percentage
0 < to < 0.25		36	11.69
0.25 0< to < 0.50		94	30.52
0.5 < to < 0.75		153	49.68
0.75 < to < 1		25	8.12
Mean	0.516017		
Minimum	0.043849		
Maximum	0.8701418		
Standard deviation	0.1872094		

Agroecology principle affecting technical efficiency

The effect of selected factors on technical efficiency was ascertained using a censored Tobit regression model as specified in Equation six (6). Table 7 shows the results of Tobit's multiple regression analysis. The existence of inefficiency was determined using the log-likelihood which gave a value of -5278.8 which was significant at 1% level. The log-likelihood statistic which determines the appropriateness of the model indicates that the model is applicable given its significant chisquare ($p < 0.000$) and the large absolute value of log-likelihood ratio of 155.89. This denotes that the Tobit regression model was appropriate in determining factors that affect technical efficiency in the study area.

Area size had a significant coefficient at 1% level and positively influenced technical efficiency. This implies that as the area size expands, the technical efficiency of organic farmers in the study area increases. From table 7, it is shown that 1% increase in area size increases the technical efficiency by 4286594 Uganda shillings organic outputs. The stability of income/production and capacity to recover from perturbations are positive and significant indicating that 1% increase in the level of resilience would increase technical efficiency by 2630955 Uganda shillings organic outputs. This relationship is significant at 1% level. This means that when organic farmers have the stability of income/production and capacity to recover from perturbations in organic farming as well as resource use, they become more efficient. Animals' diversity indicated a positive relationship with the technical efficiency as expected. From Table 7, it is shown that 1% increase in animal diversity increases the technical efficiency by 2059025 Uganda shillings organic outputs. Agricultural diversification has been promoted as an adaptive strategy to climate impacts, given that diversity is known to increase resiliency of agricultural and natural systems, such as in resistance to increased pests or diseases; it can also provide diversified income portfolios when some crops may become sensitive to climate events (Bradshaw et al. 2004; Lin 2011). Tree integration (agroforestry, silvopastoralism, agrosilvopastoralism) is an important agroecological practices which helps farmers to improve the agrobiodiversity and cover protects crop plants against extremes in microclimate and soil moisture fluctuation. Furthermore, the grazing of domesticated animals participates to energy flows, nutrient recycling, and the regulation of other organisms, especially plants and vegetation. The study showed a positive relationship of this tree integration with technical efficiency as expected. It showed that tree integration increases technical efficiency by 1740295 Uganda shillings organic outputs. Rainwater harvesting or saving refers to the collection and storage of rainy season precipitation that would otherwise have percolated into the soil or runoff into stream channels. Organic agricultural production still depends on rainfall, and the equipment or technical requirements to harvest and save water have positive relationship with the technical efficiency. From Table 7, it is shown that

1% increase in harvesting and saving water increases the technical efficiency by 1068036 Uganda shillings organic outputs.

More intense rainfall leads to water redistribution between surface and ground water in catchments as water storage in the soil decreases (green water) and runoff and reservoir inflow increases (blue water) (Liu and Yang 2010; Eekhout et al. 2018). This results in increased surface flooding and soil erosion, increased plant water stress and reduced water security, which in terms of agriculture means an increased dependency on irrigation and reservoir storage (Nainggolan et al. 2012; Favis- Mortlock and Mullen 2011; García- Ruiz et al. 2011; Li and Fang 2016; Chagas and Chaffe 2018).

Table 7: Tobit regression results on factors affecting technical efficiency.

LR chi2(12) = 155.89				
Prob > chi2 = 0.0000				
Pseudo R2 = 0.0146				
Variable	Coef.	Std. Err.	t	P>t
Area size	4286594***	652852.5	6.57	0.000
Diversity crops	-1281899	813524.8	-1.58	0.116
Diversity animals	2059025**	879567.1	2.34	0.02
Diversity Activities-products	591166	784625.9	0.75	0.452
Synergies Crop-livestock-integration	460847.5	815492.9	0.57	0.572
Synergies Soil- plants-system	873695.5	781704	1.12	0.265
Synergies Integration trees	1740295**	842326.3	2.07	0.04
Recycling biomass -nutrients	-762921	1120594	-0.68	0.497
Recycling Water-harvesting/saving	1068036**	516984.7	2.07	0.04
Recycling Management -seeds-breeds	-1953.861	1108954	0	0.999
Resilience Stability-income/capacity	2630955***	589190.1	4.47	0.000
Resilience Environmental/capacity	-222442	936260.9	-0.24	0.812
Constant	-8479620***	2477173	-3.42	0.001
Sigma	6716146	270535.1		
Log likelihood	-5278.8008			
Prob > chi2 =	0.0000			

*** Significance at 1%, **Significance at 5%,

Conclusion

The results of this study showed that organic farmers are inefficient with a mean technical efficiency of 0.5160. There is high variation of technical efficiency between organic farming in Central Uganda. The maximum likelihood estimates indicated that diversity, synergies, recycling, and resilience make significant contribution in improving organic farming output. The findings revealed the animal's diversity, the tree integration (agroforestry, silvopastoralism, agrosilvopastoralism), the rainwater harvesting and saving the stability of income/production and capacity to recover from perturbations were positive and significant in contributing to organic farming technical efficiency. The research on organic production efficiency through agroecological approaches revealed resource efficiency at improving the use of natural resources in the value-chain of organic production by focusing on diversity, synergies, recycling, and resilience. This is consistent with the improvements in agricultural production towards a green economy. However, for each country, the transition to a green economy should be based on a country-specific model like improving organic production efficiency through agroecological approaches, which is green growth that should be monitored to assess policy effectiveness and development progress.

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Discipline and discourse Eeffect of urban expansion on natural vegetation in ITU local government area of AKWA Ibom state

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Abstract

This work examines the effect of urban expansion on natural vegetation in Itu LGA of Akwa Ibom State, Nigeria. Specifically, the study assessed the land use cover of the study area between 1986 and 2021; assessed the causes and effects of urban expansion in the study area. Four objectives, four research questions and two hypotheses were formulated to guide the study. The first two objectives were analyzed using remote sensing data through Geographic Information System (GIS); The supervised image classification method using Erdas Imagine 9.2 was adopted in analyzing the satellite imageries which revealed the status and changes of urban expansion in the study area, while Survey design method was adopted for the last two objectives which comprised information on causes and effects of urban expansion on natural vegetation, information were presented using tables and analysed using Chi-square statistical technique. The population of the study comprised of 75 villages which are within the spatial coverage of Itu LGA extracted from the settlement map of the state. The sample size of 381 was determined using Krejcie and Margan formula. However, 381 copies of questionnaire were distributed systematically and successfully retrieved in good condition in the eight selected villages. It was found out from the study that urban land use cover type (built-up) had rapidly overtaken other land use cover especially in the western part of the study area. The findings in the study also indicated that urban expansion have impacted negatively on natural vegetation which causes vegetation loss as a result of the spatial spread of built up over vegetation and the identified major causes really propelled the observed changes which poses negative effect in the study area. Based on the findings, there is need for discouragement of deforestation through the use of suitable legislatures, there should be awareness campaign by government agencies on the negative effect of deforestation in the area, and the rate of population growth should be controlled through the use of rules and regulations to control immigration of people into the study area.

Introduction

1.1 Background to the Study

Globally, urban centres have always continued to experience unprecedented population growth due to the fact that they have always been seen as the engines of economic growth (Tom, 2016). The concentration of economic activities and expansion of industries also results in increase in the job potentials and trade prospects in large cities (Dierig, 1999). For these reasons, it is attracting people from rural areas and small towns, as well as migrants from other countries. This increase in the proportion of people living in the urban areas, activities, properties, and infrastructure and community services in the area is termed urbanisation (Dierig, 1999).

We are living in an increasingly urbanised world. At the turn of the twenty-first century, about half of the world's population (roughly three billion people) lived in urban areas (World Bank, 2000). In the early 1950s, about 66 percent of the entire world's population lived in the countryside (World Bank, 2000). But, today the cities are residence to half of the world's population, and in 2030, about 60% of the population will live in cities (United Nations Population Funds Activities, 2004).

As population increases in urban centres, there is also a corresponding need for expansion in human settlements to accommodate the ever increasing urban population. This growth of urban settlements (urban expansion) has been described by Ifatimehin, Musa and Adeyemi (2009) as one of the most remarkable developments in human settlements in the world. A process that always initiates the continual transformation of land from one use to the other. It represents the most profound human alteration of the natural environment through a spectrum of urban land use activities (Ifatimehin and Ufuah, 2006), which includes but are not restricted to transportation, commercial, industrial, residential, institutional and recreational land uses (Odama, 2013). The expansion that happens as a result of increase in the demand for these land uses explains the underlying and fundamental cause of urban expansion which is population increase.

Urbanisation is an unavoidable process in the world. Pathan (1991) and Kumar (2007) described urbanisation as leading to the irretrievable loss of productive agricultural lands, forests, surface water bodies and groundwater prospects. According to the United Nations (UN), more than 90% of urbanisation is taking place in the developing world (UN-Habitat, 2010). The urban populations in the developing countries will reach 2 billion in the next 20 years, increasing at about 70 million per year, which is more than one million

per week. The populations in the urban areas of Africa and Asia will be double at that time (United Nation Report, 2007). By 2030, 80% of the total world's urban population will be living in developing countries (UN-Habitat, 2010).

While the urban centres are growing in population and extent, the peri-urban areas are undergoing a two-fold transformation: with arable land coming under increasingly intense cultivation; and both arable and non-arable land being increasingly built up to provide space for commercial, industrial and residential establishments (Ifatimehin and Ufuah, 2006). The expansion takes place either in radial direction around a core or linearly along the highways.

The concept of urban expansion has been described by different scholars using major themes such as economic expansion (Anas and Rhee, 2006), geographical expansion (Pirotte and Madre, 2011) and transportation expansion (Madre, Berri and Papon, 2002, Nechyba and Walsh, 2004). Other writers have interpreted urban expansion as resulting from increasing urban densities, land use and racial segregation (Powell, 2000, Glaeser and Kahn, 2004) as well as population growth beyond the urban fringes. Urban expansion is commonly used to describe physically expanding urban areas consisting largely of a pattern of high density expansion of large urban areas into mostly surrounding agricultural areas.

Since the creation of Akwa Ibom State in 1987, urban centres have grown in number and size. Itu Local Government Area, being one of the 31 Local Government Area in the State since the creation of the state, in a bid to accommodate the high influx of people and satisfy their infrastructural needs has experienced urban expansion to surrounding suburbs and have led to widespread changes in land use and land cover" (Ekpenyong, 2008). This has given rise to the depletion of the natural vegetation. As the urban centre grows, continuous destruction of the natural vegetation has resulted, and this trend has continued for some years now.

In the past, effective monitoring of urban expansion hit serious difficulties due to non- access to adequate information and appropriate technology (Ituen, 2007). But in recent times, the integration of Remote Sensing (RS) and Geographic Information System (GIS) has been widely applied and recognised as a powerful and effective tool in detecting the trends in urban expansion. Hence, in order to effectively monitor urban growth, it is not only necessary to have the information on existing Land Use Change (LUC) but also the capability to monitor the dynamics of land use resulting from both changing demands of increasing population and forces of nature acting to shape the landscape (Ituen,2007).

Consequently, this research utilised a combination of remote sensing data and field survey in a Geographic Information System (GIS) environment to assess urban expansion and its consequences on natural vegetation in Itu Local

Government Area of Akwa Ibom State between 1986 and 2018. This is necessary to ensure sustainable use of the environment of the study area.

1.2 Statement of the Research Problem

Although urbanisation has traditionally been associated with a higher quality of life for urban dwellers as opposed to rural dwellers, a number of problems plague the environment, for instance, the alteration of land due to the removal of vegetation cover is a noticeable sign in the process of urbanisation in most Nigerian cities. In Itu Local Government Area, Akwa Ibom State situated in the tropical rainforest belt was once green with variety of tropical trees; today most of those species cannot be seen anymore (Ekpenyong, 2008). Few of these trees found in the suburbs are either planted in homestead gardens or in abandoned farmlands. This shows that Itu Local Government Area landscape has been badly de-vegetated due to wide spread changes in land use. In specific terms, the increasing building structures in Itu Local Government Area have serious implications on human environment, this unprecedented expansion has resulted in altering the vegetation cover and thus reducing the spatial extent in agricultural land in this study area, thereby threatening means of livelihood and food security.

Suffice it to say that more of Itu Local Government Area are converted to urban development especially the area closer to Uyo urban while the remaining lands are worked more intensively to cater for the food needs of the growing population as a result of loss of farm lands in the nearby cities like Uyo and Uruan in Akwa Ibom State, Arochukwu in Abia State. This has given rise to problems like golly erosion, biodiversity loss, climate change, etc., if the trend and projection of further encroachment in the near future are not visualized for proper policy making, the situation may become intractable.

1.3 Research Questions

It is against this background that the following questions formed the basis for this study:

- i. What were the statuses of land use and land cover in period 1986 and 2018?
- ii. What are the trends and rate of urban expansion over time in the study area?
- iii. What factors are responsible for urban expansion in the study area?
- iv. What are the effects of urban expansion on natural vegetation in the study area?

1.4 Aim and Objectives of the Study

The aim of this study is to assess the effect of urban expansion on natural vegetation between 1986 and 2018, in the study area.

The specific objectives of the study include to:

- i. identify the status of land use /land cover in the study area between 1986 and 2021,
- ii. assess changes in urban land cover and vegetation cover in the area,
- iii. identify the factors responsible for urban expansion in the study area, and
- iv. Examine the effects of urban expansion on natural vegetation in the study area.

1.5 Research Hypothesis

The Null hypothesis used in this study is stated as follows:

1. There is no significant change in land cover between 1986 and 2021 in Itu LGA.
2. There is no significant effect of urban expansion on natural vegetation in Itu LGA.

1.6 Significance of the Study

A major challenge in the 21st century is how to ensure adequate housing for a growing population without jeopardizing the aspects of environmental sustainability including the loss of vegetation in a habitable urban environment. Urban expansion is seen as one of the potential threats for such development. Hence study of this kind revealed the trends and extent of urban expansion taking place in the study area and the factors responsible for the growth as well as its consequences. Just as stated by Sudhira, Ramachandran and Jagadish (2004) that, understanding the patterns of urban expansion can help in natural resource planning, natural resource utilization and the provision of infrastructural facilities.

The study of this kind revealed the trends and extent of urban expansion taking place in the study area and the factors responsible for the growth as well as its consequences. Just as stated by Sudhira, Ramachandra and Jagadish (2004) that, understanding the patterns of urban expansion can help in natural resource planning, natural resource utilization and the provision of infrastructural facilities. This study will not just contribute to the body of knowledge but also help developers, environmental managers and town planners to project growth pattern and facilitate various infrastructural developments with a view to managing the growth of settlements. It is expected that, if implemented, it would checkmate unnecessary land uses and ensure continuous management of the complementary roles of urban expansion on natural vegetation in this era of food security and sustainable development.

1.7 Scope and Limitation of the Study

The study focuses basically on analysing the effect of urban expansion on natural vegetation in Itu Local Government Area. The Local Government Area has been developing at a varying unplanned pace in different directions. This uncontrolled development of the study area has intensified the transformation

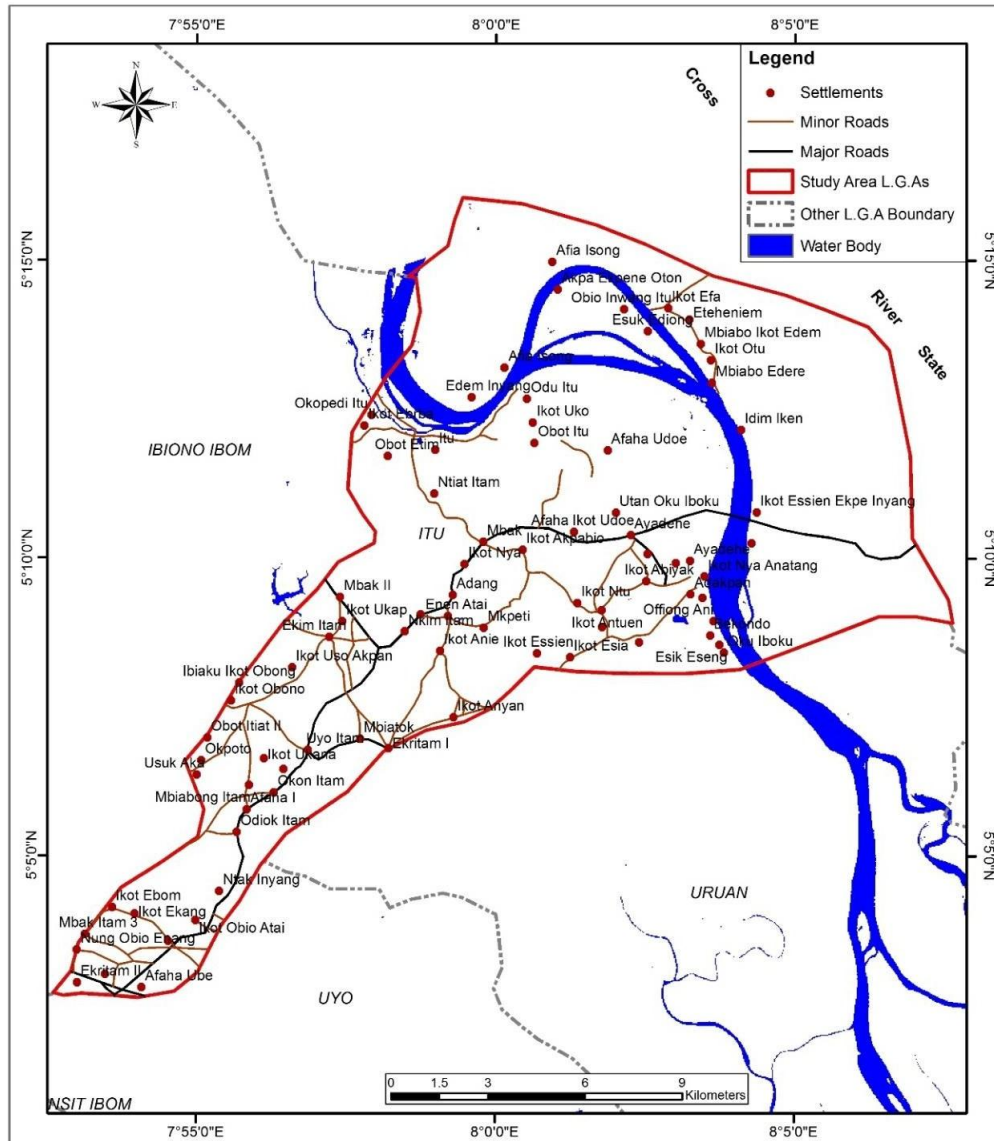
of natural vegetation to urban land use in all directions. The study will therefore access the trends, rates, magnitude and direction of changes that have taken places between 1986 and 2018. This will help to determine the effect of urban expansion on natural vegetation in the study area. The assessment of the factors responsible and the effect of urban expansion on natural vegetation in the study area will be based on questionnaire survey.

1.8 The study Area

1.8.1 Geographic Location

Itu is located in the south east of Nigeria and is a Local Government Area in Akwa Ibom State. The Local Government Area occupies a landmass of approximately 606.70 square kilometres. It is bounded in the North-East by Odukpani in Cross River State and Arochukwu in Abia State, in the West by Ibiono Ibom and Ikono Local Government Local Government Areas, in the South and South East by Uyo and Uruan Local Government Areas, respectively (Usoro, 2010).

The local government area is located between latitude 5° 3' and 5° 16'N and longitude 7° 52' to 8° 9'E.



1.8.2 Topography

The study area is situated in the coastal area of Akwa Ibom State with its physical landscape of generalizing dissected terrain, which is undulating to the erosion and depositional rivers and streams in the area. The floodplain covers one fifth of Itu, flooded by Rive Cross and Enyong Creek yearly. The area ranges from zero to 50metres in height with relatively uniform slopes. Itu River which is a major tributary of the River Cross and is the major drainage system in the study area. Other drainage systems include Enyong Creek, Ikpa River, Ikot Offoing River, and Ntak Inyng River (Inyang, 2000).

1.8.3 Climate and Vegetation

Itu Local Government Area falls within the sub-equatorial climate belt. Just as other regions in the West Africa, the area has two minor climatic seasons which are dry and wet seasons and two major climatic seasons which are Harmattan and August break. The rainy season usually begins in March and last still November. The mean annual rainfall of about 2550mm is usually recorded in the area. The dry season begins in November and ends in March (Inyang, 2000). An average temperature in the area is 27°C, and the relative humidity average is about 89%.

The vegetation which is the tropical rain forest type is almost completely deforested by human activities mainly construction and farming (Akpan, 2010).

1.8.3 Population and Settlement

Itu local government area is made up of about 79 villages and 5 clans. Its town which is the economic hub of the area is located 80 km away from the Bight of Bonny. The population census 2006 recorded that Itu has a total population of about 127,856. The settlement pattern of the area is mainly a linear type of settlement where houses are built along the major and minor roads and also along the course of river banks. The people are predominantly speaking Ibibio although some parts are Efik speaking communities due to their proximity to Cross River State (Apkan, 2010).

1.8.4 Tourism

Tourism attraction abound in the study area, e.g. beaches, navigable water system, and beautiful topography of the area.

1.8.5 Natural Resources

The area is rich in both natural and mineral resources such as crude oil, fine sand, limestone, salt, gravel and clay. Forest resources consist of timber, wild life, palm trees, gmelina plantations and firewood. Marine resources include fish, crayfish, oysters, lobster, shrimps shells, periwinkle among others.

1.8.6 Socio- Economic Activities

The primary socio-economic activities in Itu local government is farming, fishing, lumbering and trading. A smaller percentage of people are civil servants, while others work in industrial firms. Itu local government area is blessed with enormous potentials for development. The people are farmers, fishermen and traders. Petroleum resources, salt, limestone, clay, oil palm, coconut, raffia palm, iroko (mahogany) trees and other forest resources are some of the natural wealth that abound in the local government area. The waters are endowed with a wide variety of fishes, shrimps, crabs, and other sea foods, which are available in commercial quantities. (John, 2005).

Review of Related Literature and Conceptual Framework

2.1 Review of Related Literature

Related literature to the study was reviewed in line with the stated objectives. This covers the status of land use, land cover and change detection, the trend and rate of urban expansion, assessment of Urban Expansion using Remote Sensing and GIS, causes of urban expansion and effects of urban expansion on natural vegetation.

2.1.1 Status of Land Use, Land Cover and Change Detection

Franke-Scharf (2000) structured and integrated already available land use/land cover maps and remote sensing data into the regional geographic information system FirGIS and used as main source of evaluations. The image data provides the only extensively available multi- temporal up-to-date information of the research area. The analysis of the different remote sensing data was carried out by methods of digital image interpretation, on the one hand by visual interpretation and on the other hand - to a larger portion - by automatic digital procedures. The classification of all data was carried out using a common multi-level classification scheme, which was specifically adapted to the conditions in the Chad Basin and the results derived from the remote sensing data were subdivided into four dimensions of time. An important result of the work was the integration of all used data and information on land use and land cover in the Chad Basin including its neighbouring areas within the regional geographic information system FirGIS. He therefore suggested a future continuation by using thematic, spatial or temporal updated information in monitoring land use land cover. In addition, the geographic information system FirGIS offers the possibility to make already obtained data as well as information gathered in future available for all interested parties especially in the research area itself.

Closely related to Franke-Scharf was Mahiny and Turner (2003) in modelling past changes in remnant vegetation patches using remotely-sensed Multi Spectral Scanner (MSS) and Thematic Mapper (TM) imagery with GIS in the catchment of the Boorowa River in New South Wales, Australia. The images covering 27 years from 1973 to 2000 were used in detecting change in vegetation through post-classification comparison and modelling it through neural networks and logistic regression methods. Physical factors, image-based layers and landscape metrics provided the 19 predictor variables used in the modelling. Relative operating characteristic (ROC), and a modified version of multi-resolution goodness of fit (MGF) tests together with visual comparison were used to assess success of the modelling approaches. Also, the relative effect of the 19 predictor variables were evaluated through ROC and MGF methods using 19 reduced-variable models and the full model.

In addition, Ituen, Whyatt, Blackburn, and Inyang (2007) in attempting to assess the link between LULC change and agriculture over a 17 year period of 1986 and 2003 in northern Akwa Ibom State (7 LGAs), a large rural area dominated by multi-cropping as a dominant pattern of cultivation. They subjected Landsat Thematic Mapper (TM) and Enhance Thematic Mapper (ETM) satellite images of 1986 and 2003 respectively to classification, general change detection and point specific (point by point) change analysis in GIS environment. The result of the analysis indicated that 47% of the land was converted to alternative uses. The information on the 409 households surveyed confirms this conversion and useful recommendation on the establishment of agro-based small-scale industries to provide alternative means of livelihood, participatory agricultural programmes and improvement in the infrastructure base as strategies for the sustainable use and strategic targeting of land resources were made.

In a slight deviation from the above review, Braimoh and Vlek (2004), in quantifying land-cover changes, generated a short-term projection of land-cover distribution in a 2400-ha area of northern Ghana. Landsat Thematic Mapper images of 1984, 1992, and 1999 were used for land-cover mapping, whereas land-cover projections were carried out using transition probability techniques. The analyses showed that in the first period (1984–1992), the dominant land-cover change process was the expansion of the built-up area by 26 hectares per year as a result of an increase in demand for housing by the increasing population. Expansion of the built-up area continued at the rate of 35 hectares per year in the second period (1992–1999), as well as development of peri-urban agriculture by 24 hectares per year to meet the food demand of the rapidly growing population. Projection of land-cover distribution showed that the built-up area would further increase at the expense of cropland and natural vegetation, covering about 39% of the landscape by 2006.

Zubair (2006) in mapping Land Use Land Cover in Ilorin between 1972 and 2001 to detect the changes that took place between these periods used GIS and Remote Sensing. Subsequently, observed land cover changes were projected using markov chain and cellular automata analysis function in Idrisi software. Land Consumption Rate and Land Absorption Coefficient were introduced to aid the quantitative assessment of the change. The result of the work indicated a rapid growth in built-up land between 1972 and 1986 while the periods between 1986 and 2001 witnessed a reduction in this class. It was also observed that change by 2015 may likely follow the trend in 1986/2001.

Fan and Wang (2006) stated that land use/land cover (LULC) has a profound impact on economy, society and environment, especially in rapidly developing areas. Rapid and prompt monitoring and predicting of LULC's change were crucial and significant. Currently, integration of Geographical Information System (GIS) and Remote Sensing (RS) methods is one of the most important methods for detecting LULC's change, which includes image

processing (such as geometrical rectification, supervised-classification and change detection) were adopted in studying the core corridor of Pearl River Delta (PRD).

The temporal and spatial LULC's changes from 1998 to 2003 were detected by Remote Sensing (RS) data. At the same time, urban expansion levels in the next 5 and 10 years were predicted temporally and spatially by using Markov chain and a simple Cellular Automata model respectively. The result indicated thus: (1) the rate of urban expansion was up to 8.91% during 1998–2003 from 169,078.32 to 184,146.48 ha; (2) the rate of farmland loss was 5.94% from 312,069.06 to 293,539.95 ha; (3) a lot of farmlands were converted to urban or development area, and more forest and grass fields converted to farmlands accordingly; (4) the spatial predicting result of urban expansion showed that urban area was enlarged compared with the previous results, and the directions of expansion is along the existing urban area and transportation lines.

Similarly, Martin (2007) stated that land cover and land use information can be monitored and evaluated against changes in socio-economic, climatologically and other geographical data. This provides a means of identifying and managing any causes of change. One of such approach is to designate protected areas which aim to guard against perceived negative changes and to maintain biodiversity, natural and cultural resources and heritage features. He proposed two objectives, first to detect land cover changes over a 30-year period in Nini-Suhien National Park in Ghana and secondly to identify and model the causes of these changes.

Land Cover Change Graphic User Interface (LCC_GUI) and ArcGIS 9.1 software were used in processing Landsat and ASTER satellite data (30-80m and 15-30m spatial resolution respectively) to visually identify and classify land cover for a sample of the study area over a four year period. Statistical analysis using Pearson's chi-square test and Cramer's V calculations were carried out in order to detect the association of land cover changes with a set of potential causal factors, e.g. population change, proximity to roads and rainfall patterns. Result indicated that major change was from forest to agriculture. Also, forested areas was decreasing at a fast rate (40% less in 2002 than in 1986), with some early signs of decline even within the protected area. The changes were related to population growth, timber exploitation and agricultural activity. The work concluded by assessing the impact of protected area status on prevailing land use/land cover change and recommended an accurate statistical analysis of the data and the development of a predictive model.

In another development, Donohue (2008) upholds that documenting changes in land cover requires that images be classified over time, often using historical images to document landscape change. But, noted the difficulty in doing that for historical images because of not being able to ground-truth old images and lack of actual land cover data from the past. A land cover

classification scheme was developed then used with Classification and Regression Trees (CART) model generated from 2001 National Land Cover Dataset (NLCD), and summer, fall, and winter triplets of Landsat 5 Thematic Mapper (TM) imagery to predict land cover from 1985 to 2005 for Piedmont of North Carolina. Temporal and spatial analyses focused on ecosystem services of carbon sequestration and biodiversity support as affected by forest fragmentation.

The study offered a landscape-level identification of the relationships between spatial and temporal development patterns and the provision of ecosystem services. Also, the study represents the creation of a multi-annual land cover classification dataset of which few exist, thus providing a framework for further studies of landscape pattern and ecological processes.

Although this present research has some similarities with earlier works, it differs in terms of the study area, data, software and focus of the study. The data were from both primary (questionnaire) and secondary (Landsat satellite imagery for 1986 and 2018) and the analysis focused specifically on detecting the effect urban expansion on natural vegetation.

2.1.2 The Trends and Rate of Urban Expansion

The increasing urban expansion in most cities in developing countries continues to attract attention of national and international agencies but efforts had not achieved much result at checking the rate of expansion. For most developing countries, the governance and management of their towns and cities are most daunting as the cities appear to be growing beyond the control of planners, beyond management capabilities and beyond available resources (Agbola and Olurin 1998). Since man's quest for change will continue within his dynamic environment, this points to the fact that urbanisation becomes an inevitable phenomenon particularly in developing countries such as Nigeria. Federal Capital Territory Abuja is a glaring example as a result of the fast rate of urbanization and which annual rate of urban growth was 10.6km in a 19-year period (1987-2006) as revealed by Landsat ETM and Nigeria Sat - 1 Satellite data for 1987, 2001 and 2006 (Ujoh, Kwabe, and Ifatimehin, 2009). Unfortunately, there are no Nigerian cities that can be exonerated from the stigmatization of urban expansion. This is a particular concern to leaders and urban managers in Nigeria. Adeyemo (2004) noted that, the astronomical growth of urban centres in the third world countries brings about rapid rate of rural-urban migration, urban poverty, environmental deterioration and decreasing standard of living of urban dwellers thereby engendering urban planning.

According to the thematic committee (2001), in 1950, less than 15% of the total population of Nigeria was dwelling in urban centres; by 1995 and 2000, it had risen to 23.4% and 43.5% respectively and was projected to rise above 50%

by 2010. Today, rapid urbanization in Nigeria has affected 400,000 hectares of vegetation annually (Adesina, 2005). Furthermore, Heimlich and Anderson (2001) believed that while urban centres are growing in population, the peri-urban areas are undergoing rapid transformation; with land coming under increasingly intense pressure through construction to provide space for an array of urban land uses. For instance in Abuja, a study conducted by Ujoh, et al. (2009) revealed that as at 1987, bare surface and cultivated land constituted the largest land use categories in FCC (Federal Capital City) collectively occupying an area of 648.88km² representing 77.83% of the total land cover of the area, with built-up area being the least land cover type (33.60 km²) found occurring in the Federal Capital City. Similarly, statistics for the year 2001 indicated that there was a significant gain in built-up area as it was increased from 33.6km² in 1987 to 154.4km² in 2001. All other land cover types except vegetation experience significant loss between 1987 and 2001. Within this period also, built-up area was the land- cover category that had the highest rate of expansion from 154. 9km² in 2001 to 235.04km² in 2006.

Consequently, the annual rate of change gained in built-up area between 1987 and 2001 was 14.39 km², while the total built-up area gained within the same period (14 years) was 201.4km². All these are indications of the rate of urban growth resulting from the expansion in built-up area which includes residential and official buildings, shopping malls plazas, infrastructures and facilities such as schools, hospitals, recreational parks and gardens, roads and other paved surfaces. According to Ujoh, et al. (2009) FCT has expanded from a city with a few developed districts such as Garki, Wuse, Asokoro and Maitama districts to include such districts as Utako, Jabi, Guzape, Mabushi, Gwarimpa, Asokoro extension, Gishiri, Katampe, Gudu and Apo districts. This expansion has occurred over a period of less than 20 years (1991 to 2006). The period of this expansion was when the Federal Government issued a directive requesting all government ministries and extra-ministerial bodies, departments and parastatals to move their head office from Lagos to Abuja, the new FCT. With this directive came a great influx of population into the FCT which consequently, reflected in the need for growth and expansion on the infrastructure and facilities of the Federal Capital City to cater for the increasing population.

Similarly, Essien and Akpan (2013) asserted that, the rate of urban development is seen penetrating rural-urban fringe with 90% of rural land engulfed by urban development and only 10% remaining as undeveloped (Village) land, the rate of urban growth is significant. They gathered data on previous land use survey in 1998 and were compared with data on land use in 2009 to observe 10-year difference in land use in the rural-urban fringe. The 10 – year land use ratio was the ratio of land use in rural-urban fringe in 2009 to the land- use in 1998.

The leap-frogging in 10 -year (1986 -2018) urban development land uses in rural-urban fringe in Itu LGA is a realism of the fact that the characteristic change in the fringe is significant from one decade to another or one development influence to another; and its characteristic change over time from largely rural to largely urban but uncoordinated spread of development.

Ewing (1997) argued that suburbanization is not the issue but the wasteful form of development that characterized the environment. Therefore, urban expansion creates an effects on natural vegetation and inefficient use of land since it is easier for development to spread uncontrollably as in the case of the adjoining Local Government Area of Itu.

2.1.3 Assessment of Urban Expansion using Remote Sensing and GIS

The complexity of urban systems makes it difficult to adequately address their changes using a model based on a single approach (Allen and Lu, 2003). Therefore, it is ideal to use a tool such as a Geographic Information System (GIS) as part of research on urban expansion because of its capacity to reveal the trend and rate of expansion, as well as handle many different types of spatial data.

A study conducted on the Washington-Baltimore Consolidated Metropolitan Statistical Area (CMSA) used a cellular automata model combined with historical maps in a GIS to determine where future development may occur (Clarke and Gaydos, 1998). The cellular automata model assumes an action within a given space, viewed in this case through a GIS grid, a set of initial conditions, and a set of behaviour rules (Clarke and Gaydos, 1998). GIS grid data layers were incorporated into IDRISI, GIS software, and iterations were performed to show different growth scenarios given different behaviour rules (Clarke and Gaydos, 1998). The same study was also able to use the GIS to produce maps of different growth scenarios, which allowed visualization of the results. A GIS will not only allow for powerful visualization of urban sprawl within the study area by providing maps, but it will also allow for an in depth analysis of the data by providing the capability to examine all of the data in one system therefore facilitating the measurement of urban expansion.

A GIS is also an extremely powerful tool for creating new data from existing data and is often referred to as a decision support system (Burrough and McDonnell, 1998). In China, A GIS was used as a decision support system to test different development scenarios and land consumption parameters for use by planners and local government officials (Yeh and Xia, 1998). Using the neighbourhood function in the GIS, the researchers were able to test development scenarios that would reduce the fragmentation of new growth, a component of urban expansion. In another study by the same authors, it was concluded that Landsat TM images coupled with an entropy integrated GIS was successful in measuring and monitoring urban expansion patterns when

the area is large and land use changes quickly (Yeh and Xia, 2001). In 1998, they employed a Shannon's entropy technique with the integration of remote sensing and GIS. Shannon's entropy is another landscape metric calculation technique whereby the authors measured urban expansion patterns statistically based on the spatial variation and temporal changes of growth areas (Yeh and Xia, 1998). A numeric value was given to the new growth areas to quantitatively describe how dense and connected growth areas were (Yeh and Xia, 1998).

The methods used to quantify urban expansion throughout the literature are dependent on the intended purpose and the individual aim of each piece of research. The objective of the research conducted on the Washington-Baltimore Consolidated Metropolitan Statistical Area (CMSA) was to relate observed changes in land cover to economic and demographic drivers of that change (Masek, Lindsay, and Goward, 2000). They used historic and present-day satellite imagery to measure land use change, but it was unclear how the researchers were going to link those changes to economic and demographic data. The purpose of the study was to quantify and map urban growth thereby determining the geographic extent, pattern, and class of such growth over time. The researchers categorized satellite-derived imagery into three classes: developed, non-developed, and water. Then, a window technique was used within a GIS to analyse each picture element (pixel) according to its neighbouring pixels. The value of each pixel was added up and attributed to the centre cell of the window each time it passed over the study area. This is an extremely effective method to measuring urban growth patterns over time and therefore classifies that growth as urban expansion.

In East and West St. Paul, Winnipeg, Manitoba, Canada, most urban expansion were occurring on prime agricultural land (Hathout, 2002). In that study, a GIS was used to predict future growth patterns and the impacts that such growth would have on natural vegetation. Hathout (2002) used the data base analysis capabilities found in a GIS to analyze aerial photographs of the study area from 1960 to 1989 to determine impacts on natural vegetation. For that study, land use derived from the aerial photographs in the GIS was placed in one of three main categories: urban, agriculture, and others (Hathout, 2002).

In South Carolina, a GIS-based integrated approach to modelling and prediction of urban growth in terms of land use change was employed to meet the challenge of studying urban expansion (Allen and Lu, 2003). The researchers used satellite imagery incorporated into a GIS to map predictions of urban growth in the study area. The predictions were based on variables such as road density, forest, slope of the land, and population density. Each variable was entered into the system as a data layer and multiplied by a coefficient to determine how likely it was that a given parcel of land would be converted to urban land use (Allen and Lu, 2003).

In Nigeria, Zubair (2008) used GIS and Remote Sensing in monitoring settlement (built-up) growth in Ilorin between 1972 and 2001 so as to detect the changes that have taken place between these periods. His main aim was to document the growth of Ilorin Township as obtained from satellite data and GIS between 1972 and 2001 and also predict the pattern of growth in same over a given period. Landsat data for three epochs were used in the study. Supervised classification was carried out to identify five land use and land cover types with particular emphasis on settlement. Subsequently, an attempt was made at projecting the observed growth in the next 14 years. In achieving this, Land Consumption Rate and Land Absorption Coefficient were introduced to aid in the quantitative assessment of the change. The result of the work showed a rapid growth in built-up land between 1972 and 1986 while the periods between 1986 and 2001 witnessed a reduction in this growth. It was also observed that change by 2015 may likely follow the trend in 1986 to 2001.

Additionally, Vanum and Hadgu (2009) analysed the urban expansion dynamics in Greater Visakhapatnam for three temporal periods of 1975, 1990 and 2009 using GIS and Remote Sensing techniques in conjunction with Shannon's entropy. The expansion pattern was mapped and measured from various viewpoints to identify the specific local factors which control the growth pattern in the study area. The study pointed out that spatial growth of the city was restricted by physical barriers on the north, south and east. The city was growing along the southwest, northwest and northeast directions. The rate of land development was as high as 78% during a 35 year study period while the population growth rate was 26%. Thus the per capita land consumption had increased remarkably especially at the peripheral zones a strong indicator of expansion. The distribution of population density in various wards also justifies the above characteristics expansion – "dense core and dispersed suburbs". The higher entropy values at different points during the study period indicate high rate of expansion even in early seventies and sustained throughout. Therefore, the entropy approach proved to be efficient in measuring and monitoring the spatio-temporal patterns of urban phenomena.

According to Al-Dosary and Khan (2010) urban expansion has turn out to be an issue of worldwide interest, mainly because of its alleged negative impacts on the social, economic and environmental aspects of the city. Many studies indicate that it is the pattern, density, and rate of new urban growth that lead to expansion. The proportion of the total population in a region to the total built-up area of the region is a measure of quantifying expansion. This paper presented a quantitative method to analyse urban expansion based on computation of indicators of GIS techniques. It was found out that for the study area, the percentage change in the built-up area between 1980 and 2005 was 14 times higher than the percentage change in the population growth, and also, the analytical capabilities in GIS software determined the patterns and densities of new growth thereby classifying some of those areas as expansion patterns.

2.1.4 Causes of Urban Expansion

Doygun, (2009) analysed spatial changes by interpreting the digitized data derived from a black-white monoscopic aerial photograph taken in 1985, panchromatic IKONOS image of 2000 and two pan-sharpened Quick bird images of 2004 and 2006. The analysis revealed that the area of olive groves decreased by 25% from 460.55 ha in 1985 to 344.46 in 2006, while the number of parcels increased from 170 to 445. Of the total areal loss, 60% was due to building constructions, with the rest being due to clear-cut for new residential gardens composed of exotic plants, new buildings, or new roads. It was found out that rapid population growth; increased land prices due to urban expansion, and abandonment of agricultural practices to construction of multi-storey buildings were the main causes of the process that transformed the olive groves into urbanised areas. Results pointed to an urgent need to (1) revise the national and municipal land management practices, (2) balance the gap between the short- and long-term economic benefits that urban and community development plans ignore, and (3) monitor land-use changes periodically by using high resolution satellite images.

Different factors are responsible for urban expansion especially in Nigerian cities. The unprecedented increase in population in the Nigerian cities continues to put pressure on the existing housing facility. The inability of the housing delivery to cope effectively with the housing need has succeeded in pricing out majority of the low income earners from the housing market. Most affected groups are the immigrants from the rural hinterland that prefer to settle at the suburbs of the cities. Often times, this is responsible for the development of squatter's settlement at the peri-urban zones (Olujimi and Gbadamosi, 2007). Cities present unlimited socio-economic opportunities, particularly in area of landed property development. The operations of the economic forces in the supply of land for commercial development within the city centre are encouraging the acquisition of land at the suburb of the city for residential property development. This has sufficiently propelled the greed for land speculation and hoarding at the suburbs. Unfortunately, most of the isolated parcels of land hoarded at the suburb are not subjected to conventional design into layouts that could seek planning approval. Even when such parcels of land are designed into layouts, most of them are not properly charted to allow for coordination. Hence, most of the layouts are not linked to others for accessibility purposes. Another factor that is responsible for the promotion of urban expansion is the inability of government to effectively develop their compulsorily acquired parcels of land in some cities. This is predicated on the non-readiness of government to pay compensations on un-exhausted resources in the acquired land fully to the owner. Thus, the unwillingness of the owner to release full the acquired land to government and their continuous disposal of the land to individuals, that continues to develop the land without reference to the planning authorities to seek planning permission. However, the planning

authorities put in place are expected to control physical development in all parts of the city including the expanding areas but the ineffectiveness of the development control tool at putting such expansion at bay is hindered by a lot of factors. These among other include lack of political will to implement development control measures, insufficient planning staff to carryout effective monitoring, and lack of equipment such as development control monitoring vehicles.

Economic Growth: Bhatta (2009) stressed that expansion of economic base (such as higher per capital income, increase in number of working persons) creates demands for new housing or more housing space for individuals in urban centre. This also encourages many developed countries to rapidly construct new houses in urban centres as population continues to increase. According to Bhatta (2009) rapid development of housing and other urban infrastructure often produces a variety of discontinuous uncorrelated developments. Establishment of new industries in country side increases impervious surfaces rapidly. The transition process from agricultural to industrial employment demand more urban housing.

Physical Constraint: Sometimes, expansion is caused because of unsuitable physical constraint (such as rugged terrain, wet lands, mineral lands, and ravine or water bodies) for continuous development. According to Barnes, Hayes, and Roche (2001) this often creates leap frog development. Important to mention that, in many instances these problems cannot be overcome and therefore should be overlooked. Uyanga and Ekop (2014) noted that location has affected peri-urbanization in Itu in terms of physical accessibility as this is particularly obvious along Uyo and Odukpani zones.

Lack of Affordable Housing: Lack of affordable housing is similar to living and property cost. Wilson (2015) noted that affordable housing is a term used to describe dwelling unit whose total housing cost one deemed “affordable” to those that have a median household income. A common measure of community wide affordability is the number of homes that a household with a certain percentage of median income can afford. Wilson (2015) stressed that lack of affordable housing within the city forces people to set their residence in the suburb.

Desire for Home Ownership: Uyanga and Ekop (2014) noted that pressures for change at the peri-urban areas of Itu are necessitated by demand for accommodation which by itself may result from increasing population and desire for home ownership. In recent years, Uyanga and Ekop (2014) stated that, Itu peri-urban land is now in “acute” supply and subject to intense competition, conflicting demands and uses because people see land for housing as a commodity that every man desires to possess, not just for economic reasons but for socio-cultural reasons as well. Thus, many institutions and individuals desire for the ownership of land for housing.

2.1.5 Effects of Urban Expansion on natural Vegetation

In areas where expansion is not controlled, the concentration of human presence in residential and industrial setting may lead to an alteration of ecosystem patterns and processes (Grimm and Schade, 2000). Development associated with expansion not only decreases the amount of forest area or farmland, but also breaks up what is left into small chunks that disrupt ecosystem and fragment habitats. The reach of urban expansion into rural natural area such as wood land and wet land ranks as one of the primary forms of wildlife habitat loss. Roads, power lines, subdivisions and pipelines often cut across natural areas, thereby fragmenting wildlife habitat and altering wildlife movement patterns.

Urbanization generally, and expansion in particular, contributed to loss of vegetation cover and open spaces (Berry and Plant, 1978). The loss of agricultural land to urban expansion means not only the loss of fresh local food source but also the loss of habitat and species diversity, since vegetation includes plant and animal habitat in woodlots. The presence of vegetation on the rural landscape provides benefits such as green belt, rural economic stability and preservation of traditional rural lifestyle.

Shelby (2012) stated that urban expansion is threatening the limited highly fertile land in the Nile Delta of Egypt. Landsat TM satellite images of 1984 and 1992, and ETM+ of 2006 was used to study the impact of urban expansion on agricultural land in the Nile Delta. Visual interpretation using on-screen digitizing and change detection techniques were applied for monitoring the urban expansion. Combining the soil and land capability maps, in one hand, and the urban thematic layers, in another hand, using GIS, made it possible to point out the risk of urban expansion on the expense of the highly capability class. The results show that a total expansion of urban area amounted to 2,536.3 km² during the study period from 1984 to 2006. The urban expansion during the 1984 – 2006 was on the expense of the most fertile soils where, the high capable soils (Class I) lost 797.9 km² and the moderate capable soils lost 310.93 Km², while the low capable soils lost only 672.3 km² during the same period. The urban encroachment over the non-capable soils was very limited during the 1984 and 1992 period, where 25.83 Km² only was lost. The pattern of urban expansion was changed during the 1992 to 2006 period whereas much larger area (426.47Km²) of the non-capable soils was converted to urban. It was concluded that the urban expansion is one of the dominant degradation process in the Nile Delta.

Singh, Ajay, and Kumar (2014) in studying urbanization of Jaipur city and its impact on natural environment includes remotely sensed data collected from LANDSAT MSS for 1973, TM for 1998 and ETM+ for 2011 and other secondary data such as population data collected from census of India. Land

use/land cover maps were prepared by hybrid classification (visual interpretation and unsupervised classification) and the statistics calculated for different years with the help of ERDAS software. Land use data shows that built-up area increased at a very fast rate and reached 19,479.2 hectares in 2011 from 1,854.36 hectares in 1973. Population was also found to have increased with time and highest growth 65.59 % is found in 1941-51 and follow 62.77 % in 1991-2001. Other land use types such as crop land, waste land and scrub/grass land showed decreasing trend with time.

The study further concluded that the expansion of built-up area is at the cost of de- expansion of crop land, waste land and scrub land. This type of land use changing trend is alarming for natural environment. It was suggested from the study that urbanisation must be on waste land not on natural vegetation cover.

In summary, review of related literature showed that several monitoring and prediction of LULC's change has been carried out over the years. However, integration of Geographical Information System (GIS) and Remote Sensing (RS) methods such as image processing was not widely applied until recently. Most of the studies on the use of Geographical Information System (GIS) and Remote Sensing (RS) in land use/land cover (LULC) change analyses started in early 2000. In most cases, the temporal and spatial LULC's changes were considered by Remote Sensing (RS) data.

Urban expansion levels for the past 30 years have been studied temporally and spatially by several authors. Result obtained showed that rate of urban expansion has increased up to 8.91% in 2000, rate of farmland loss has increased by 5.94% implying that a lot of farmlands have been converted to urban or development area, and more forest and grass fields converted to farmlands accordingly. Previous studies have also showed spatial expansion in urban area compared with the previous results, and the directions of expansion however, are more in transportation lines. According to the review, changes in land cover were related to population growth, timber exploitation and agricultural activity. The impact of land use/land cover (LULC) is enormous ranging from economy, society and environment, especially in rapidly developing areas.

Considering urban expansion, the reviewed showed that the dominant land-cover change process was the expansion of the built-up area as a result of an increase in demand for housing by the increasing population. Also, the review showed that there are no Nigerian cities that can be exonerated from the stigmatization of urban expansion. This is a particular concern to leaders and urban managers in Nigeria.

2.2 Conceptual Framework

2.2.1 The Concept of Land Use Transition

The concept of land use transition is as old as the town itself. Many ancient and pre-colonial cities have undergone different stages of town growth in order to be compatible with the periods of man's development. Man in many ways altered the environment which resulted in having unique and different patterns of land use. Land use is the various ways into which land is put to use depending on human needs.

The term transition is defined by Martens and Rothmans (2002) as a process of societal change in which the structural characteristics of society is transform. Lambin, Geist, and Lepers (2003) remarked that transition results from a set of connected change, which reinforce each other but takes place in several different components of the system. Central to the concept of transition are multiple causality and co-evolution of different sectors of society resulting from the development interactions. (Martens and Rothmans, 2002).

The use of this concept in studying urban expansion spans both the spatial and temporal scales. Lambin, et al. (2003) have identified transition-like trajectories which suggested that over a decade or so, households undertake management of already cleared areas following a period of rapid deforestation, and even undertake afforestation within individual parcels. While Raskin, Banuri, Gallopin, Gutman, and Hammond (2002) noted that changes in land use/land cover are associated with other societal and biological changes through a series of transitions. Martens and Rothmas (2002) therefore suggested that transition be viewed as "possible development paths where the direction, size, and speed can be influenced through policy and specific circumstances".

In an attempt to capture analysis of urban expansion in Itu Local Government Area, Akwa Ibom State; the concept of transition seems plausible in offering explanation. In the study area, many factors may be combining in a complex adaptive loop to bring about the different phases in the transition process of land use and land cover of the area. In a place-based study such as this, the concept of transition could be captured more in its temporal implication over a defined area such as Itu Local Government Area.

Boserup (1965) grouped land use systems into different phases on the basis of increasing intensity as induced by population. This ranged from forest-fallow cultivation, bush-fallow cultivation, short-fallow cultivation, annual cropping to multi-cropping. He was therefore able to illustrate the transition from yearly clearing of virgin forest to multi-cropping. The proximate causes and underlying drivers of land use change here is interaction. Therefore, an area that originally belongs to the forest area has experienced tremendous transition owing to a combination of biophysical and socio-economic factors interacting at different levels over the years. In the face of such transition, the

suitability level of the area for current and potential use may be affected and as such needs careful assessment. From the above view it is now clear what method would best proffer solutions to the challenge of the research.

Therefore, from the understanding gained, that development of any sort should be done in a manner that the environment is still preserved to support the livelihoods of the future generations and that they should be a careful transition from one land use/land cover to another, the study of this kind shall necessitate the use of administrative map, satellite imagery for better options. In the case of analysing the trend in urban expansion, comparison and analysis of land cover classes assessment will be better since spatial extent of expansion shall be ascertained thus making it possible to provide the needed link with the household level decision-making critical to this work.

2.2.2 The Concept of Peri-Urban Area

As a specific and non-neutral space, a peri-urban area refers to a transition or interaction zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications, induced by human activities (Douglas, 2006). Peri-urban areas, which might include valuable protected areas, forested hills, preserved woodlands, prime agricultural lands and important wetlands, can provide essential life support services for urban residents. McGranahan, Satterthwaite, and Tacoli (2004) observed that peri-urban zones are often far more environmentally unstable than either urban or rural settings. From the ecosystem's point of view, physical, chemical and biological factors generally interact among themselves, and are integrated with socio-economic forces. These forces have their own functions, which can be enhanced or reduced depending on the conditions of other factors in the same system (Fang, Gertner, Sum, and Anderson, 2005).

A peri-urban area is not only a zone of direct impact experiencing the immediate impacts of land demands from urban growth and pollution, but is also a wider market-related zone of influence that is recognizable in terms of the handling of agricultural and natural resource products (Simon, McGregor, and Thompson, 2006). When urban centres grow disorderedly and expand to peri-urban areas, this process can be referred to as pre-urbanization. Pre-urbanization can be regarded both as a driver and an effecter of global environmental changes. Observing land use and land cover change over time can have perceived effects and impacts of urbanization on peri-urban areas.

Peri-urban areas experience significant physical and socio-economic changes as cities continue to expand. Notable among these changes is the transformation existing in land use land cover change. While urban centres are growing in population and in extent, the peri-urban areas are undergoing a two-fold-transformation; with arable land coming under increasingly intense cultivation and both arable and non-arable land being increasingly built over to

provide space for commercial, industrial, and residential establishments (Ifatimehin and Ufuah, 2006). Peri-urban arrangement is a process of transformation of a hitherto rural setting into a town or city by the provision of certain amenities that encourage people to live together to pursue their various goals. The most significant effect of peri-urban area is observed in a new land use pattern and the change in land cover, together with the concentration of population within a designated land area. For instance in Itu Local Government Area, the transformation that takes place, involves the destruction of existing plant cover to make room for buildings and other infrastructural provisions such as roads and schools. This action in Itu Local Government Area has led ultimately to the loss of natural vegetation due to the change in land use at the suburbs. The trade-offs of peri-urban area of Itu Local Government Area is easily felt in deforestation leading to loss of biodiversity

RESEARCH METHODOLOGY

3.1 Data set and sources

Data for this study were collected from both primary and secondary sources. The primary data comprised information on socio-economic and demographic data, land use/ land cover change (LUCC), causes and effect of urban expansion. The primary sources of data collection include structured questionnaire, oral interview, and personal observation. Secondary sources of data include satellite imagery between 1986 and 2018, and was obtained from Advance Space Centre at the University of Uyo Main Campus, Population Census report was obtained from National Population Commission, and map of Itu obtained from the Akwa Ibom State Ministry of Lands and Town Planning. Other sources of secondary data include published and unpublished materials such as journals and internet materials.

Data set were collected on the following:

1. Data on the trends and rate of urban expansion were obtained using remote sensing technique
2. Data on the causes of urban expansion: These basically were the factors encouraging the expansion of urban areas into natural vegetation of the study area. The data were obtained using questionnaire that was structured to collect information on various driving forces of urban expansion
3. Data on the effect of urban expansion on natural vegetation in the study area: These comprised information on the consequences/problems of urban expansion in the study area. They were obtained using questionnaire survey.
4. Other sources of data included political map of Akwa Ibom State and map of Itu L.G.A.

3.2 Method of Data Collection

This research adopted both primary and secondary sources of data collection.

- a) Primary Data: the primary data include;
 - i. Questionnaire: Questionnaires was distributed to the sampled respondents in order to obtain information
 - ii. Direct observations: information was obtained through direct observation of the study area
- b) Secondary data: Satellite imagery information on landuse /land cover changes between 1986 and 2018 was obtained using the imageries for the two time periods.

3.3 Population of the Study

The population of the study comprise of all settlements (villages) within the spatial coverage of Itu L.G.A. The number of settlement (villages) that make up the study area as extracted from the settlement map of the state were seventy-five (75) settlements.

From the study population, a systematic random sampling technique was adopted in selecting the settlements to be sampled. Eight (8) settlements out of 75 settlements representing 10.6% of the total settlements were considered. The settlements were selected at a regular interval of 9 after fixing the origin at settlement number 4. The settlements selected for sampling were: Afaha Ube, Ekit Itam 11, Idiok Afaha Itam, Ikot Ayan Itam, Ikot Esia, Ikot Obio Atai 11, Mbak Itam111, and Nung Ukot Itam comprising of a total population of 44,874 for year 2020 as projected from the 1991 Population Census.

The formula for population projections to 2020 is as followed:

$$P_t = \frac{P_o(1 + r)^n}{100}$$

Where:

P_o = base population (1991 population), n = number of years (29 years),

r = population growth rate (3.4% for Akwa Ibom State), P_t = current population to be determined, and

1 = constant.

For example, Afaha Ube:

$$= 1770(1 + 3.4/100)^{29}$$

$$= 1770 (1+ 0.034)^{29}$$

$$= 1770 (1.034)^{29}$$

$$=1770 (2.636)$$

$$= 1770 \times 2.636$$

$$= 4665$$

3.4 Sampling Size and Sampling Techniques

In this study, the Krejcie and Margan (1970) method of determining sample size for research activities was used.

These method is expressed as

$$S = \frac{X^2 NP (1-P)}{d^2 (N-1) X^2 P (1-P)}$$

Where:

S = required sample size N = the given population

P = the population proportion that is for the table construction has been assumed to be 0.05, as this magnitude yields the maximum possible sample size required.

d = the degree accuracy as reflected by the amount of error that can be tolerated in the fluctuation of a sample proportion P about the population. Proportion P – the value of d being .05 in the calculations for entries in the table, a quantity equal to + 1.96

X² = table value of chi square for one degree of freedom relative to the desired level of confidence, which was 3.841 for the .95 confidence level represented.

The study population was done by choosing the origin at number 4 and selecting the settlements after a regular interval of 9. After which the population of these settlements were projected to 2020. A systematic sampling technique was used in choosing households from the eight sampled settlements and questionnaire was administered on them. However, for effective and adequate administration of questionnaire all routes in each of the eight settlements were noted. In each of the settlement an origin household was picked, thereafter, households were picked at intervals of 9. In each of the households, household heads were willing individuals irrespective of gender, were given the questionnaire to respond. Therefore, a total of 381 respondents were sampled systematically from the selected settlements. During sampling procedure, the error margin was placed at 0.05 this implies that the researcher tolerated 5% of error. Table 3.1 presents the summary of the households that were sampled in each of the villages.

Table 3.1: List of Settlements Studied and their 2020 Projected Populations from 1991 Census Figures

Name	Population 1991	Projected population 2020	Household	Sample Size	%
1. Afaha Ube	1770	4665	777	40	10.5
2. Ekit Itam 11	1550	4085	680	35	9.2
3. Idiok Afaha Itam	1257	3313	552	28	7.3
4. Ikot Ayan Itam	1712	4512	752	38	10.0
5. Ikot Esia	2027	5348	891	45	11.8
6. Ikot Obio Atai 11	4375	11535	1922	98	25.7
7. Mbak Itam 111	2123	5596	932	48	12.6
8. Nung Ukot Itam	2027	5817	969	49	12.9
Total	17021	44874	7475	381	100

Source: Extracted from National Population Census Figures (1991)

- To derive the number of households in a settlement, the 2020 Projected Population figure was divided by an estimated average household size of six (6) (National Population Policy, 1988).
- To derive sample size for each settlement, the number of households in a settlement was divided by the sum of households in the study area, and then multiplied by the sample size of 381

Therefore, questionnaires were administered to 381 households for data collection. The systematic random sampling technique was used in distributing the questionnaires in order to ensure coverage of the households.

3.5 Methods of Data Analysis

This section considers methods of image processing and statistical techniques for the testing of hypothesis formulated for the study.

3.5.1 Remote sensing and geographic information system (GIS) Application

The remote sensing and geographic information technology (GIS) was applied in carrying out the land use and land cover analysis on the satellite imageries of the study area. Remotely sensed data of the study area were collected from Landsat 1986 TM and 2018 OLI_TIRS and other secondary data such as population data were collected from census of Akwa Ibom State,

Nigeria. Also, Land use/land cover maps between 1986 and 2018 were classified according to Anderson's classification using (visual interpretation and supervised classification) and the statistics were calculated for different years (between 1986 and 2018) with the help of ERDAS IMAGINE 9.2 software. This was done to obtain data on the resulting land use/land cover types, and also to determine the rate and the direction of change and expansion, as well as the area calculated in hectares.

The GIS technology provides a flexible environment for entering, analysing and displaying digital data from various sources necessary for urban feature identification, change detection and database development. As a result, it was a handy tool applied to carry out this research.

i. Status of Urban Expansion.

The first three objectives were analyzed using image processing tool with this, satellite images between year 1986 and 2018 were pre-processed and classified with the aid of Anderson's classification technique using unsupervised classification method. After which change analysis was carried out for each of the classes generated and this shows the status of land use/land cover classes. This was done using Erdas Imagine GIS software and area in hectares of the resulting land cover types generated for the study years.

ii) Factors of urban Expansion and effect of urban Expansion: These objectives were analyzed and presented using tables, graphs, pictures, charts and chi-square.

iii) Statistical Analysis:

The land use/land cover statistics that were obtained for the different time periods identified the changes that occurred by comparing the figures (in hectares) to obtain the trends and rate of change and analysed. Data collected on the effects of urban expansion were subjected to statistical analysis., Thus, hypothesis "There is no significant effect in land use land cover between 1986 and 2018 in Itu LGA" was analyze using confusion matrix, while hypothesis two "There is no significant effect of urban expansion on natural vegetation in Itu LGA" was analysed using Chi-square statistical technique.

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.1 : Demographic Data of Respondents

The study relied on information from respondents who were matured, well-educated and informed about the subject matter of this study. Table 4.1 reveals the fact. It is shown from this table that more of the respondents were male (57%), of the active age bracket 35-44 (38%) and married (38.6%). Also, more of

them had secondary (34.6%) and tertiary (24.9%) education. Moreover, a high percentage of the respondents were civil servants (19.2%) , farmers (23.8%) and traders (24.7%). In view of the forgoing, the accuracy of the information provided and used on this study is high and not in doubt.

Table 4.1: Demographic Data of Respondents

SEX.	FREQUENCY.PERCENTAGE	
Male	217	57.0
Female	164	43.0
Total	381	100.0
AGE	FREQUENCY PECENTAGE	
24-34	137	33.95
35-44	145	38.06
45 and above	99	27.0
Total	381	100.0
MARITAL STATUS	FREQUENCY PERCENTAGE	
Single	100	26.3
Married	147	38.6
Divorced	68	17.8
Others	66	17.3
Total	381	100.0
EDUCATIONAL QUALIFICATION	FREQUENCY PERCENTAGE	
Primary	89	23.4
Secondary	132	34.6
Tertiary	95	24.9
Non-formal	66	17.1
Total	381	100.0

Source: Field Data, (2021).

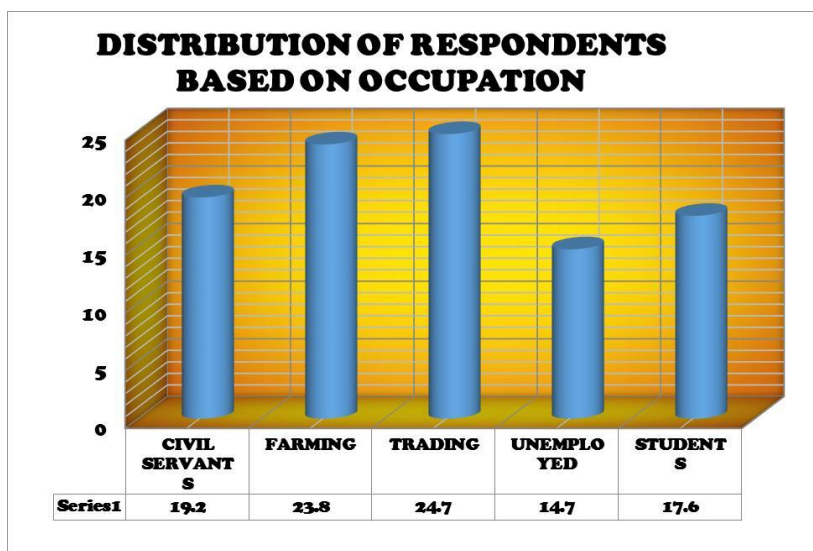


Figure 4.1: Simple pie chart showing the distribution of respondents based on occupation.

4.2 : Urban expansion and natural vegetation

4.2.1 : Land Use Land Cover Status

The land use land cover status of the periods under study were analysed using imageries of 1986 and 2018. The land use land cover mapping of the study area using two epochs remote sensing data as shown in Table 4.2 revealed that, swamp forest covered 10204.91ha (38.90%) in 1986 and it reduced to 6625.01 (25.30%) in the year 2018. In 1986, disturbed forest and cultivated land increased from 4381.33ha (16.70%) and 4381.83 (16.70%) to 8671.64ha (33.10%) and 4031.14 (15.40%) in 2018. Built-up /bare land covered 2965.56ha (11/30%) in 1986 and it further increased to 5710.68 (21.70%) in 2018. This is an indication of the extent of urban expansion in the area during the period under investigation.

Table 4.2: Land use land cover matrix

LULC	1986		2018	
Classes	Area in Hectares	%	Area in Hectares	%
Water body	1435.53	5.50	1176.59	4.50
Swamp Forest	10204.91	38.90	6625.01	25.30
Disturbed forest	7232.23	27.60	8671.64	33.10
Cultivated land	4381.83	16.70	4036.14	15.40

Builtup/bare land	2965.56	11.30	5710.68	21.70
Total	26220.06	100.00	26220.06	100.00

Source: Researcher's Compilation, (2021).

4.2.2 : LAND USE/LAND COVER CHANGES

Land Use Land Cover Class		Land Use Land Cover 2018					Grand total
		Builtup/ bare land	Cultivated land	Disturbed forest	Swamp forest	Water body	
Land Use Land Cover 1986	Builtup/ bare land	1620.59	602.12	594.01	98.10	44.24	2959.05
	Cultivated land	1661.24	1124.33	1234.40	291.96	20.68	4332.62
	Disturbed forest	1466.09	1442.47	3020.69	1280.50	28.21	7237.95
	Swamp Forest	710.57	736.52	3679.76	4848.17	76.49	10051.51
	Water body	239.45	47.32	77.03	71.73	1006.48	1442.01
	Grand total	5697.94	3952.75	8605.88	6590.47	1176.11	26023.15

Table 4.3: Land use Land cover change matrix for Itu LGA between 1986 and 2018. Source: Researcher's compilation, (2021).

This was done using Arcmap and compiled using Microsoft Excel.

Figure in bold (diagonally) represent area under that particular land use in 1986 and 2018. Figures in the same row represent the change in area to other land uses in 1986, while Figures in the same column represent the change in area to another land uses in 2018.

From Table 4.3, it shows the changes between land uses, that is, changes from one land use to another. Between 1986 and 2018, built up/bare land gained from cultivated land with 602.12 and 1661.24km², disturbed forest with 594.01 and 1466.09km², swamp forest with 98.10 and 710.57km², water body with 44.24 and 239.45km² respectively and this brought about the progressive change from 2959.05km² in 1986 to 5697.94km² in 2018. This change was due to the other land uses which were being converted to built-up area because of urban expansion. Between 1986 and 2018, cultivated land changed from 4332.62km² to 3952.75km² respectively. This was a regressive change because much of cultivated land use cover had been changed to built-up (urban) area. Disturbed forest also changed from 7237.95km² in 1986 to 8605.88km² in 2018. This is an indication that the primary vegetation cover (natural vegetation) have

been changed to secondary vegetation due to built-up and cultivated land uses. Swamp forest changed from 10051.51 in 1986 to 6590.47 in 2018. The reasons responsible for the expansion of river valley of the study area was due to erosion activities such as transportation and deposition of more water into the river channel and the time the image was captured as the image of 1986 have much vegetation cover covering the river channel thereby reducing the aerial coverage of the water body, while the image of 2018 tends to have an increase in water body because much vegetation cover have been removed causing an expansion in area of the river channel. Also, in 1986, water body occupied 1442.01km² which later changed to 26023.15km² in 2018. This progressive change is because of the presence of the Itu River and the amount of rainfall in the study area.

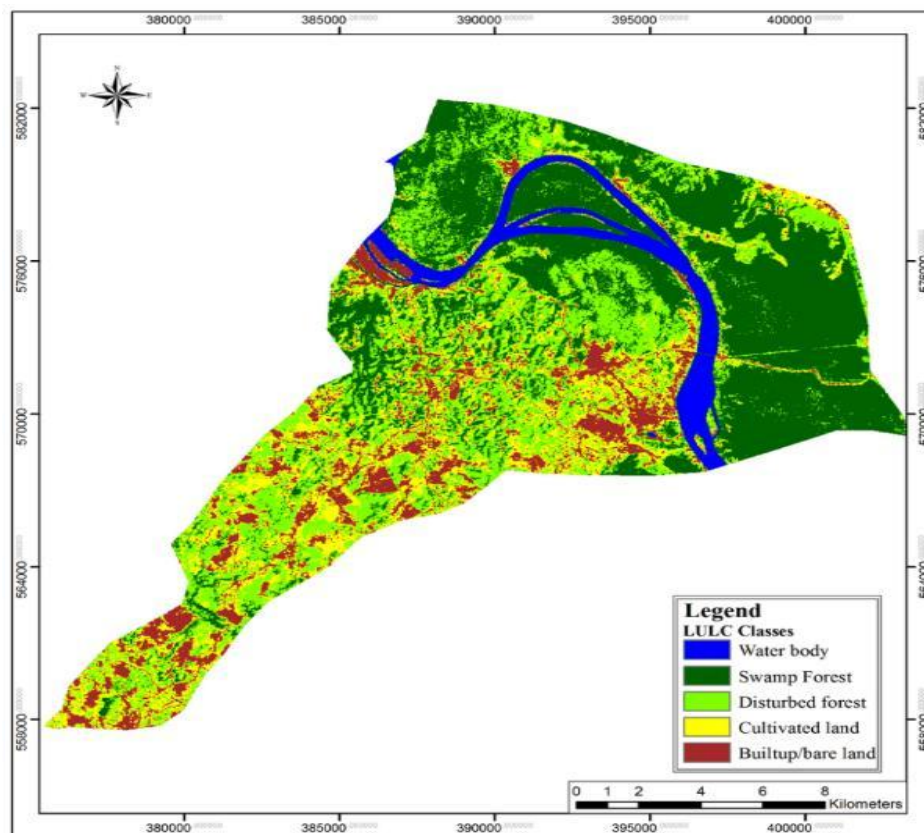


Figure 4.2: Itu Local Government Area; Land Use/Land Cover in 1986

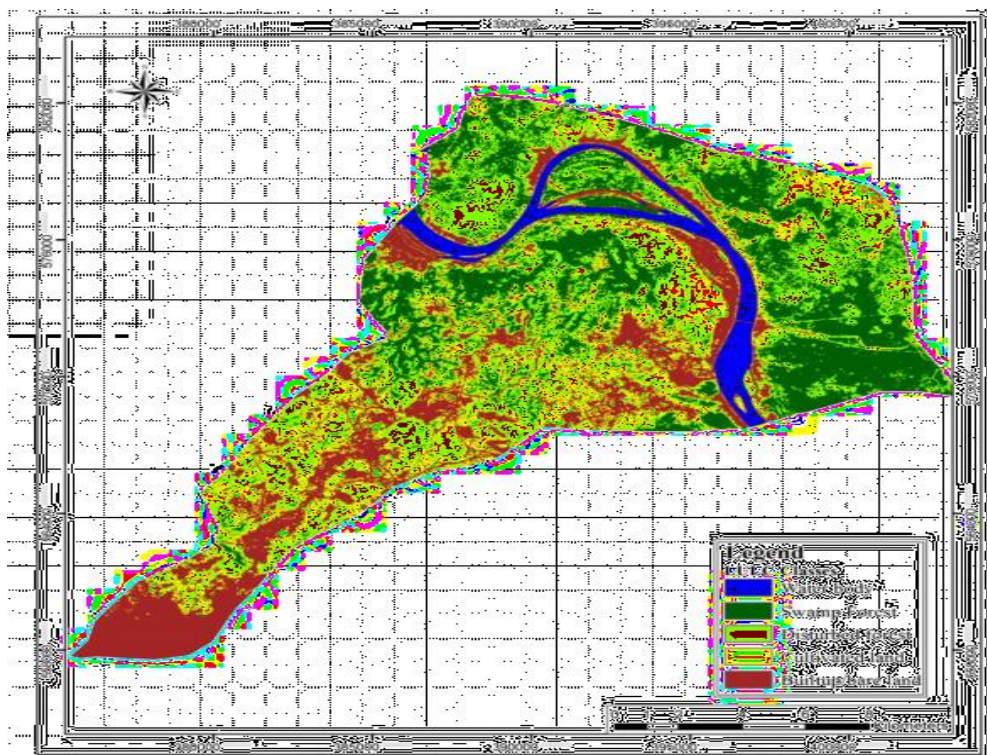


Figure 4.3: Itu LGA: Land Use/Land Cover in 2018

4.3 : Causes of Urban Expansion

During the course of this study, a total of 381 questionnaires were distributed to the sampled population to investigate the causes of urban expansion on natural vegetation. Table 4.4 shows some major and identified causes of urban expansion in the study area:

Table 4.4: Responses on the causes of urban expansion

Causes of urban expansion	Frequency	Percentage (%)
Population growth	126	33.1
Economic growth	85	22.3
Physical constraint	51	13.4
Desire for home ownership	67	17.6
Lack of affordable housing	52	13.6
Total	381	100.0

Source: Field Data, (2021)

From Table 4.4 above, population growth, was the major cause of urban expansion in the area. 126 (33.19%) of the respondents attested to this, followed by economic growth with 85 respondents (22.3%), physical constraint accounted for (13.4%) with 51 respondents. Desire for home ownership followed with 67 respondents (17.6%), **while lack of affordable housing had 52 respondents of the total sampled population of 381.**

4.4 : Effects of Urban Expansion

Table 4.5: Responses on the Major Effects of Urban Expansion

No. Of Effects	Respondents
Air pollution	90
Land pollution	79
Water pollution	52
Flooding	62
Erosion	48
Deforestation	50
Total	381

Source: Field Data (2021)

The responses on the effects of urban expansion from the sampled population as stipulated in this study focuses mainly on the negative impact that urban expansion have on natural vegetation in the study area.

The data obtained obtained from the field through the use of structured questionnaires shows that 90 respondents (23.6%) accounted for air pollution has been one of the major effect caused by urban expansion. This is because the study has its focus on urban area rather than the rural were the vegetation cover is still in abundance. The removal of natural vegetation which was meant to absorb the carbon dioxide released by human and its activities is left to blow on the air thereby causing air pollution. The activities going on at Itam park and drastically polluted the air as poisonous substances are been released from automobile vehicles. Land pollution accounted for about 79 respondents. The land is polluted due to improper waste disposal generated from Itam market and from residential areas of the LGA and this effect is caused by urban expansion. Water pollution accounted for 62 respondents. Flooding and erosion are other major effects identified by the sampled population and it accounted for about 60 and 48 respondents respectively.

4.5 : Testing of Hypothesis

The null hypothesis state that: (there is no significant effects of Urban Expansion on natural vegetation in ITU LGA). This was tested using Chi-square. The result of the test reveals the calculated value to be 23.61 and Table value to be 11.070

Decision:

Since the calculated value of (23.61) is greater than the table value of (11.070), we reject the HO (The null hypothesis) which states that “there is no significant effect of urban expansion on natural vegetation in Itu LGA” and accept the alternative hypothesis of H1 which states that there is a significant effect of urban expansion on natural vegetation in Itu LGA.

4.5: Discussion of Findings

This study which investigated the effect of urban expansion on natural vegetation came up with the following findings: it was identified in the study that; five dominant land use/cover categories exist in the study area. These land use/cover categories include water body, swamp forest, disturbed forest, cultivated land and built-up/bare land.

From the analysis of the satellite imagery, it was revealed that these land use/cover categories have been experiencing various forms of changes, with the built-up/bar land use category having the highest form of depletion at the expense of natural vegetation. During the study period, it was also revealed that built up have more from what it was between the periods 1986 to 2018.the changes to urban land cover is due to urban expansion. Echoing the same view point, Ohwo and Abotutu (2005) stated that urban growth, industrial expansion and pressure from increasing population have reduced the extent, diversity and stability of Nigerian forest.

Based on the findings obtained on the major causes of urban expansion, population growth was mentioned by majority of the respondents as the major cause of urban expansion in the study area. This cannot be disputed as the LGA has continued to witness influx of people due to the presence of the large market and the motor park at Itam. The high rate of influx of people into the LGA will result in uncontrolled urban growth. This finding is supported by the findings of Bhatta (2009) who insisted that population growth is a key factor responsible for the occurrence of Urban expansion. He argued that rapid growth in population strains a city's capacity to provide services such as education, health care, transportation, sanitation and physical security. Since the government has fewer funds to spend on the basic upkeep of the people and the provision of services, and such individual development efforts, in most

cases, lead to urban expansion and the natural vegetation is converted to built-up environment to accommodate the growing population of the study area. This in turn reveals that more of natural vegetal cover have been depleted to cater for the needs and wants of the growing population.

Economic growth was another cause of urban expansion in the study area as viewed by the respondents. This also is indisputably so because Bhatta (2009) stressed that expansion of economic base (such as high per capita income, increase in number of working persons) require rapid provision of housing facilities for the workers and other operators in urban centre. For instance, the siting of Itam Motor Park and the large marked resulted in the influx of labour workers into Nung Ikot Itam, Mbak Itam 111 and other nearby communities in the study area.

Physical constraints such as the ITU River, deep gullies, eroded plains and soil slides are prevalent in the study area thereby hindering human settlement in those areas of the LGA that are being affected. This also causes urban expansion as most people are seen clustering around the Itam axis of the LGA due to the flat terrain void of physical constraints thereby causing more expansion at that area of the LGA.

As human population increases in number, in affluence, status and economic ability, there is a desire for home ownership as more number of houses are required to accommodate the growing population and this has led to urban expansion and thereby causing negative effects on natural vegetation. Thus, this in turn agrees with the findings of Uyanga and Ekop (2014) who noted that pressure for change at the peri-urban area of Itu LGA are necessitated by demand for accommodation which by itself may result from increasing population and desire for home ownership.

On the major effects of urban expansion, the respondents mostly stated that urban expansion has led to air, land and water pollution; development of flooding, erosion and deforestation were also revealed as effects of urban expansion in the LGA. Flooding and erosion are the direct effects of the removal of natural vegetation cover which is meant to absorb water into the underground. Over congestion of houses and the improper disposal of waists into gutters which are the activities of urban areas have hindered the passage of running water during the rainy season thereby causing flooding and erosion in the study area. Deforestation is also the direct effect of urban expansion in the study area. This is because urban expansion can only take place where the natural vegetation is removed in order to erect buildings. The process of cutting down trees (deforestation) has made the solid earth prone and fragile. It can therefore be deduced that urban expansion has negative effect on natural environment with the resultant effect on air, water and land pollution, erosion, flooding and deforestation menaces affecting the natural environment of the LGA and this also have led to the loss of vegetation cover especially around the

Itam axis of the study area. This agrees with the findings of Berry and Plant (1978) which states that urbanisation generally, and expansion in particular, contributed to the loss of vegetation cover and open spaces and that of Atu, Offiong, Eni, Eja, Esien and Obia (2012) who found that urban expansion had impacted negatively on the environment in Calabar, Nigeria by reducing their spatial extent and density and then fragmenting them into smaller sizes of less than 100metres square.

Finally, the study also revealed that there is a significant effect of urban expansion on natural vegetation based on the test of hypothesis using Chi-square statistical technique with the resultant effects are air, water and land pollution, flooding, erosion and deforestation.

5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 : Summary of Findings

The aim of this research is to examine the effect of urban expansion on natural vegetation in Itu Local Government Area with the view to identify the status of urban expansion, assess the changes that have occurred on the vegetal cover, examine the major causes and the effect of urban expansion on natural vegetation in the study area. At the end of this research, the summary of findings are as follows;

1. The result obtained from the changes that have occurred in urban land cover and vegetation cover reveals that urban expansion is at daily increase at the detriment of natural vegetation as much of cultivated land, swamp and disturbed forest have been lost to urban expansion due to the need to accommodate the ever growing population of the study area.
2. Urban expansion is caused by population and economic growth, desire for home ownership, lack of affordable housing and physical constraints. Population and economic growth were the most identified causes of urban expansion. This shows that as human population continue to increase in number, there is going to be more expansion (urban) having an after effect on natural vegetation cover of the LGA.
3. As regards to the effects of urban expansion, air, water and land pollution; flooding, erosion and deforestation were identified. Based on this, it is obvious that urban expansion has significant effect on natural vegetation of the study area.

5.2 : Conclusion

The study analysed the effect of urban expansion on natural vegetation in Itu L.G.A between 1986 and 2018. The analysis above shows that urban expansion has been rapid within the study area at the expense of vegetal cover. This is evidenced in the changes that took place on the five land use/land cover categories. Of the changes, urban land use category tends to have the highest

rate of change and expansion. The continuous increase in human population is said to be one of the major cause of urban expansion due to rural urban migration and in-migration from the neighbouring villages and LGAs. This now have resulted in water and air pollution, soil erosion and flooding in the study area. The presence of the Itam naternational park and the large market, the nearness of the LGA to the state capital city have also led to much expansion as people are seen living in the study area as a suburb.

In conclusion, it is obvious from the study that urban expansion has negative effect on vegetation in the study area as it is responsible for deforestation, pollution of air, land and water; the flooding of initially dry lands, erosion of soils, land slide and excess heat in the urban area due to man-made features and also the removal of forest meant to absorb heat.

5.3 : Recommendations

Based on the findings of this study, the following recommendations are hereby proffered:

1. Suitable legislatures should be put in place to control and discourage deforestation in the area.
2. There should be awareness campaign by government agencies on the negative effect of deforestation and also the implementation of environmental policies to help control the changes taking place in the urban land use/land cover to prevent it from further expansionand also to protect the vegetation cover from further depletion. . At such, relevant authorities should endeavor to carry out regular land use/ land cover changes assessment. This will help in determining the trend and rate of expansion in the light of the ever- growing urban population.
3. The rate of population growth has been one of the major cause of urban expansion and it should be controlled. This should be achieve through use of rules and regulations to control in-migration and rural urban migration of people into the LGA.
4. On the causes of urban expansion, population and economic growth have been identified as the leading factors. At such, economic activities should be provided such as large market to avoid clustering of people around the urban area of the LGA.
5. The major effects of urban expansion are air, land and water pollution, flooding, erosion and deforestation. All of these points to the fact that, the livelihood and health status of the people are affected as well so government should provide other sources of livelihood and health facilities to the vulnerable ones in the study area.

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APPENDIX A
Research Questionnaire

SECTION A: PERSONAL INFORMATION (PLEASE TICK [✓] AS APPROPRIATE).

1. Sex: Male ☐ Female ☐
2. Age: (a) 24 - 34years ☐ (b) 35 - 44 years ☐
(c) 45 years and above ☐
3. Educational Qualification: (a) Primary ☐ (b) Secondary ☐
(c) Tertiary ☐
(d) No Formal Education ☐
4. Occupation: (a) Civil Servant ☐ (b) Farming ☐ c) Trading ☐
(d) Unemployed ☐ (e) Student ☐
5. Household Size: (a) 1 - 3 ☐ (b) 4 - 6 ☐ (c) 7 - 9 ☐ d) 10 -12 ☐
6. Marital Status: (a) Single ☐ (b) Married ☐ (c) Divorced ☐
(d) Others ☐

SECTION B: CAUSES OF URBAN EXPANSION AND EFFECTS ON NATURAL VEGETATION

7. To what extent do you agree or disagree with the assertion that urban expansion has negative consequences on vegetation in your area? (a) Strongly Agree ☐
(b) Agree ☐ (c) Disagree ☐ (d) Strongly Disagree ☐
8. In your opinion, what are the major causes of urban expansion? (Tick as appropriate)

SN	Causes of Urban Expansion	Tick
1	Population growth	
2	Economic growth	
3	Physical constraint	
4	Desire for Home Ownership	
5	Lack of affordable housing	

9. Which of the following major effects of urban expansion do you observed in your area? (Tick as appropriate)

SN	Major Effects of Urban Expansion	Tick
1	Air Pollution	
2	Land Air Pollution	
3	Water Pollution	
4	Flooding	
5	Erosion	
6	Deforestation	

APPENDIX B

LIST OF STUDY POPULATION

Adang Itam
Afaha 1
Afaha 11
Afaha Ube
Afia Isong
Akon Itam
Akpa Ekpene Oton
Atai Ibiaku Itam
Edem Inyang
Efi-Itam
Efik Ebuno
Ekit Itam
Ekritam 11
Ema Itam
Enen Atai
Esu Ufot/Ikot Offiong
Esuk Itu
Etehe Ntem
Etim Itam
Eton Ani
Ibiaku Ikot Obong
Idiok Afaha Itam

Ikot Abasi Itam
Ikot Abiyak
Ikot Adakpan

Ikot Akpabio
Ikot Andem
Ikot Anse
Ikot Antuen
Ikot Arie Itam
Ikot Ayan Itam
Ikot Ebom Itam
Ikot Efa
Ikot Eka Iko
Ikot Ekang
Ikot Ekop Itu
Ikot Ekpuk
Ikot Ekwere
Ikot Emier
Ikot Esia
Ikot Esien
Ikot Ikono
Ikot Mbonde
Ikot Ntu
Ikot Nya
Ikot Obio Atai 11
Ikot Obong Edong

Ikot Offiong
Ikot Oku Oboku
Ikot Ononi
Ikot Otu
Ikot Udo
Ikot Ukap
Ikot Uso Akpan
Itot Obio Enang
Mbak Itam 11
Mbak Itam 111

Mbiabo Edere
Mbiabong Itam
Mbiatok Itam 1
Mbribit Itam 11
Mkpanaruk
Mkpeti
Nkim Itam
Ntak Inyang Itam
Ntiat
Nung Ukot Itam
Nwut Usiong
Nya Anating
Obong Itam
Obot Etim Itu
Obot Itu
Offion Ani
Okono
Uyo Itam

APPENDIX C

Determination of Sample Size from a Given Population

N*	S**	N	S	N	S
10	10	220	140	1,200	290
15	14	230	144	1,300	297
20	19	240	148	1,400	302
25	24	250	153	1,500	306
30	28	260	155	1,600	310
35	32	270	159	1,700	313
40	36	280	162	1,800	317
45	40	290	165	1,900	320
50	44	300	169	2,000	322
55	48	320	175	2,200	327
60	52	340	181	2,400	331
65	56	360	186	2,600	335
70	59	380	191	2,800	338
75	63	400	196	3,000	341
80	66	420	201	3,500	346
85	70	440	205	4,000	351
90	73	460	210	4,500	352
95	76	480	214	5,000	357
100	80	500	217	6,000	381
110	86	550	226	7,000	364
120	92	600	234	8,000	367
130	97	650	242	9,000	368
140	103	700	248	10,000	370
150	108	750	254	15,000	375
160	113	800	260	20,000	377
170	118	850	265	30,000	379
180	123	900	269	40,000	380
190	127	950	274	50,000	381
200	132	1,000	278	75,000	382
210	136	1,100	285	1,000,000	384

Note: N* is Population Size S** is Sample Size

1. Sample Size for 90% Confidence that the difference in the population and sample percentage is not more than 05.
2. Descriptive and correlational research typically should have larger samples than are required for experimental studies.

3. Sample size should increase as variability within the population increases. In other words, larger samples are needed in heterogeneous population as compared to a homogeneous population.
4. When samples are to be divided into smaller groups to be compared, the initial sample size should be large enough that the subgroups are of adequate size to make meaningful comparisons.

APPENDIX D

TESTING OF HYPOTHESIS

Null hypothesis (Ho): There is no significant effect of urban expansion on natural vegetation in Itu LGA.

Alternative hypothesis (H1): There is.

This hypothesis was tested using Chi-square statistical test given as:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where:

O = the observed value or distribution

E = the expected value or distribution

The data for this analysis was gotten from question (9) in the questionnaire which was used to assess the effect of urban expansion on natural vegetation:

Responses on the Major Effects of Urban Expansion

No. Of Effects	Respondents
Air pollution	90
Land pollution	79
Water pollution	52
Flooding	62
Erosion	48
Deforestation	50
Total	381

Source: Field Data (2021).

Mean ($\bar{x}$) of number of effects= $90+79+52+62+48+50=381/6=63.5$ So, the mean ($\bar{x}$) number of (63.5) becomes the expected frequency.

$$\chi^2 = \sum \frac{(O-E)^2}{E} \quad \text{Becomes:}$$

$$\begin{aligned} & \frac{(90 - 63.5)^2}{63.5} + \frac{(79 - 63.5)^2}{63.5} + \frac{(52 - 63.5)^2}{63.5} \\ & + \frac{(62 - 63.5)^2}{63.5} + \frac{(48 - 63.5)^2}{63.5} + \frac{(50 - 63.5)^2}{63.5} \end{aligned}$$

$$= 11.06 + 3.78 + 2.08 + 0.04 + 3.78 + 2.87$$

$$= 23.61$$

Therefore: $\chi^2 = 23.61$ (calculated value) D/F = N-1
 $= 6-1 = 5$ at 0.05

V= 5 at 0.05 Chi-square distribution

$$= 11.070 \text{ (Table Value).}$$

Energy consumption in Sub-Saharan African countries: Should we ignore innovation?

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University Of Dschang, Cameroon

Abstract

This article examines the effect of innovation on energy consumption in Sub-Saharan Africa, using a panel dataset of 31 Sub-Saharan Africa (SSA) countries from 2000 to 2018. Energy consumption is measured through energy use in kg of oil equivalent, fossil fuel and renewable energy consumption. Related to Innovation two components are used. One is financial innovation and another, technological innovation (TI). The generalised method of moment (GMM) was used to take into consideration endogeneity problems and variable omissions. The results show that, except for the negative effect of financial market indices and TI variables on renewable energy, others financial and TI indicators have a positive and significant effect on the components of energy consumption.

1. Introduction

Africa's energy demand is increasing twice as quickly as the rest of the world. African continent has a double-digit rise in the deployment of renewable energy due to its abundant renewable energy resources and declining technology costs. Africa is becoming a significant force in the international oil and gas markets as a result of the increasing demand for modern, efficient energy sources (Africa Energy Outlook, 2019). This question of energy consumption has gained ground among energy economists and environmental scientists for at least two reasons. First, as a production factor, energy supply determines firms' investments on the one hand and household well-being by offering enormous uses to people life on another (Chiu & Lee, 2020). Second, energy consumption is strongly related to environmental issues and its implication for pollution. The need to reduce such pollution and environmental hazards has gain interest in recent time (Adebayo & Kirikkaleli, 2021; Avom et al., 2020). For some scholars, improvement in technology and innovation such as the introduction of Information and communication technology (ICT) can

reduce environmental issues as it improves efficient and renewable energy use (Avom et al., 2020). Being a key production factor, world energy consumption is expected by the United State Energy Information Administration (USEIA, 2017) to increase by about 50% from 2018-2050. It becomes necessary to think at energy consumption management.

However, as Sadorsky (2012) postulates, the subject of how to reduce energy consumption in economies by turning more heavily to information technology (TI) has gained widespread interest since the two oil shocks of the 1970s. The introduction of new potential determinants in the energy consumption equation such as ICT is due to the inconclusive evidence regarding energy consumption-economic growth nexus and energy consumption income nexus. It is in this view that Karanfil (2009) earlier suggested the inclusion of other important variables beyond just income into the energy consumption model. The relationship between ICT and energy consumption is not all that recent as it dates as far as to the work of (Walker, 1985). But the effect of ICT on energy consumption presents two contradicting views. The first, posits that a greater use of ICT improves energy efficiency and increase the production and use of renewable energy (Avom et al., 2020). In fact, technological innovations through ICT reduces environmental degradation as it favours the use of electrical grids, the building of smart cities (Houghton, 2010). The second argument outlines the fact that ICT will increase energy consumption through the increase use of electricity as Walker (1985) postulated. In this argument, ICT is said to increase pollution. ICT's adverse effects manifest themselves through a variety of avenues, including a rise in industrial productivity, an increase in energy consumption, globalization, and a more prosperous financial system.

While many studies such as (Edo et al., 2019) shows that internet adoption has a significant positive impact on financial innovation and development, the development of the financial sector, on the other hand, is also thought to have a significant impact on energy used (Zhang, 2011). The widespread use of internet technology has also resulted in developments that appear to be promoting efficiency and financial innovation and inclusion in developing countries (Edo et al., 2019). However, two main arguments emerge as regard the nexus between financial innovation and energy consumption. The first argument based on the theoretical work of Sadorsky (2010), Zhang (2011), Ozturk and Acaravci (2013) consider that, an increase in energy consumption is brought about by financial development as a well-developed financial system, could provide low cost funds for enterprises. This facilitates the expansion of their production scale and therefore, increases enterprise energy demand. The second argument however, relies on the reasoning that financial development and innovation reduces energy consumption, as a developed financial system can help enterprises update production technologies and equipment by mitigating financial constraints, which could effectively bring about energy efficiency (Hermes & Lensink, 2003; Kim & Park, 2016; Tamazian et al., 2009).

The digitalisation of communication and financial services has been critical to the development of mini-grids and solar home systems markets. In some countries in Sub-Saharan Africa, the widespread availability of mobile phones, mobile money accounts, and associated telecommunication and payment infrastructures have helped the development of a wide array of energy services (USEIA, 2017). While the effect of technological innovation such as ICT and financial development reduces energy consumption for some and increases for others, the former approach although relevant, is against the paradox of Jevons (Alcott, 2005) for whom, technological improvement rather boosts energy consumption. Thus exposed, we note a dissonance, at least theoretically, between technological innovation-ICT and financial innovation on the one hand and energy consumption on the other. Therefore, in the case of SSA countries, what is the effect of innovation (Technological ICT and financial) on energy consumption? in other words, does Technological innovation-ICT and financial development reduces or increases energy consumption in SSA countries?

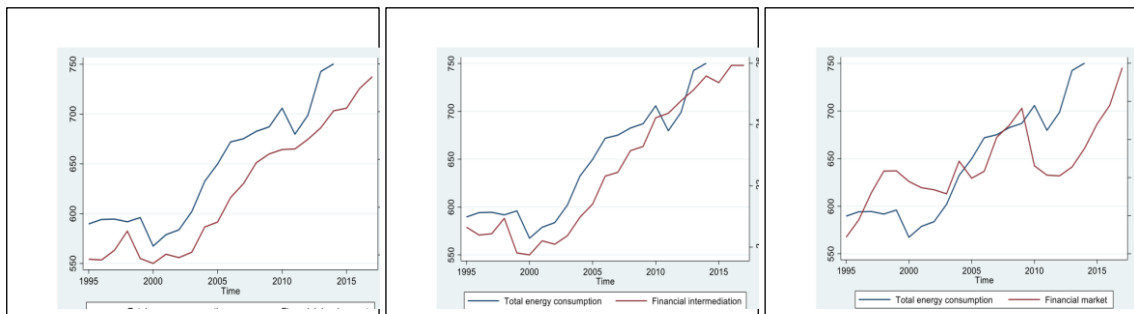
Two levels justify the importance of this preoccupation. One is related to the role of energy in an economy. In this case, this study aims at presenting via the determinants and especially ICT and financial development, the way by which, energy consumption can be managed in SSA. Another is linked to the method and data used. In fact, the generalised method of moment (GMM) was used to take into consideration endogeneity problems and variable omissions. Moreover, we make use of relevant indicators for financial development based on efficiency, and access both on financial institution and market. To the best of our knowledge, there is no study based on SSA countries which links energy consumption on financial development using this approach coupled with ICT. Doing that, these two components constitute the specificity of our study. Six sections structure the article; this ending introduction being the first. The next two sections present some stylized facts and expose the literature review while the fourth and the fifth section emphasize on method and finding. The last section concludes the article.

2- Stylised Facts

Figure 1 below presents the relationship between energy consumption trend and that of three indicators of financial development. It appears that, those aggregates (financial market, financial intermediation, financial development; energy consumption) move in the same direction. In terms of financial intermediation and provision of private credit, the average ratio for private credit (scaled by GDP) was only 17% for SSA, and for other developing countries, ranged from 32% to 43% (WDI, 2021). Nevertheless, African financial systems have been undergoing adjustments and stabilisation from the negative shocks of the global crisis (Allen et al., 2011). The different reforms carried out in Africa have been stimulated by rapid improvements in global conditions and global technology connecting Africa with the outside world (Otchere et al., 2017). In a study documented by the IMF on financial development in SSA in

2016 for example, it fully appreciates the potentials for financial expansion in this part of the continent, as has obtained some progress over the past decades (See figure 1).

Figure 1: financial development, market, intermediation and energy consumption in SSA



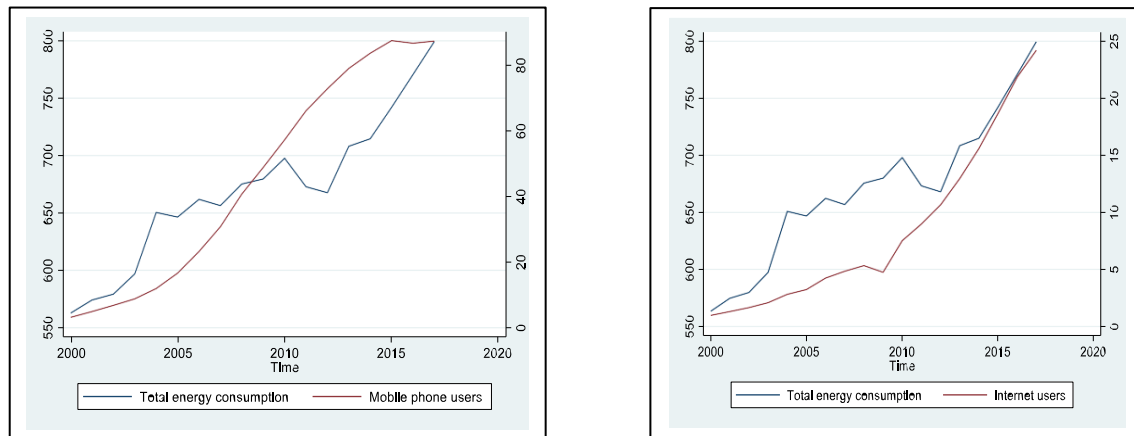
Source: authors

Globally, internet usage in sub-Saharan Africa has grown pretty quickly and generated a lot of activities that have tended to foster sectoral growth. Although several academics have made an attempt to explore the role of internet adoption, including Wilhelm (2001), (Claessens et al., 2001) and others, much work has to be done on the economic impacts of this adoption in sub-Saharan Africa. Internet penetration in Sub-Saharan Africa increased from less than 1% in 2000 to nearly 50% in 2016 (Edo et al., 2019) making it the region with the fastest internet growth globally. Even more intriguing is the enormous growth potential in nations like Nigeria and Kenya that have already attained a phenomenal level of internet usage. Nigeria and Kenya rank as the two nations with the highest usage of the internet due to the greater number of people who have access to it there than in any other nation in the area. The spread of this internet adoption and mobile phones has facilitated financial innovations in many countries. for example, the development of the M-Pesa mobile money transfer platform in Kenya was made possible by the availability of the internet. By making services available to more people, households, and companies in rural areas, M-Pesa has enhanced financial access and changed the face of payments. Overall, internet and mobile phone users have been increasing in SSA (See figure 2)

In term of energy, evidence shows that many African countries face a lot of challenges in struggling to achieve their development and social obligations because of inadequate access to modern energy services. This situation needs to be improved upon if the different sub regions and the continent as a whole, is to achieve sustainable development, while being economically competitive with other developing regions of the world. A major constraint regarding energy sector resource development in SSA is the lack of financial capacity (IEA, 2019), to raise funds necessary to undertake huge energy projects. Though its financial market has been improving, it is still in its embryonic stage, not capable of

providing long term financing to power energy projects. However, the demand for energy has increased by 50% since 2000 reaching 590 Mtoe in 2014 (IEA, 2014) while accounting for only 4% of the world's energy demand.

Figure 2: Mobile phone use, internet use and energy consumption in SSA



Source: Authors

The region's largest energy consumers happen to be Nigeria and South Africa with 133 Mtoe and 141 Mtoe respectively, thereby accounting for more than 40% of the total demand. The average energy consumption per capita in Africa is only one-third of the global average and just 50% of the level of Southeast Asia, the second most energy-poor region in the world. SSA is faced with the challenge of achieving its development as well as its social obligations owing to inadequate modern energy service. The IEA estimates that electricity demand in sub-Saharan Africa grew by about 35% from 2000 to 2012 to reach 352 terawatt hours (TWh), and it is forecasted that total demand for electricity in Africa will increase at an average rate of 4% a year through 2040. This eventually shows the importance of addressing the issue of energy in SSA.

3- Lesson for literature

3.1. Financial development energy consumption nexus

Two evocations are concerned here. One is related to the basic theory on financial development and another, is based on empirical works. The first case is inspired from finance-led-growth theory. Sadorsky (2011) theoretically postulates how financial development affects the consumption of energy. He identifies three channels through which, financial development has repercussions on energy consumption. The direct effect channel as the first, holds that a developed financial system induces an increase in energy demand via the actions of consumers (consumer effect). An efficient financial intermediation gives easy access to resources, permitting consumers to buy big tickets items for satisfying their day-to-day wants and needs (Mahalik et al.,

2017). The business effects as the second channel, follow an indirect link running from financial development to economic growth (investment and innovation activities, expansion of existing and new ventures). A well-developed financial system helps firms since it provides the essential function of channeling funds to businesses at reasonable interest rates. Consequently, these funds increase their investment and innovation activities.

The third channel is the wealth effect. As a product of improved financial development, it also leads to an increase in a country's rising demand for energy (Mahalik et al., 2017). Though increased stock market activity is being regarded as a leading indicator of economic growth and prosperity, it also creates wealth effect. This further helps in boosting confidence among consumers and producers whose results are felt on increased economic activity and creating energy demand (Shahbaz et al., 2016). If consensus appears on the theoretical studies, it's not the case with empirical one.

With regards to the empirical framework, two tendencies emerge. One establishes the positive relationship between financial development and energy consumption when another exposes a negative relationship. In the first case, one of the first to empirically investigate such a link in a panel of 22 emerging countries between 1990 to 2006 is Sadorsky (2010). He finds that financial development has a positive and significant effect on energy consumption when financial development is measured using three stock market variables. In 2011, the same author, using a panel data of nine central and eastern European frontier countries, found that three banking variables had a significant and positive effect on energy consumption. Moreover, when using three stock market variables, only stock market turnover was found to have a positive relationship with energy consumption. These results are in line with those of Al-Mulali and Lee (2013). In fact, the later examined the effect of financial development on energy consumption in Gulf Cooperation Council (GCC) countries. He finds that both in the short and long run, financial development was an important factor promoting the increase in energy consumption. This conclusion is confirmed by that of Ahmed (2017) in a panel of BRICS (Brazil, Russia, India, China, and South Africa) countries using data from 1991 to 2013. He concluded that financial development increases energy intensity in BRICS countries, despite the adoption of sustainable development measures.

Contrary to the first strand, others found a negative effect of financial development on energy consumption. Farhani and Solarin (2017) studied the relationship between financial development and energy demand with a newly developed Lagrange Multiplier unit root test and quarterly data of the United States from Q1 1973 to Q4 2014. They concluded that although financial development stimulates energy demand in the short term, it rather reduces in the long term. Destek (2018), using the common correlated effect (CCE) estimator and annual data from 1991 to 2015, shows that the development of the banking and bond markets has a significantly negative effect on energy consumption. Ouyang and Li (2018) looked at the effect of financial development on energy consumption using a GMM panel

VAR (Vector Autoregressive Regression) approach. Using the quarterly panel data of 30 Chinese provinces from Q1 1996 to Q4 2015, they found that financial development could significantly reduce the consumption of energy. Gómez and Rodríguez (2019) analyzed the impact of financial development on energy consumption in North American Free Trade Agreement (NAFTA) countries using a series of panel data methods from 1971 to 2015 and financial development was found to have a negative relationship with the consumption of energy.

3.2- ICT and Energy Consumption nexus

One potential method for accelerating economic growth more effectively and with less energy use is information technology (Sadorsky, 2012). According to the Schumpeterian theory, new information technology will result in significant energy savings, the assumption that energy demand in developed nations will decline while economic growth can increase is based on this. The connection between ICT and energy consumption is a crucial and urgent subject that has not received enough attention. The majority of prior research examining how ICT affects energy consumption has been done for developed economies with little known about developing countries. However, whether ICT increases or reduces energy consumption is still a debate.

A first strand of literature affirms that the development of the internet and telecommunication network increases energy consumption. Dabbous (2018) analyses the effect of ICT on energy consumption in MENA (Middle East and North Africa). Using a dynamic panel model, the author finds that ICT increases energy consumption. In a study in 19 emerging countries, Sadorsky (2012) examines the effect of ICT on electricity consumption. Using a dynamic panel demand model, the authors find that an increase in ICT usage increases electricity consumption. Schaefer et al. (2003) examined the energy consumption of mobile phone services in Germany. They discovered that only 7% of the energy used annually by the German mobile phone industry is consumed by the handsets, while 93% is used by the network components. The percentage of total energy consumed by mobile telephone services rises to 45% when stand-by charges are taken into account. ICT variables have a favourable impact on power usage in the Next Eleven Emerging Economies, according to Afzal and Gow (2016). In a panel of 67 nations, Saidi et al. (2017) analyse the effect of ICT on power usage and demonstrate a favourable and statistically beneficial relationship between the two variables. According to Takase and Murota (2004) if the income effect brought on by economic vitalization brought on by higher levels of IT is stronger than the substitution effect brought on by a change in the industrial structure, as it is in the case of the United States, then an increase in IT level could result in an increase in energy consumption.

The second argument relies on the premises that technological innovation such as ICT brings about efficiency in energy use and thus a reduction in energy consumption. To this, Cho et al. (2007), shows that investments in ICT will lower

electricity consumption in some manufacturing sectors in South Korea, but they will increase it in the service industry. Takase and Murota (2004) examine how investments in ICT affect energy use and CO₂ emissions in Japan and the US. They separate the impact of ICT investment into substitution and income effects and discover that the income effect and substitution effect is more prevalent in the US and Japan, respectively. Their results show that increased ICT investment in Japan could result in energy savings. ICT and energy use in the French service industry are examined by Collard et al. (2005) using a factor demand model. After accounting for variables such as costs, heated areas, and technological advancement, they discover that while the production of electricity is more intensive with computers and software, it is less intensive with the spread of communication devices. To put it another way, the impact of communications technology is higher than that of information technology. In a study on ICT-Energy consumption nexus, Ishida (2015) finds that investment in ICT contributes to a moderate reduction of energy consumption in Japan. The above two controversial arguments confirm Laitner (2002) argues that regarding the future of ICT and energy consumption that prediction that it is less certain how ICT will affect energy use in the future. This is especially true if numerous new ICT products are created and widely used. In SSA, the existence of empirical analysis regarding this area of study remains limited. This study therefore fills the existing gap regarding this domain in SSA.

4- Data and Method

This paper makes use of 31 SSA countries and data comes from the WDI (World Development Indicator) and the Financial Development Index of IMF database (FDI-IMF). They cover the period 2000-2018. Countries and the period were chosen based on the availability of data. As a dependent variable, energy consumption is measured by total energy use (kg of oil equivalent per capita), fossil fuel energy consumption (in percentage of total as a measure of non-renewable energy) and renewable energy consumption (in percentage of total final energy consumption). In this study two variables of interest are used. Financial innovation and Technological innovation (TI). First, financial innovation as an interest variable, is measured using two indicators (access and efficiency) each related to financial institutions (FI), and financial markets (FM) (Svirydzenka, 2016), as used in recent studies (Adom et al., 2023; Habiba & Xinbang, 2023; Habiba et al., 2021; Hu et al., 2022; Ma et al., 2022). Second, TI is proxied by mobile cellular subscriptions (Alola et al., 2021) and individuals using the Internet. The analysis equally takes into consideration other control variables which can influence energy consumption in SSA countries. The choice of the variables is with respects the existing literature on energy consumption. The variables used and their sources are reported in table 1.

Table 1: Variables and source

Variable	Symbol	Measurable indicator	Source
Energy consumption	EC	Energy use (kg of oil equivalent per capita)	WDI-WB
Fossil Fuel consumption	FF	Fossil fuel energy consumption (% of total)	
Renewable energy consumption	RE	Renewable energy consumption (% of total final energy consumption)	
Economic Growth	GDP	GDP per capita (constant 2010 US\$)	
Foreign Direct Investment	FDI	Foreign direct investment, net inflows (%GDP)	
Industrialization	IND	Manufacturing, value added (% of GDP)	
Trade Openness	TRADE	Trade (% of GDP)	
Energy Price	CPI	Consumer price index (2010 = 100)	FDI-IMF
Mobile cellular subscription	MCS	Mobile cellular subscriptions (per 100 people)	
Internet Access	IA	Individuals using the Internet (% of population)	
Financial institutions Access	FIA	Financial institutions Access Index	
Financial institutions Efficiency	FIE	Financial Institutions Efficiency Index	
Financial Markets Access	FMA	Financial Markets Access Index	
Financial Markets Efficiency	FME	Financial Markets Efficiency Index	

Source : authors

Our empirical approach considers the generalized method of moments (GMM) dynamic panel estimators. The aim is to rigorously address the potential omitted variables and measurement errors issues which use to cause endogeneity problem (Ma and Fu, 2020). We apply a standard energy consumption model whose foundations have already been laid by microeconomic theory and that has been used by Hsing (1994) and Sadorsky (2011) in the literature. Therefore, by including financial development and ICT as potential factors explaining the desired energy demand, the reduced form of the linear model can be expressed by considering the following equations:

$$ECit = \beta_1 + \beta_2 FDI_{it} + \beta_3 ICT_{it} + \beta_4 X_{it} + \eta_i + \mu_{it} \quad (0)$$

Where:

EC stands for energy consumption

FD stands to financial development

ICT stands for information and communication technology

i and t represent the country and time index respectively;

X is a specific vector of other control variables hypothesized to affect energy consumption;

η is a time invariant unobserved country effect term;

μ is the error term.

The dynamic panel model is given as:

$ECit - EC_{i,-1} = \beta_1 EC_{i,-1} + \beta_2 FDI_{it} + \beta_3 ICT_{it} + \beta_4 X_{it} + \eta_i + \mu_{it} \quad (1)$ By transformation, we can write equation 1 as follow

$$ECit = (1 + \beta_1) EC_{i,-1} + \beta_2 FDI_{it} + \beta_3 ICT_{it} + \beta_4 X_{it} + \eta_i + \mu_{it} \quad (2)$$

$$ECit = EC_{i,-1} + \beta_2 FDI_{it} + \beta_3 ICT_{it} + \beta_4 X_{it} + \eta_i + \mu_{it} \quad (3)$$

To estimate (3), we apply the general method of moments (GMM) proposed by Arellano and Bond (1991), Arellano and Bover (1995), Blundell and Bond (1998). The objective is to express (3) as a dynamic panel regression and then take the first difference to eliminate country-specific effects. Then, the regressors in the first-difference equation are instrumented using the right-hand-side series lagged one period or more, under the assumption that time-varying disturbances in the original equations are not serially correlated. This strategy is

known as a difference GMM (D-GMM) estimation. Following Arellano and Bond (1991), (3) can be transformed into a first-difference equation as follows:

$$EC_{it} - EC_{i,-1} = (EC_{i,-1} - EC_{i,-2}) + \beta_2(FD_{it} - FD_{i,t-1}) + \beta_3(ICT_{it} - ICT_{i,t-1}) + \beta_4(X_{it} - X_{i,-1}) + \mu_{it} - \mu_{i,-1} \quad (4)$$

If variables are persistent, however, their past values convey little information about their future changes, making their lagged value a weak instrument for their differenced series (Acemoglu & Robinson, 2008). This may be the case for financial development variables, which may lead to a biased estimation of parameters in small samples and larger variance asymptotically. Arellano and Bover (1995) suggested a combination of the differenced (4) and level (3). Blundell and Bond (1998) showed that this estimator is able to increase the efficiency through its reduction in biases, and imprecision characterized by the D-GMM estimator, especially the above mentioned weak instrument problem. Arellano and Bover (1995), Blundell and Bond (1998) proposed a system general method of moments (S-GMM) estimator in estimating the moment conditions. That is the case in this article.

5- Results and discussions

This section presents on one hand, the main results (table 2 and 4) and on the other hand, the robustness check (tables 3).

5.1- Main results.

Table 2 below shows the estimated results of our research. The first two columns show that the coefficients of financial institution access and financial institutions efficiency are all positive. This implies that financial innovation proxied by financial institution access and efficiency therefore has a positive influence on total energy consumption. Financial institution access which measure the capacity of people and business in an economy to have access to money (in this case access is measured by the Bank branches per 100,000 adults and ATMs per 100,000 adults) increases energy consumption, as it leads to a tendency for customers purchasing goods in quantity, such cars, refrigerators, and air conditioners, increasing the nation's energy consumption and perhaps raising energy intensity (Sadorsky, 2010). These results are in line with those of Sadorsky (2010), Shahbaz and Lean (2012), Chang (2015) who found that financial development had a positive influence on energy consumption. again, these results agree with those of Köksal et al. (2021) who affirm that financial efficiency positively influences energy consumption through the income, business and wealth channel.

Column 4 to 6 shows that both indices of financial institutions have a positive influence of fossil fuel consumption and renewable energy. This means that while efficiency of financial institutions increases fossil fuel consumption, it however, provides the necessary channels for the development renewable

energy. These findings confirm the study of Habiba et al. (2021) who finds that the development of financial institutions increases CO₂ emission in the G20 countries through fossil fuel energy consumption. However, the indices of financial institution access and efficiency has a positive influence on renewable energy consumption. Two reasons may justify this. While on one hand, financial innovation through access and efficiency increase renewable energy consumption through technological advancement as

Table 2: GMM results of the effect of FIA and FIE on Energy Consumption

Dependent Variable	(1) Energy use	(2) Energy use	(3) Fossil Fuel	(4) Fossil Fuel	(5) Renewable Energy	(6) Renewable Energy
FIA	0.282** (0.107)		17.37*** (4.784)		8.617*** (0.870)	
FIE		0.0839** (0.0310)		3.617** (1.347)		4.314** (1.579)
GDP	0.00489*** (0.00140)	0.00554*** (0.00167)	0.111* (0.0558)	0.0847*** (0.0125)	-0.0497*** (0.0117)	0.0553 (0.0469)
FDI	-0.000809 (0.00120)	-0.000620 (0.000962)	-0.0830* (0.0460)	-0.0336 (0.0201)	-0.0611*** (0.0156)	-0.0565** (0.0209)
Manufac	0.00763*** (0.00113)	0.00475** (0.00175)	-0.188* (0.0937)	0.0918*** (0.0149)	0.0464** (0.0194)	0.267*** (0.0349)
Trade	0.00186*** (0.000250)	0.00135*** (0.000346)	0.0282 (0.0176)	0.0148*** (0.00148)	-0.00222 (0.00256)	0.0152*** (0.00379)
CPI	5.68e-05 (0.000117)	0.000183*** (6.42e-05)	-0.0153* (0.00821)	0.00694*** (0.00240)	0.00390** (0.00167)	0.00789*** (0.00225)
Constant	0.161*** (0.0477)	-0.000722 (0.0306)	1.183 (2.184)	-3.818*** (0.708)	-4.440*** (0.318)	-8.455*** (1.779)
Observations	308	308	308	307	487	487
Number of id	25	25	25	25	29	29
Number of instruments	26	26	26	28	35	28
Hausman OIR	0.363	0.738	0.640	0.650	0.771	0.491
AR(2)	0.141	0.114	0.998	0.984	0.330	0.495
AR(1)	0.00520	0.00446	0.00826	0.00619	0.00266	0.00291

Notes: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Standard errors reported in parenthesis

Source: Authors

Table 3: GMM results of the effect of ICT on Energy Consumption

Dependent Variable	(1) Energy use	(2) Energy use	(3) Fossil Fuel	(4) Fossil Fuel	(5) Renewable Energy	(6) Renewable Energy
Mobile Phone	0.397*** (0.123)		0.00921*** (0.00196)		-0.0125* (0.00661)	
Internet Users		0.0120** (0.00453)		0.0232** (0.0108)		-0.0105** (0.00418)
GDP	2.619*** (0.454)	0.00149 (0.00187)	0.0756*** (0.0205)	0.00145 (0.00184)	0.157** (0.0664)	0.00568*** (0.000803)
FDI	-3.911*** (0.763)	-4.87e-05 (0.000703)	-0.0206 (0.0138)	0.00294*** (0.000608)	0.0407 (0.0546)	0.00258*** (0.000667)
Manufac	5.783*** (1.667)	0.00322 (0.00260)	0.0829** (0.0338)	0.00706** (0.00264)	0.277*** (0.0636)	0.00146 (0.00106)
Trade	0.140 (0.112)	0.000156 (0.000171)	0.00799*** (0.00142)	0.000586** (0.000273)	0.00596 (0.00574)	-0.000317*** (0.000108)
CPI	-0.315** (0.123)	-3.22e-06 (0.000114)	0.00469* (0.00274)	-4.01e-05 (0.000230)	0.0197*** (0.00617)	0.000250** (0.000107)
Constant	-25.71 (27.38)	-0.0366 (0.0519)	-1.709** (0.657)	0.0175 (0.0641)	-5.275*** (0.933)	0.0173 (0.0269)
Observations	307	304	307	295	484	480
Number of id	25	25	25	22	29	29
Number of instruments	35	28	35	28	21	35
Hausman OIR	0.907	0.888	0.867	0.783	0.387	0.789
AR(2)	0.283	0.234	0.944	0.731	0.582	0.365
AR(1)	0.161	0.00740	0.00767	0.00268	0.00130	0.0656

Notes: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Standard errors reported in parenthesis.

Source: Authors

shows the work of Anton and Nucu (2020), on the other hand, renewable energy can increase alongside with fossil fuel as in the case of increased energy demand, fossil fuel is used by electricity generators (Apergis & Payne, 2010).

With regards to control variables, the coefficient of GDP is positive and significant for all the models. The innovation of the financial sector which brings about investment and economic growth, increases energy consumption. These results are consistent with those of Shahbaz and Lean (2012), Gaies et al. (2019) and Yue et al. (2019) who found that energy consumption was positively influenced by economic growth. The coefficient of FDI is negative and significant. Considering the fact that FDI provides an avenue for the transfer of advanced technology from developed economies to developing ones, this in turn, is expected to enhance productivity in developing regions such as SSA and eventually reduce fossil fuel consumption. We can moreover note that, its effects on renewable energy consumption are negative and statistically significant. The implication of this result remains unexplained in the context of SSA. The coefficient of trade openness is positive and statistically significant with all measures of energy. This result implies that trade openness boosts economic growth and thereby increases energy consumption. These results are consistent with those of Habiba and Xinbang (2021) who found that trade openness increases environmental degradation through economic growth.

Energy prices proxied by the consumer price index (CPI) positively and significantly affects all the components of energy consumption. While these results is contrary to our expectation in the African context, it however couple with the study of Anton and Nucu (2020) in the European Union who found a positive relation between CPI and renewable energy.

Table 3 presents the results of ICT (mobile phone and Internet use) on energy consumption. The first 4 columns shows that the effect of ICT on energy consumption is positive and significant. There the use and penetration of mobile phones and internet in developing countries, increases energy consumption. For Avom et al. (2020), the adoption of ICT enhances trade openness, financial development and consequently leads to an increase in energy consumption. Again, the positive effect of ICT on energy consumption could be due to the inefficient use of energy by a large number of ICT equipment. These results are in line with those of Sadorsky (2012) and Dabbous (2018) who concluded that higher ICT penetration rates are associated with high energy consumption. The positive result of ICT on energy consumption is equally in line with those of Dabbous (2018) who found that ICT increases energy consumption in MENA countries. The coefficient of ICT associated with renewable energy in column 5 and 6 (table 4) is negative and significant. This result shows that the adoption of ICT has a negative effect on renewable energy consumption in developing countries. While internet adoption increases in the developing countries, access to renewable energy in this part of the world is still

problematic due to its expensive nature. Even if these ICT appliances uses electrici

5.2- Alternative measure of financial innovation

Table 4 shows the effect of financial market access and efficiency on the three components of energy consumption. In the first 4 columns, the coefficients of financial market access and efficiency are positive and significant. This implies that the development of the financial market to enable easy access, contributes to investment and hence an increase in energy consumption. Financial market efficiency which looks at the Stock market turnover ratio (stocks traded to capitalization) increases energy consumption, increases total energy consumption but is negatively associated with renewable energy. The negative relationship between FMA, FME and renewable energy can be justified by at least two reasons. First, SSA's financial market are not yet well developed to impact significantly the use of renewable energy. Secondly, the production of renewable energy is most often linked to high initial capital expenditures. Moreover, investing in renewable energy technologies may produce energy output at a high price to potential consumers compared to fossil fuel-based energy (Mohammed et al., 2013). In the context of SSA, present capital markets do not favor small-scale investment (Amigun et al., 2008), which is usually a prerequisite for renewable energy development especially in remote areas. Credit facilities to develop the renewable energy sector are not often available for investors and where they do, interest rates are high such that investors are not disposed to get on the high risk involved. Again, financial markets in low-income countries are inefficient and underdeveloped that do not motivate industries to adopt green technologies and also lack proper regulations that make firms not to invest in environmentally friendly projects (HABIBA & Xinbang, 2021). The control variables of GDP, trade openness and CPI are in accordance with results found in table 2ty power, 89% of this is generated from nonrenewable sources (USEIA, 2017).

Table 4: GMM results of the effect of FMA and FME on Energy Consumption

Dependent Variable	(1) Energy use	(2) Energy use	(3) Fossil Fuel	(4) Fossil Fuel	(5) Renewable Energy	(6) Renewable Energy
FMA	0.662*** (0.111)		6.681*** (2.286)		-0.340*** (0.0843)	
FME		0.0961*** (0.0185)		0.144* (0.0817)		-0.695*** (0.0791)
GDP	0.00206** (0.000821)	-0.00123 (0.000979)	0.327*** (0.0594)	0.00268 (0.00221)	0.00720*** (0.00122)	0.00688*** (0.00122)
FDI	-0.00160 (0.000996)	-0.00162*** (0.000508)	-0.00606 (0.0408)	0.00431** (0.00176)	0.000639 (0.000455)	0.00231*** (0.000579)
Manufac	-0.000389 (0.00247)	0.00162 (0.00103)	-0.179*** (0.0473)	0.000995 (0.00445)	-0.00416*** (0.00116)	-0.000990 (0.00191)
Trade	0.00240*** (0.000554)	0.000277** (0.000128)	0.0382*** (0.0104)	0.000117 (0.000367)	-0.000653*** (0.000153)	-0.000934*** (0.000105)
CPI	0.000760*** (0.000268)	0.000246*** (5.18e-05)	-0.00606* (0.00338)	0.000294* (0.000170)	-1.85e-05 (5.11e-05)	-4.01e-06 (4.04e-05)
Constant	0.409*** (0.0931)	0.0821*** (0.0254)	-1.130 (1.013)	0.0488 (0.0844)	0.217*** (0.0374)	0.208*** (0.0380)
Observations	261	307	308	298	487	487
Number of id	25	25	25	22	29	29
Number of instruments	27	28	26	28	35	35
Hansen OIR	0.696	0.673	0.894	0.631	0.715	0.793
AR(2)	0.0794	0.303	0.719	0.670	0.387	0.400
AR(1)	0.0201	0.00689	0.00496	0.00271	0.0413	0.0327

Notes: *, **, *** denote statistical significance at the 10%, 5% and 1% levels respectively. Standard errors reported in parenthesis.

Source: Author

6-Conclusion

The aim of this article was to empirically examine the effect of financial and technological innovation on energy consumption in SSA. The GMM system was used. Estimation results from the models show that both measures of financial innovation have a positive and significant effect on energy consumption in SSA region. This implies that the increase in financial innovation would encourage consumption, investment, economic growth and subsequently, energy consumption. Moreover, this study reveals that an increase in technological innovation through ICT penetration increases the consumption of energy in SSA. However, the effect of financial market innovation and ICT on renewable energy is negative. One implication of these results show that energy demand models for SSA economies which that do not take into account financial development variables are likely to underestimate the demand for energy in these countries. This could lead to planning problems in securing adequate supplies of energy and even perhaps issues with national energy security. Energy security issues could be of great concern for many of these countries since most of them are net energy exporters. The energy sector is positively influenced as portrays the result.

SSA countries should then take precautions to this increase in energy consumption which can in the long run witness a shortage. One of the ways could be by investing more in the energy sector. Conventional energy for both importing and exporting countries contributes to oil price fluctuations and a reduction in environmental quality. Therefore, governments should develop

policies that attract national, regional and foreign investments in renewable energy sector and that contribute to the transfer and diffusion of technology in the region. Policies to cut energy use and improve opportunities for energy savings in all areas should go hand in hand with an increase in the use of ICT. Utilizing energy-saving methods or more effective equipment that consume less electricity is one option.

The findings regarding the relationship between financial innovation and energy consumption show that in the 32 SSA countries taken into account in this study, a more developed financial system will lead to higher energy consumption. As a result, measures that encourage the growth of financial markets can be implemented while taking precautions about any negative impacts on energy use.

Many other measures can be taken including feed in tariffs, renewable energy subsidies, tax incentives. Moreover, policy makers should reform fossil fuel subsidies which are among the main barriers to the deployment of renewable energy in the region. In terms of economic growth and the undoubted role financial development has on the development of SSA, energy consumption increases as these economies grow. As a recommendation, countries should

endeavour to see into it that they secure their sources of energy. This will help in procuring energy for their ever-growing economies.

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Discipline and discourse Globelics@20: Environmental sustainability and innovations: What we know and room for improvement

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Abstract

This paper discusses what we know after 20 years of research on environmental sustainability and innovations, and what further room for improvement emerges to improve our knowledge. This two-step approach is performed for three key topics of Globelics research on environmental sustainability and innovations: first, the development of sustainability capabilities in countries of the South; second, methodological issues on the heuristics to be used to analyse case studies; third, the specific role of the state to achieve the envisaged changes.

Key results are that the South has been increasing its capabilities from “catch-up” towards leapfrogging. New data sources and new forms of innovation will be important new topics. The widely used heuristics of technological innovations systems and MLP have to be enlarged and embedded within other subsystems to analyse sustainability transformations. Fostering environmental sustainability innovations require additional governmental activities compared to “normal” innovation systems. The roles of the state will be further increased and become more differentiated with the move from fostering technical innovations towards transformation of systems. In addition, the focus on renewable energy and climate mitigation will broaden towards climate adaptation and the interplay of climate technologies and with circular economy. Increasingly, different perspectives and research approaches need to be combined and integrated. This requires true interdisciplinary research and reflection processes about the normative assumptions.

Key Words: environmental sustainability innovations, capabilities, heuristics of innovation system analysis, role of the state

1. Introduction

Over the last 20 years, Globelics has constantly pushed forward research on environmental sustainability and innovations. Already on its first annual conference in Rio, the topic of sustainability and innovation in the South was on the agenda on the opening day of Globelics 2003 (Walz and Meyer-Krahmer 2003). Over the 20 years of Globelics, numerous contributions and publications followed, and research on environmental sustainability innovations were established as important part of Globelics research.

Sustainability is a widely used but a differently interpreted term. This article is based on an interpretation that relates sustainability to ecological challenges, which require energy and environmental innovations and transformations, but must also be addressed with regard to social and economic consequences and opportunities for inclusive development. Although the importance of innovations for achieving environmental goals was recognized early on in the sustainability discussion, systematic research on sustainability innovations can only be said to have been conducted in the last 20 years or so. For about 10 years, there has been a considerable increase in the number of publications on this topic (Maier et al. 2020). In the meantime, it is possible to speak of an independent literature and specific approach to the analysis of environmental sustainability innovations. This research is also often discussed under other terms (e.g. innovations for renewable energies). Thus, innovation research which relate to the energy transitions are also considered as environmental sustainability topics in this paper.

The objective of this article is twofold: First, it aims at stock-taking the development of research on environmental sustainability innovations over the last 20 years, by relating the state-of-the art development to topics relevant for the specific research in the context of Globelics. Second, it aims at identifying promising areas for improvement, which also can give impulses for the direction of future research within Globelics.

Given the enormous scope and the many strings of research, such an endeavour has to focus on specific elements. Therefore the article concentrates on three specific elements of research on sustainability innovations: first, the development of sustainability capabilities in countries of the South; second, methodological issues on the heuristics to be used to analyse case studies; third, the specific role of the state to achieve the envisaged changes. Within each of these elements, first a stock-taking of what we know after 20 years of research is performed, followed by an identification of issues for further improvement. In many instances, this room for improvement is linked to that it is increasingly

acknowledged that environmental sustainability needs transformation of whole systems, and not only single technological innovations.

Following this logic, the paper is structured as follows: Paradigmatic for Globelics over the last 20 years has been the development of learning, innovation and competence building systems in countries of the South. Thus, section 2 of this paper looks how these capabilities have developed in the last 20 years, and what room for improvement is seen with regard to this string of research in the future. Characteristic for research on sustainability innovations within Globelics are also numerous case studies on innovation systems, which have contributed to understanding change and have identified barriers to and opportunities for inclusive development. Thus, section 3 looks on methodological issues about the heuristics to be used in such case studies. With regard to room for improvement, we will also look what new methodological challenges and avenues arise to cope with the trend that the level of analysis moves from a focus on single technological innovations more towards system transformation. Section 4 deals with the role of the state. It first looks on the specific role of the state – in comparison to “normal” innovation systems – as a precondition for fostering environmental technological innovations. It then looks on new challenges and opportunities, which are linked to the trend towards systems transformations towards sustainability. Section 5 summarizes the results and discusses conclusions for further research.

2. Capabilities for sustainability innovations in the South

2.1 What we know: Conceptual issues for increasing and measuring capabilities

Around 2000, the concept of the Environmental Kuznets Curve (EKC) was debated intensively within the environment community with regard to possible emission trends in countries of the South. According to the EKC-hypothesis, environmental pressure grows faster than income in a first stage of economic development. This is followed by a second stage, in which environmental pressure still increases, but slower than GDP. After a particular income level has been reached, environmental pressure declines despite continued income growth. Graphically, this hypothesis leads to an inverted U-curve similar to the relationship Kuznets suggested for income inequality and per capita income. Within that string of research, it has been argued that Newly Industrializing Countries (NIC) in the South do not necessarily have to follow the emissions path of the traditional industrialized countries of the North. An alternative development path can be labeled “tunneling through the EKC” (Munashinghe 1999; Perkins 2003; Gallagher 2006). It was argued that countries catching up economically can realize the peak of their EKC at a much lower level of environmental pressure than the developed countries. Developing countries could draw on the experience of industrialized countries allowing them to leapfrog to the latest sustainability technology. This leads to a “strategic

tunnel” through the EKC. Here, environmental economists put faith into quick technological development and knowledge transfer as a key for reconciling environmental sustainability with economic development in NICs. However, this concept, very prominent within the global climate negotiation circles, puts the Global South in a technology dependent position and does not account for generation of green innovations and production of climate technologies also coming from the Global South itself (Herman 2023).

Within the Globelics community, the concept of the EKC was put in the context about the debate on technological catch-up and leapfrogging (Walz and Meyer-Krahmer 2003; Watson and Sauter 2011; Walz and Marscheider-Weidemann 2011; Hansen and Lema 2019; Pegels and Altenburg 2020). This debate had gained prominence among the scholars developing an evolutionary theory of trade, many of them being also connected to the Globelics community (Soete 1985; Perez and Soete 1988; Dosi et al. 1990). Technological cooperation focuses on the knowledge base required by the technologies and on enabling competences in the countries. Since the end of the 1980’s, the concepts of Social or Absorptive Capacity (Abramovitz 1986; Cohen and Levinthal 1990) and technological capabilities (Lall 1992; Bell and Pavitt 1993) were widely known. The results of the catching-up research within Globelics (e.g. Fagerberg and Godinho 2005; Nelson 2007; Malerba and Nelson 2008) and of empirical studies on developing capabilities especially in the context of the Asian countries (Lall 1998; Lee and Lim 2001; Lee 2005; Lee et al. 2005; Rasiah 2008) underlined the importance of absorptive capacity and competence building. Another aspect related to the effect of globalization on the mechanisms for knowledge dissemination. Archibugi and Pietrobelli (2003) stressed the point that importing technology has per se little impact on learning, and called for policies to upgrade cooperation strategies towards technological partnering. Nelson (2007) highlighted the changing legal environment and the fact that the scientific and technical communities have been moving much closer together. All these factors led to the conclusion that indigenous competences in sustainability related science and technology fields were increasingly seen as a prerequisite for the successful absorption of sustainability technologies in NICs on the one hand. On the other hand, the same process could also yield the potential for leapfrogging. This goes beyond the mere idea of diffusion of technologies generated in the North, which dominates the perception within the UNFCCC, but opens up the perspective of green technologies becoming part of an economic development strategy for the Global South (Herman 2023). Based on this conceptual framework, the experience with innovation indicators to measure technological capabilities, which have been highlighted by scholars such as Grupp (1999), Smith (2005) or Freeman and Soete (2009), was transferred to measure capabilities for sustainability innovations in countries of the South.

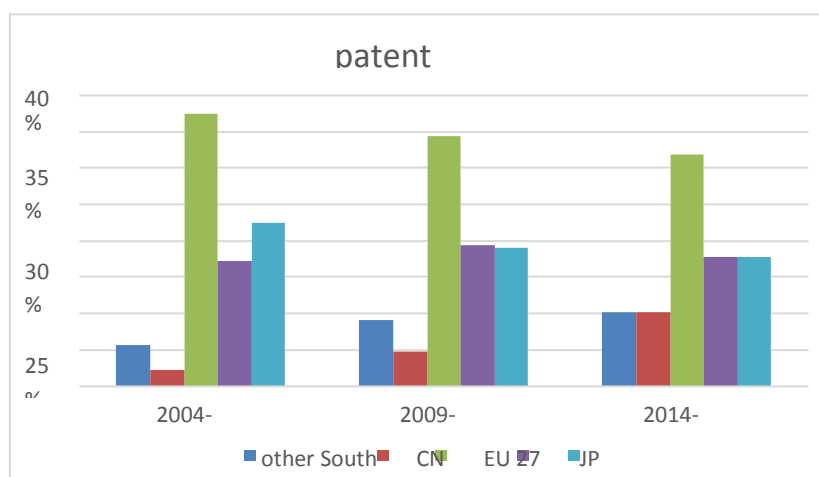
2.2 What we know: Empirical evidence of capabilities for environmental sustainability innovations in the South

Scientific publications belong to the intermediate innovation indicators, which show the level of knowledge creation. Previous research has already indicated that publications on green technologies show much higher dynamics in particular in countries of the South than the average of all publications. This has resulted in a strong increase of the share of the publications from the NICs, with about half of all green technology publications coming from NICs (Walz et al. 2017). The major part of this increase in the share of NICs can be attributed to China, which almost accounts for one quarter of the green technology publications. Clearly with regard to knowledge creation, the South has not only successfully caught up with the North, but is taking the lead (Walz et al. 2017; Her- man 2023).

Patents are among the most used indicators in innovation research. They belong also to the intermediate output indicators of knowledge build up, but are more directly related to technological capabilities than scientific literature. Previous research indicated also an increase in the share of NICs until 2012 (Walz et al. 2017). However, the level was much lower than for publications. To gain a better understanding of the development, an up- dated analysis of the development of patents for environmental sustainability innovations is performed in this paper. The analysis primarily draws on patent applications at the World Intellectual Property Organization and thus transnational patents (for the concept see Frietsch and Schmoch 2010). North is defined as all EU-27 countries plus the other traditional OECD-countries. The South consists of China and all other countries.

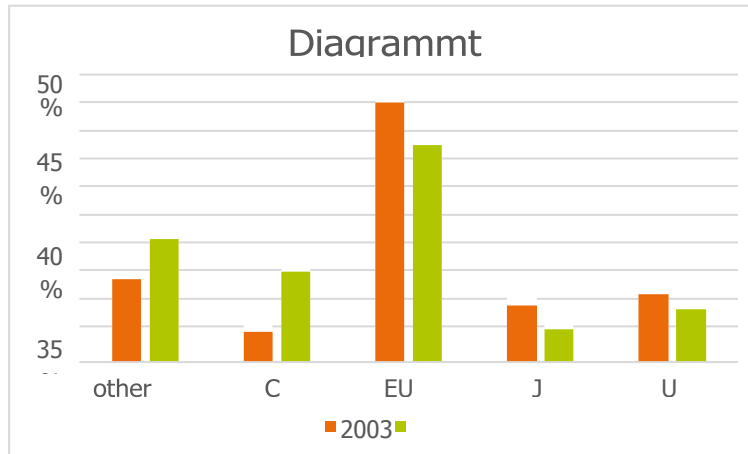
Figure 1 shows the data for various countries respective country groups. China and the other countries of the South have continued to increase their share at transnational pa- tents. China accounts now for about 10 % of the worldwide transnational patents, which makes it number 4 behind Japan and the US (both 18 %) and Germany (13 %). Among the other countries of the South, it is in particular South Korea with 7% and India, Singa- pore and Turkey with about 1 % each which contribute to the share of countries of the South.

Figure 1: Shares at worldwide transnational green patents



Source: own compilation based on data from PATSTAT

Figure 2: Shares of countries and country groups at world exports of green technologies



Source: own calculation, based on data from COMTRADE

International trade figures indicate the degree to which a country is able to compete internationally. The competitiveness with regard to technology intensive goods such as energy and environmental technologies is influenced by the technological capabilities of the countries. Thus, trade figures for these technologies also indicate the degree of technological capabilities. Previous research indicated also an increase in the share of NICs at export of environmental technologies (Walz et al. 2017). However, as this analysis is also already some years old, an updated analysis is performed in this paper. The technological areas chosen reflect sustainability innovations in the field of sustainable energy supply and energy efficiency, waste management technologies and circular economy, sustainability related mobility technologies, as well as technologies for protecting water resources and reducing noise and air pollution.

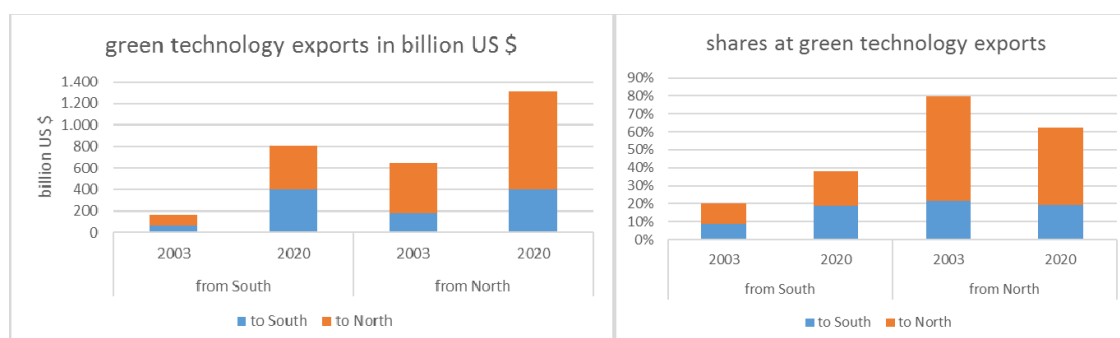
Figure 2 shows the export shares of green technologies in 2003 and 2020. China and the other countries of the South have almost doubled their share at world exports of green technologies from accumulated 20 % in 2003 to 38 % in 2020. China alone accounts now for about 16.1 % of the world export in green technologies, which makes it number 1 in front of Germany (12.8 %), the U.S. (9.4 %) and Japan (5.9 %). Among the other countries of the South, it is in particular South Korea with 4.5 %, Mexico and Malaysia (between 2 and 3 %) and Brazil, India, Indonesia, Singapore, Thailand and Vietnam with about 1 to 2 % each, which contribute to the share of countries of the South.

This export data does not differentiate the place of destination of the exports. However, if we want to examine whether the world market for sustainability technologies follows a North-centred development, with countries of the South

trying to catch up and to compete on the same markets, or whether segmented markets with different supplier-importer patterns are emerging, we have to look at regional markets. Therefore we divide the world markets into North and South. Thus, we yield four different supplier-importer segments: exports from the North and exports from the South, both of which are either exported to the North or to the South. North is defined as all EU-27 countries plus the other traditional OECD-countries. The South consists of all other countries.

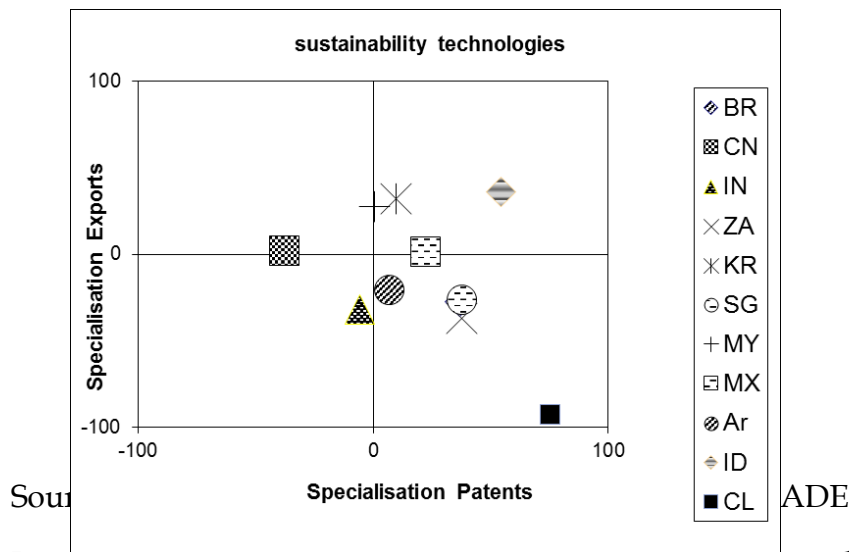
Between 2003 and 2020, the exports of all four segments of the markets were growing in absolute terms (Figure 3, left hand side). However, the growth of exports from the South exceeded the growth of exports from the North, resulting in rising shares of exports from the South to both markets in the South and in the North (Figure 3, right hand side). The data shows a remarkable change of the pattern after 2003. Most of the growth of exports is to markets in the South. Especially the exporters from the South benefitted from this increase: The share of exports from South to South of overall exports has been increasing substantially between 2003 and 2020, and is now making up almost 20 % of world exports. In contrast, the share of exports from the North to the South has been declining from 22 % in 2003 to also about 19 % of all exports. Thus, the increase in the share of exports going to the South (from 30 % in 2003 to 38 % in 2020) can be attributed to an increase of exports from the South. As the share of exports of the South to the North is also in the same order of magnitude as the exports of the North to the South, it can be concluded that the South does not run a trade deficit with the North with regard to environmental technologies. Clearly the strong dependency of the South on green technology imports from the North has been ended during the 20 years of Globelics. This corresponds with an increase of the importance of China as a supplier of green technologies, in particular for the South. In 2003, China accounted for only 5 % of green technology exports to countries of the South. This share has risen to 20 % in 2020.

Figure 3: Export and export shares of green technologies for countries of the South and North



Source: own calculation, based on data from COMTRADE

Figure 4: Trade and patent specialization of countries on environmental innovations in 2020



In order to account for different country sizes, different developmental stages and different propensities to patent, we also calculated the specialisation for patents (RPA) and exports (RXA). Here we find considerable heterogeneity among countries of the South. Clearly this heterogeneity reflects that countries are following a specific path which reflects their strengths and weaknesses. Three countries which are specializing on green technology exports are Malaysia, South Korea and Indonesia, with the latter two at the same time also specializing on green patents. Albeit running a negative trade specialization, Singapore, South Africa and Chile are clearly specializing on green technology patents. With many of the countries located in the two quarters at the right hand side, it nevertheless gives an indication that many countries of the South seem to address the challenges but also the future opportunities of growing green markets by specializing on green patents. One clear exception is China, which is a special case in itself. Its strong increase in share of patents can be attributed to its overall dynamics in increasing patents, not to a specialisation in this sector. On the other hand, China reaches an average trade specialization. Given the enormous expansion of China's overall exports, this results in an enormous increase in export shares shown in Figure 2. However, the higher specialization on green technology exports than patents perhaps suggest that China is also absorbing a lot of cutting edge knowledge from countries of the North and uses this knowledge in form of production capabilities serving both the Chinese and export markets.

2.3 Room for improvement: improved databases, new forms of innovation

Econometric analysis using indicators to analyze determinants of development of green capabilities has been increasing for OECD countries over the last 15 years (see del Rio et al. 2016 and Herman and Jun 2022 with a review of latest results). However, as typically this analysis uses panel data, time series for

various countries are required. The limited data availability for countries of the South has limited econometric panel estimation in the past. Some indicators, e.g. green patents, require a certain threshold of number of patents in order to be used for a meaningful econometric analysis. Even though data per se might be available for a considerable time series, this additionally reduces the number of years for which meaningful data is available.

Econometric analysis involving green innovation indicators and capabilities in countries of the South therefore have been concentrated on specific instruments first, such as effects of the Clean Development Mechanism (CDM) on technology transfer (e.g. Doranova et al. 2011 or Gandenberger et al. 2016). More recently, the use of innovation indicators such as patents in this kind of research has been increasing (see Herman and Jun 2022). So far, these analysis mainly includes larger New Industrializing Countries from the South, due to the data restrictions. But with improving data situation it can be foreseen that this kind of research will increasingly also cover additional countries of the South.

The indicators discussed so far are only a small part of innovation indicators. Business surveys are another common type to retrieve indicators about innovation (Gault and Soete 2022). In the OECD countries, some of these surveys also include questions about green innovations, which have been used to analyze the drivers for green innovations. However, del Rio et al. (2016) in their review point out that these analysis have been concentrating on few Western European Countries only. Therefore they conclude: “Analyses in other developed country contexts and in middle-income and developing countries are missing. In addition, only a few comparative international studies have been published. Therefore, more studies in other countries and more international comparative studies should be carried out” (del Rio et al. 2016, p. 2168). The Worldbank has started a program on enterprise surveys, with a section on innovation as well, but almost no questions for environmental sustainability so far. It remains to be seen whether this database will expand in the future and could build a basis also for the needed analysis.

Using indicators to measure innovations have many caveats (see Gault and Soete 2022). Most important, however, are two main problems, which reduce the validity of indicator based analysis as such. First of all, it is increasingly acknowledged that environmental sustainability needs transformation of whole systems. Transformation itself requires co-evolution with regard to institutions and policies being of high importance. Thus, to portray such developments, it is no longer enough to look at innovation indicators only. They must be complemented by indicators which describe the process of transformation and development of institutions and policies. Second, technological innovations measured by the innovation indicators will be more and more complemented by innovations below the radar (e.g. frugal innovations) and

social innovations. The existing indicators, however, are not able to picture the development in these domains. This also has implications for evaluating the role of the Global South in generating environmental sustainability innovations. The concept of frugal innovations, for example, did arise first in the countries of the Global South, are most prominent there, and now slowly diffuses also to countries of the North (Tiwari and Herstatt 2019; Gandenberger et al. 2020). Thus, taking these forms of innovation into account shows an even stronger development of environmental sustainability innovations capabilities in the South than the analysis with traditional innovation indicators. It clearly underlines the conclusion that the times of “catch-up” are over with regard to environmental sustainability innovations: Countries of the South are no longer just a place for diffusion of sustainability innovations developed elsewhere only, which requires “catch-up”, but are a major place where these innovations are generated, too.

3. Heuristics for analyzing environmental sustainability innovation systems

3.1 Case studies of energy and environmental innovation systems as topic of Globelics research

Case studies to analyse how environmentally sustainable innovations are generated, what obstacles have to be overcome and which supporting policies are necessary has been a second major theme of research within Globelics. Sessions on environmentally sustainable innovations have been a common feature of the annual Globelics conferences, as they are of the latest bi-annual ones, with most of the contributions analysing case studies. There are also various special issues and publications which did grow out of this already in the early 2010s, building on innovation system concepts and MLP concepts. Examples are the special issues “Sustainability innovations in newly industrializing countries” (International Journal of Globalisation and Technology 2011 (6), “Sustainability-oriented innovation systems in China and India” (Innovation and Development 2012

(1) or “Low Carbon Innovation and Development: Insights and future challenges for research” (Innovation and Development 2015 (2)), or more recently Latecomer Development in a “Greening” World (World Development 141, May 2021). The Globelics Thematic Review on “Low Carbon Innovation and Development” (Lema et al. 2014) characterizes perhaps best the impetus and the key issue of this research. The remainder of this chapter, however, does not focus on reviewing the extremely broad and rich empirical evidence, which might be best summarized with the conclusion that there is no single road to build up environmental sustainability. Instead, we focus on methodological issues, and challenges, which are key to further progress of research in this domain. Therefore we look on the development of the state-of-the-art of the key heuristics of technological innovation systems and MLP-

approaches, and what new challenges we see arising in the future from a methodological point of view.

3.2 What we know: Heuristics used for analysing environmental sustainable system development

In the late 1990's and early 2000s, innovation research developed the concept of technological innovation systems (TIS). This approach complemented innovation **systems** approaches developed for national and sectoral systems (see e.g. Lundvall et al., 2002; Malerba, 2005). In particular technological innovations in the energy sector (especially renewable energies) have been investigated in numerous case studies for OECD countries since the early 2000s. In parallel, the concept of the functional approach was developed within the TIS approach to account for the systemic nature of innovations (Smits and Kuhlmann, 2004; Hekkert et al., 2007; Bergek et al., 2008; Hekkert and Negro, 2009; Markard et al. 2015). In this context, the fulfilment of the following innovation functions is considered central to the success of an innovation system:

- *knowledge generation (F1),*
- *knowledge diffusion (F2),*
- *guidance of search (F3) (directing R&D and search for new solutions with respect to technology and market),*
- *entrepreneurial experimentation (F4),*
- *facilitation of market formation (F5),*
- *legitimization (F6) (recognising a growth potential for the technology and the ability to counteract political resistance and to push for political support),*
- *resource mobilisation (F7).*

This approach has been widely used since the late 2000s. Characteristic of the drivers of change are the feedback loops between the seven innovation functions under consideration. They can lead to self-reinforcing effects (virtuous cycles) that accelerate the further development of the TIS under consideration (cf. Hekkert and Negro 2009).

Parallel to the development of the TIS approach, the multi-level perspectives (MLP) approach emerged. This approach combines ideas from evolutionary economics with the research tradition of social science and technology studies (STS), and has found wide application in the analysis of sustainability transition over the years (cf. Wang et al. 2022). The multilevel perspective distinguishes between landscape, socio-technical regime, and niche (cf. Geels 2011; Weber and Rohracher 2012). While the landscape describes overarching societal conditions and developments, socio-technical regimes organize specific sub-areas, such as energy supply with its basic technologies and organizational and institutional structures. Drivers of change are, on the one hand, the innovation activities of individual actors in the niches in which completely new solutions

are tried out. Other drivers of change are mediated primarily by the interactions of the three levels: landscape, regime and niche. On the one hand, long-term developments at the landscape level can negatively affect the functionality of the existing socio-technical regime, leading to destabilization. On the other hand, alternative developments emerging in the niche can grow into an alternative to the existing regime. Ultimately, these drivers can then bring about a change in the socio-technical regime.

3.3 Room for improvement: Adapting the heuristics to analysing transformations

The transformation of entire socio-technical systems has gained importance as a term. Transformation of the energy system, but also objectives such as new forms of mobility, sustainable water management or the move towards a bioeconomy aim at the transformation of entire systems and sectors in the direction of ecological sustainability (Salomaa and Juhola 2020; Linner and Wibeck 2021). Typically, such transformations bundle multiple technological innovations together. At the same time, transformations require institutional innovations on the most diverse levels. Especially in the case of sustainability transformations, new roles (e.g. prosumers), changed values (e.g. sharing instead of owning goods) and new norms (e.g. in the food sector) and thus social innovations are increasingly being addressed. Characteristic of transformations are the interweaving of several types of innovation, but also diverse interactions with the social and political environment, in which the most diverse interests of those involved come into play.

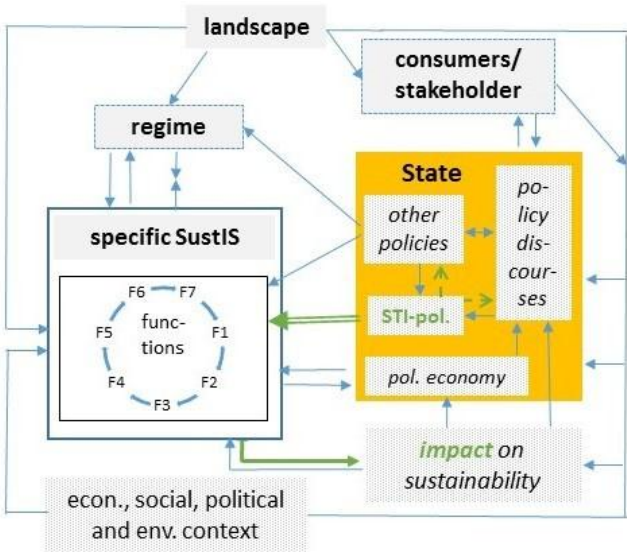
From the point of view of the MLP approach, a sustainability transformation always faces the challenge of which transition path can be used to overcome the path dependency resulting from the strength of the regime (Geels and Schot 2007). Transition paths can be characterized by conflicts between the existing regime and growing niches. Such conflicts are for example likely if the transformation involves so-called exnovations – that is the targeted phase out of established but sectors which are detrimental to sustainability, such as e.g. fossil fuel supply. Here, any social and economic hardships that may arise must be cushioned and long-term changes initiated and facilitated. For the TIS approach, taking a transformation perspective means that the embedding of the technological innovation system in the existing sectoral and national innovation systems, but also the interactions with other social subsystems must be taken into account (Bergek et al. 2015). The transformation character thus increases both the number of actors to be considered and the associated interactions and impact dimensions.

The literature on TIS and MLP already addresses the need to consider more political contexts (Geels 2014; Kern 2015). The increasing entanglement with the context factors in the course of the transformation requirements reinforces this requirement. Questions of power and political economy, but also the social

acceptance of innovations and sovereignty over transformation discourses become central context factors. The drivers of change are becoming more heterogeneous and their analysis increasingly complex. All of this requires that the analysis carried out within the TIS and MLP approaches are systematically linked to other social subsystems.

The overlap between the TIS and MLP approaches and the perspective of using them together has been already addressed early on by Markard and Truffer (2008). In this line of thinking, Walz and Köhler (2014) defined TIS in renewable energy, energy efficiency, or transport as niches from a MLP perspective. They are integrated into a MLP framework which reflects the sectoral regimes and the landscape. More recently, the influence of contextual factors, such as the sectoral background of actors or of political factors, is increasingly recognized (Ulanen and Bergek 2021; Nevzorova 2022). Approaches such as the nested approach used by Holm Andersen and Lema (2022) reflect this line of thinking. Another approach is to enlarge a combined TIS/MLP framework by integrating consumers and stakeholders, economic, social political and environmental context factors together with factors which influence the political economy and the policy discourse into the analysis. Figure 5 shows the elements of such an enlarged system: A specific emerging sustainability technological innovation system is interpreted as a niche. This TIS is characterized by innovation functions which are connected with each other by various feedback loops. The integration of consumers, context factors and activities of the state enlarges the number of feedback loops in such an analysis: In addition to the feedback loops between the different innovation functions, the societal subsystems interact with each other, the emerging TIS, and the sectoral regime. This increases the complexity of the analysis considerably, and has led to calls to accompany the analysis of case studies with a modelling of the dynamics of the system (Köhler et al. 2018; Papatristos 2019; Maldonado and Grobelaar 2019).

Figure 5: Scheme of combined TIS/MLP approach enlarged with additional subsystems



Source: own compilation

4 Role of the state

4.1 What we know: the pivotal role of the state in environmental sustainability in- novation policy

In the prevailing neoclassical economic theory, a justification for government intervention is based primarily on the logic of a market failure. In more neoclassical innovation eco- nomics, it is undisputed that difficulties in the economic acquisition of new knowledge can create an incentive for too little innovation activity, and that measures to secure the economic benefits from innovations and financial support for undertaking R&D activities are therefore necessary. From a systemic understanding of innovation, which builds on an understanding as innovation as a social process, there is a broader spectrum for government innovation policy necessary, which also addresses various systemic failures in the innovation system (cf. Weber and Rohrer 2012). Research within Globelics clearly is based on such a systemic understanding of innovation system which assigns a high importance of government action in fostering innovation and to shape it towards inclusive development.

However, it is also undisputed that there is an additional rationale for the state in envi- ronmental sustainability innovation policy, even among neoclassical economists. Envi- ronmental externalities are this additional reason for government action. Neoclassical environmental economists emphasize the increase in the cost of using the environment as a central factor in stimulating demand for environmentally friendly solutions. Rennings (2000) derived from this the “double regulatory challenge” of environmental innovations. Without government intervention to correct the market mismatch resulting from the pres- ence of environmental externalities, the demand for environmental innovations remains at too low a level. From the perspective of innovation research, however, the generation of demand for environmental innovations derived from the neoclassical logic by making the use of the environment more expensive is nothing else than a demand-oriented in- novation policy. An increasing role of the state in environmental sustainability innovations can be also derived from regulatory economics. From the perspective of regulatory eco- nomics, many sectors that are particularly relevant to sustainability (electricity and gas, railways, water management) can be regarded as monopolistic bottlenecks, resulting in sectoral regulation requirements. The economic sector regulation can have either pro- moting or inhibiting effects on the respective sustainability innovations. This adds an ad- ditional dimension to the “double regulatory challenge” resulting in a "triple regulatory challenge" (Walz 2007) for sustainability innovations in these sectors. Thus, it can al- ready be deduced from the neoclassical economic theory discussion that sustainability- oriented innovation systems are characterized by a particularly high degree of political measures. If one adds the systemic perspective to this, it

clearly can be seen that the state holds a pivotal role in achieving environmental sustainability innovations.

The high importance of government activities also emerges from the empirical TIS literature. The positive feedback loops that are particularly important for the dynamics of TIS are often triggered by government activities (Hekkert and Negro 2009; Bergek et al. 2008). The focus here is on innovation functions such as market formation (in line with the neoclassical double regulatory challenge), but also guidance of search and legitimization, where normative ideas are particularly obvious as drivers of change. At the same time, the importance of governmental activities is also evident in the MLP approach with its ideas on transition management and protective space (Smith and Raven 2012). The range of measures discussed in these approaches in the sense of a "comprehensive failure framework" (Weber and Rohracher 2012) is much wider than in the neoclassical argumentation.

What is central, however, is that the intensity of government activities has to be greater in environmental sustainability innovation systems than in "normal" innovation systems. This is a necessary consequence of the directionality of sustainable innovation systems, where the innovations are supposed to contribute to the achievement of environmental goals, but at the same time are hindered in their diffusion by the "double regulatory challenge". Therefore, the increase in government activities takes place in demand-side innovation policy.

The increased importance of demand-side innovation policy also affects the importance of the instruments discussed for innovation policy (cf. Edler and Fagerberg 2017). In general, it has been noted for innovation policy that it has long been very focused on supply-side innovation policy measures in terms of the set of instruments. In "normal" innovation systems, measures such as government procurement and the role of standardization have recently gained importance. While government procurement is significant for the establishment of an initial market and the first upscaling of solutions, standardization affects both the demand side and the supply side (Edler and Fagerberg 2017). However, within the innovation policy discussion of "normal" innovation systems, measures to promote the broad diffusion of private actors have so far played a lesser role. Here, the willingness of lead users to adopt new innovations and the diffusion mechanisms described in the diffusion models of Rodgers and others play central roles. These are market-driven processes supported by innovation management. In environmental sustainability innovation systems, on the other hand, the promotion of private demand - listed as one of 15 instrument types in Edler and Fagerberg (2017) - plays a very central role as a driver of change. The importance of the TIS approach in this context also lies in a better understanding of the interplay of measures to promote diffusion and innovation. Thus, the TIS approach is able to explain the role of different types of instruments in the renewable energy field. In

particular, central themes have been the role of feed-in tariffs and the importance of policy mixes in promoting innovation (see Bergek et al. 2015; Reichardt et al. 2016; Reichardt et al. 2017; Jacobsson et al. 2017). This research, primarily operating with case studies, has been complemented in the last 10 years by econometric studies on the determinants of environmental and energy innovations. In this context, analyses of company surveys show the importance of government measures for environmental innovations (del Rio et al. 2016; Horbach 2016; Horbach and Rammer 2021). Other studies show the impact of different types of support mechanisms such as feed-in tariffs on innovation in renewable energy technologies, as measured by patent numbers (Johnstone et al. 2010 and Costantini et al. 2015). However, Schleich et al. (2017) in particular also point out that factors other than the type of instrument are important. These include, for example, policy style and the guidance function of ambitious and credible targets. To sum up the significance of all this empirical research: For all the differences in detailed statements, both the qualitative case studies and the quantitative statistical analyses underscore the importance of early demand stimulation for further innovation of environmental sustainable technologies. As mentioned in section 2.3, future research could increasingly use such databases also for countries of the South.

4.2 Room for improvement: accounting for additional roles of the state in steering sustainability transformations

It is becoming increasingly clear that the intensity and magnitude of the environmental sustainability challenges require speed of sustainability transformations. Such transformations also entail considerable structural distortions and distributive consequences. The most prominent example is the phasing out of fossil fuel industries. But transformation also goes hand in hand with the desirability of social change, including new patterns of consumption. This is particularly evident in the debate on sufficiency, which is addressed both instrumentally as a means to achieve ecological goals, but also as a goal in itself (Jungell-Michelsson and Heikkurinen 2022). Together with the distributional conflicts, this leads to sustainability transformations being discussed in a far more conflictual manner than technological sustainability innovations. Clearly the ability to shape discourses and to deal with the political economy are becoming even more important as they are already today.

Another difficulty is that in the course of environmental sustainability transformations, new adaptation requirements suddenly appear in the system, which make it difficult to define ex ante how a transformation strategy looks like. This need for adaptations in the transformation strategy can have very different causes:

- Behind the sustainability challenges lie complex, non-linear environmental systems. Thus, individual manifestations of the

challenges are difficult to predict, and may entail an adjustment in the required sustainability transformation.

- Crises from different domains increasingly interact with each other (Homer-Dixon et al. 2022). For example, geopolitical shifts and foreign policy conflicts can suddenly lead to the need to readjust even targeted sustainability transformations, e.g., if a resource intended as a bridging technology suddenly disappears.
- A sustainability transformation can also have negative impacts on other sustainability challenges. An example is the increasing demand for certain critical raw materials resulting from renewable energy technologies. This requires to adapt strategies to cope with the multitude of challenges, including value-based decisions on trade-offs between different environmental dimensions.
- The hallmark of sustainability transformations is precisely their stronger integration into other societal subsystems. Economic and social impacts of sustainability transformations can themselves be perceived as disruptions and interact with societal acceptance and political willingness to support sustainability transformations. These processes are also non-linear and may require adaptation of the sustainability transformation to account for political context situations.
- To sum up, these developments lead to additional expectations on the state regarding the steering of a transformation. On the other hand, the state's ability to manage the complex transformation processes is limited. This requires to improve the steering capacity of the state. Five central aspects emerge that appear to be urgent:
- Improvement of the science-policy interface and of anticipatory capabilities,
- Improvement in the methodologies to analyse the impact of STI policies on sustainability,
- adaptations of governance to interdepartmental integration and resilience requirements,
- improving the conditions for and influencing societal discourse, and
- systematic inclusion of the political economy in strategy formation.

In the area of the science-policy interface, improvements are needed both on the part of science and on the part of policy: To strengthen the knowledge base for sustainability transformations, there is a recognized need for stronger inter- and transdisciplinary orientation as well as problem- and application-orientation of research. However, this also requires a much better understanding in the political arena of the significance of such analyses. Thus, increasing the absorptive capacity of government within the science - policy interface is increasingly coming into focus (Edler et al. 2022). Closely related to systemic analytical capacities is the anticipatory capacity of policy. The broad use of foresight approaches represents a valuable approach to increasing anticipation

capacity here. In this context, it will be important to anchor foresight processes in government action.

As mentioned above, sustainability transformations will be discussed in a far more conflictual manner than technological sustainability innovations. In this process, the potential consequences of strategies for achieving the sustainability goals, but also what economic and social impacts follow, become important. Traditionally, the evaluation of STI policies follows an IOOI logic, i.e. inputs lead to outputs and outcomes, from which in turn the impact follows. However, the end-point of these impulses on reaching the environmental sustainability goals and on its economic and social consequences are typically not included in these assessments. There are two fundamental issues which make such an assessment difficult:

- The impact on sustainability goals cannot be attributed to a single factor (attribution problem). This is because numerous (success) conditions must be in place for a successful contribution of sustainability strategies, such as a successful demand side innovation policy which complements the supply side.
- The impacts occur with a considerable time lag and can therefore not be extracted in parallel from monitoring (ex-ante problem). This requires to develop methodologies for future-oriented assessments.

The need to deal with these conceptual issues currently leads to a search for new methodological approaches. One approach is to adapt macroeconometric models for such an assessment of STI policies, which is very prominent within the EU (see Taylor 2022). Another approach might be to link qualitative oriented evaluation methodologies with more quantitative based methodologies, which are employed for scenario based strategic impact assessment of sustainability strategies. Clearly there is room for improvement to develop and use such methodologies also to analyse STI policies for environmental sustainability transformations in countries of the South.

The systemic consideration of interdepartmental issues is already a challenge for governance in the case of single sustainability innovations. The problem becomes even more acute in the governance of sustainability transformations. The challenges that arise can be illustrated by the example of climate policy: Climate mitigation measures to accelerate the diffusion of innovations also have an effect on the generation of further innovations in the sense of demand-oriented innovation policy in interaction with supply-side STI policies. The challenge now is to ensure that the sector-specific planning of mitigation measures includes not only the sector-specific know-how of the sectoral departments, but also sufficient supply-side functional know-how regarding the effects of the sectoral climate protection plans on the generation of innovations. However, the knowledge required for this goes beyond the traditional field of activity of the sectoral departments. It will be necessary to

resolve the contradiction between sectoral responsibility and available functional know-how.

The above-mentioned shaping of discourses under the conditions of the political economy are also related to the central task of politics to build understanding and trust between society, science and politics. Transformation narratives should be developed early, purposefully and consciously. At the same time, it is to be expected that the measures to support the transformations will be fiercely contested politically. The associated political conflicts, as well as the respective conditions for success and existing power asymmetries, will thus become important drivers that determine the speed and direction of change. The targeted induction of policy feedbacks, support in coalition building, and the unblocking of transformation-blocking discourse hegemonies will complement the range of tasks of a policy to promote sustainability innovations (Jordan and Matt 2014; Hess 2016; Bayer and Urpelainen 2016; Hajer 2006).

The recent changes in the geopolitical landscape will also effect the patterns of cooperation for sustainability innovations. On the one hand, the international climate governance system is built on the idea of international cooperation to reach a common goal. It is not clear how these architecture will look like in the future, and what implications for innovation processes will results. On the other hand, environmental sustainability strategies are also associated with an increasing demand for hydrogen and certain key strategic minerals for environmental technologies. Strategies of countries of the North look into increasing imports of these resources from countries of the South. It will be necessary to analyse how these developments will play out, and whether or not we will experience new forms of imperialism or perhaps a greater room for manoeuvring for the South under the changing geopolitical landscape. However, given the increasing role of China as a major supplier of environmental sustainability technologies, the cooperation pattern between China and countries of the South (e.g. Lema et al. 2021) will also become a major topic.

5. Conclusions and outlook

This paper discusses what we know after 20 years of research on environmental sustainability and innovations, and what further room for improvement emerges to improve our knowledge. This two-step approach has been performed for three key topics of Globelics research on environmental sustainability: first, the development of sustainability capabilities in countries of the South; second, methodological issues on the heuristics to be used to analyse case studies; third, the specific role of the state to achieve the envisaged changes.

Analysing capabilities for sustainability innovations in the South builds on the notion that indigenous competences in sustainability related science and technology fields were increasingly seen as a prerequisite for the successful absorption of sustainability technologies in NICs on the one hand. On the other hand, the same process also yields the potential for catch-up and leapfrogging. This paper presents novel empirical trade and patent data how these competences have been changing over the last 20 years. Clearly the strong dependency of the South on green technology imports from the North has been ended during the 20 years of Globalics, and South-South trade has seen the strongest increase in trade relations. Using the improving data base for econometric analysis is a promising line of future research. More important, however, seems to increase research and analyzing capabilities in particular for transformation of whole systems and for social and below-the-radar innovations, which are not accounted for with the typical innovation indicators. Taking these forms of innovation into account shows an even stronger development of environmental sustainability innovations in the South than the analysis with traditional innovation indicators. It also allows a stronger focus on innovations in developing countries which do not belong to the NICs. All of this clearly underlines the conclusion that the times of “catch-up” are also over with regard to environmental sustainability innovations: Countries of the South can no longer be seen predominantly as the place for diffusion of sustainability innovations developed elsewhere, but as a major place where these innovations are generated, too.

The concepts of innovation systems have been important methodologies for Globalics as such, and also for research on environmental sustainability innovations within Globalics. With regard to analysing environmental sustainable innovations systems, the last 20 years have seen the emergence of the TIS and MLP approach. Characteristic of the drivers of change within the TIS approach are the feedback loops between the seven innovation functions under consideration. Drivers of change within the MLP approach are, on the one hand, the innovation activities of individual actors in the niches in which completely new solutions are tried out. On the other hand, change is mediated primarily by the interactions of the three levels: landscape, regime and niche. The empirical results obtained within Globalics showed that there is no single road to build environmental sustainable innovation systems, but that the specifics of countries have to be accounted for. Room for improvement of the methodology relates mainly to the need to more systematically account for transformation of whole systems. Questions of power and political economy, but also the social acceptance of innovations and sovereignty over transformation discourses become central context factors. The drivers of change are becoming more heterogeneous and their analysis increasingly complex. All of this requires that the analysis carried out within the TIS and MLP approaches is systematically linked to other social subsystems. Thus, there is room to improve methodology by employing nested approaches or by embedding combined

TIS/MLP approaches into a wider systems environment which accounts for additional actors and system logics.

The roles of the state within Globelics research in general follows a system logic, which sees a stronger role for state actions than neoclassical economics. The last 20 years have also clearly shown that the role for government action is in particular strong for environmental sustainability innovations. In the case of environmental sustainability innovation systems, influencing private demand within the framework of demand-side innovation policy plays a far more important role than in "normal" innovation systems. Both qualitative case studies and the quantitative statistical analyses underscore the importance of early demand stimulation for further innovation of environmental sustainable technologies. In innovation policy, this leads to an increase in the importance of demand - side policy instruments and sector-specific governmental departments. This further intensifies the already existing challenges of integrating innovation policy into the various ministries. There is also room for improving research on the role of the state: New requirements to steer environmental sustainability transformation requires the state to take on additional roles and to address further social subsystems outside the actual innovation systems. This will require improvements in the science-policy interface, increased foresight and impact assessment capabilities, adjustments in governance, an increase in the state's ability to engage in discourse, and strategic inclusion of the conditions of the political economy. To analyse these requirements and policy options are a field for further research within Globelics.

There are also additional developments which might shape future research on environmental sustainability innovations within Globelics. Most analysis dealt with climate mitigation so far, in particular with renewable energies. However, this needs to become more heterogeneous in the future: First, it can be foreseen that climate adaptation will play a much larger role in the future. With climate adaptation linked to other sectors such as water resources and agriculture, research at the intersection of environmental sustainability and other sectors beyond energy will increase. Second, the link between climate mitigation and circular economy will become more important. On the one hand, a circular economy can play an additional key for reducing industrial CO₂-emissions by lowering the demand for production of primary basic materials. On the other hand, climate mitigation technologies also drive up the demand for certain raw materials. Thus, we might see also research in this area linked to difficult debates about trade-offs. Third, novel substances have been lately identified as another key areas in which the planetary boundaries are exceeded (Persson et al. 2022), which calls for innovations research in this area of environmental sustainability challenges.

Dealing with transformations in research will be a key challenge for research on environmental sustainability innovations. However, this is also true for other

innovation domains , such as in the digital or biological transformation of production. As in the case of sustainability transformations, the level of analysis is expanding here, and interactions with other subsystems - such as with the world of work in an "Industry 4.0" or the change in lifestyles in the course of digitalization - are gaining in importance. This is accompanied by an increase in normatively shaped discourses about the living conditions to be strived for and how to deal with the disruptions triggered by the transformations. The roles of the state become more diverse. All of this has also implications for the scientists working in the field of innovation research themselves. Increasingly, different perspectives and research approaches need to be combined and integrated. All of this requires a willingness to engage in genuine interdisciplinary research, in which existing analyses are not merely juxtaposed, but patterns of thought are integrated, if necessary broken up, and jointly developed further. For Globelics, this also requires to open up towards other research communities. Finally, the increasing normativity in the subject area of the analyses also requires in-depth reflection processes in which the respective scholars also have to question themselves with regard to their own normative assumptions, including reflections about political processes and the own position taken. Thus, research on environmental sustainability innovations also involves reflecting about the ethical foundations and fostering personal competences of the researchers – clearly a task for Globelics worth striving for.

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Effect of innovation on carbon emissions: Evidence from developed and developing countries

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1. Introduction

With increasing evidence of climate change and environmental destruction across the world, it has become imperative for countries to pursue environmentally sustainable economic growth. The transition from fossil-fuel driven growth to green and sustainable growth can be attained by investing in innovation to optimize the use of resources and adopt technologies that minimize the carbon footprint (Foxon, 2010; Ganda, 2019). The relevance of technological progress and innovation for economic growth has been underlined by Solow (1957) and later established in the literature by the endogenous growth models (Romer, 1986; Lucas, 1988; Grossman & Helpman, 1991). Much earlier, Schumpeter (1932) had expounded on the significance of industrial innovation or ‘creative destruction’ for growth.

However, an examination of the growth trajectories of the developed countries of the world indicates that development has been at the cost of the environment. The Environmental Kuznet’s Curve (EKC) postulates an inverted U-shaped relationship between economic growth and environmental degradation (Grossman & Krueger, 1991; Panayotou, 1993). It hypothesizes that pressure on the environment rises in the initial stages of industrialization, but declines beyond a point when per capita income rises (Dasgupta et al, 2002 among others).

We believe that innovation is a key factor that sustains this relationship between growth and environmental quality as it drives technological change which improves productivity and leads to the generation of cleaner and energy-efficient technologies. It is well-established in the literature that innovation fuels productivity and by extension optimizes resource use (see for example, Mohnen & Hall, 2013; Crespi & Zuniga, 2012; Joseph, Kakarlapudi & Arun, 2021). Engaging in efficient production methods and sustainable technologies are observed to be effective methods to combat climate change (Masui et al,

2006; Rafindadi, 2016). However, innovation is costly and riddled with uncertainty which makes it difficult for low-income countries to spend greatly on it (Mazzucato, 2011). Investing in in-house innovation is a big challenge for developing countries also because most of them are much below the technological frontier to the point that some of the earlier technological revolutions are yet to reach complete diffusion in them (UNCTAD, 2023). It is also not helpful that a few rich countries hold the majority of the patents in frontier technologies¹. Innovation drives productivity growth and inability to engage in frontier innovation can act as a hurdle for countries, especially the less- developed ones to adopt a low-carbon growth strategy.

However, it is intriguing that the many of the countries in the Global North figure both in the list of the most innovative economies as well as the top CO₂ emitting countries (European Commission, 2022)². Data on per capita CO₂ emissions indicate that these countries are highly energy intensive and that despite a slight decline in the overall trend in the last 50 years, they still have high levels of emissions. Countries such as the United States, China, Russia, Japan and the EU27, together with emerging economies like India, Brazil, South Africa, Mexico and Turkey account for the lion's share of total carbon emissions in the world (European Commission, 2022). This observation also goes against the estimation (made by existing empirical studies on EKC. See, Dasgupta et al, 2002 for details) that pollution will begin to decline as per capita incomes go beyond \$5000-\$8000. All the countries mentioned above, with the exception of India have a per capita GDP above this range.

Thus, contrary to the expectations of EKC, recent data shows that innovativeness or income levels need not necessarily lead to better environmental consciousness and lower carbon emissions. This inconclusiveness in prediction calls for an empirical examination of the innovation-emission relationship to confirm its cogency as well as to corroborate the empirical validity of EKC. This relationship has implications on innovation policy and the popular push for green technologies. We also believe that the nature of innovation undertaken by countries can influence this relationship. Countries with greater income and technological capabilities undertake independent in-house R&D, which lead to cutting edge innovations and very high productivity. Developing countries whose innovation may largely be reliant on import of embodied and disembodied technology are often less efficient as there is a time lag in technology diffusion in them.

This study is organized into six sections including the introduction (Section I). Section II details the key insights from the literature, while Section III explains the data and the variable construction. Section IV specifies the empirical strategy while Section V discusses the results. The final section concludes the paper and explains the key policy implications of this study.

II. Insights from the literature

Income growth affects environmental quality through broadly three channels (Grossman, 1995; Dinda, 2005). There is a scale effect, i.e., an increase in the scale of economic activity is expected to enhance environmental degradation as the pressure on natural resources rise. However, over time with rising depletion of resources, the environment becomes a scarce commodity and there would be a greater demand to protect it (Jaeger, 1998). Some scholars explain the EKC to be the effect of a structural change or a shift from the primary to the secondary and later to the cleaner tertiary sector (composition effect). This is also accompanied by the technique effect or the replacement of polluting conventional technologies with superior cleaner ones. If the scale effect is overcome by the composition and technique effects, the EKC becomes possible (Elkins, 1997). Thus, the relative strength of the three effects determines the relationship between income and environmental quality in different regions. Some scholars also theorize that the inverted U of the EKC is observed because in the initial stages of growth, all the capital in the economy is allocated to production, which generates pollution as a by-product. As the economy matures, an optimal level of the capital is dedicated for pollution abatement which brings down the degradation levels (Andreoni & Levinson, 2001; Dinda, 2002). The focus of our study is the technique effect or the technological change that leads to improvements in environmental quality as income increases.

EKC is largely considered an empirical phenomenon which have been confirmed by a large number of studies since the 1990s (Larson et al, 2012). However, there have been variations in the results with respect to the pollution variable used. For example, Cole et al (1997) confirm the inverted U relationship only in the case of local pollutants and observes a monotonic increase with income in the case of global measures.

Studies which confirm the EKC identify structural change (composition effect) coupled with technological change (technique effect) and improvement in regulatory systems as well as awareness about the environment to be the factors driving the relationship. Zhang (2004) finds that more than the structural shift, it was the technique effect that caused the decline in industrial energy use in China in the 1990s. In their study on the effect of economic growth as well as public investment in energy-related R&D in OECD countries, Balsalobre et al (2015) note that energy innovations help reduce the energy intensity of countries as well as mitigates greenhouse gas (GHG) emissions. This study undertakes a similar yet broader approach and examines the impact of different modes of innovation on carbon emissions in both developed and developing countries.

While there have been some country-level studies detailing the innovation-emission relationship (especially in the context of China; for example, Gao & Yuan, 2021) there are few cross-country works on this topic. Moreover, the

international studies that exist in this domain are in the context of developed countries (for example, Alwarez-Herranz et al, 2017; Fernandez et al, 2017; Ganda, 2019). We believe that there could be a difference in the kind of innovation undertaken by developing countries vis-a-vis their developed counterparts and that this variation could affect the innovation-emission relationship. As technological change takes place through deliberate investments in different kinds of innovation including R&D, import of embodied and disembodied technology, it is pertinent to explore the effect of varied kinds of innovation on emissions. We expect our study to throw light on issues that may help developing countries in formulating their innovation policy and in planning on how they can 'leapfrog' into a low-carbon growth strategy.

III. Data and Variables

The variables used in this study are sourced from the World Bank's database on countries. Countries are grouped based on their income level. The first group includes the high-income countries, while the second group comprises of upper-middle-income and lower-middle-income countries. The time period considered for our analysis is 2009 to 2019. This is primarily due to data availability for most of the countries in this period. The years after 2019 are not considered in order to avoid the influence that the pandemic may have on the variables under analysis. Countries lacking information on any of the variables used in the analysis are excluded from the dataset. Additionally, countries with CO₂ emissions that are significantly above or below the average are considered outliers and are also excluded³.

The dependent variable in our analysis is carbon dioxide emissions (metric tons per capita). This is a well-accepted measure of pollution in the literature and has a direct impact on global warming and climate change. The key independent variables used in our study are as follows:

- Research and development expenditure (% of GDP)
- High-technology imports (% of total imports)
- High-technology exports (% of manufactured exports)
- Renewable energy consumption (% of total final energy consumption)
- Ratification of the Kyoto Protocol (Dummy variable)

Research and development expenditure (% of GDP): Investment in R&D has an impact on productivity and growth, which has a consequence on levels of environmental pollution (EKC) (Hasan & Tucci, 2010). The role of R&D expenditure in driving growth has been theorized by the endogenous growth theorists (Romer, 1990; Lucas, 1988; Grossman & Helpman, 1991). R&D expenditure is a widely used input measure of innovation, often used as a

proxy for technological innovation (for example, see Bogliano, 2014; Piva et al, 2005).

High-technology imports (% of total imports): Import of embodied and disembodied technology is an important channel of technological transfer that triggers technological innovation in the home country (Almeida & Fernandes, 2007) R&D undertaken by the foreign trade partner is embedded in the import of capital (Coe & Helpman, 1993). It has been established in the literature that there is a 'virtuous link' between imports and productivity and consequently, growth (for example, see Thangavelu & Rajaguru, 2006; Awokuse, 2011).

High-technology exports (% of manufactured exports): The proportion of high-technology exports reflects the economic complexity of the country and its global competitiveness (Erkan & Yildirimci, 2015). The idea of economic complexity is constructed in such a way that countries with a higher degree of sophistication in exports and diversified capabilities are deemed more complex (Hidalgo, 2009). Innovation is the engine which drives technological capability building and hence economic complexity is reflective of the innovation prowess of the country. The importance of integration into global value chains as a mode of exchange of knowledge is also well-documented in the literature (Pietrobelli & Rabellotti, 2010). Exporting relationships cause knowledge spillovers through feedback loops, thereby fuelling innovation (Salomon & Shaver, 2005). Filipescu et al (2013) find that increased breadth of export leads to higher R&D intensity and innovation.

Renewable energy consumption (% of total final energy consumption): This is a proxy for investment in green technologies. According to OECD (2023), energy industries are the highest contributors to greenhouse gas (GHG) emissions, accounting for 28% of the total emissions in OECD countries. Thus, investment in renewable energy is a sure-shot mechanism to reduce carbon emissions. Many of the green technologies such as green hydrogen and electric vehicles involve frontier innovations whose market is expected to grow manifold in the next decade (UNCTAD, 2023). Multiple empirical studies conducted especially in the context of developed countries underline the significance of switching to renewable sources in combating environmental pollution (for example, Bilgili et al, 2016; Alwarez-Herranz et al, 2017; Ahmad et al, 2021; Dradra & Abdennadher, 2022)

Additionally, we use Gross Domestic Product (constant 2015 US\$) and participation in the Kyoto Protocol (policy dummy) as control variables.

IV. Empirical strategy

We examine the effect of innovation on CO₂ emissions in a set of developed and developing countries over a 10-year period. Hence, we use a basic panel data model and evaluate the possible existence of fixed and random effects.

The fixed effects method utilizes panel data to control for (omitted) variables that differ across individuals or entities (e.g., country), but are constant over time. It assumes that the characteristics of an individual may impact or bias the predictor or outcome variables and needs to be controlled for. This model removes the effect of those time-invariant characteristics and enables us to assess the net effect of the predictors on the outcome variable.

In fixed effects models, the slope coefficient of the population regression line is the same for all individuals or entities, but the intercept of the population regression line varies across countries (Stokes and Watson, 2019).

The following equation shows an individual fixed effects regression model:

$$y_{it} = \beta_0 + \alpha_i + \beta_1 x_{1,it} + \epsilon_{it},$$

where α_i is the term capturing all individual fixed effects. The time-invariant variable x_2 , from the previous section is not explicitly included as α_i includes any and all time-invariant factors that may explain y_i .

A panel regression model may also have individual and time fixed effects:

$$y_{it} = \beta_0 + \alpha_i + \gamma_t + \beta_1 x_{1,it} + \epsilon_{it},$$

where γ_t is the time fixed effect. This captures the same effect a dummy variable for each time would capture.

Given the presence of unit roots, it was necessary to employ first differences for some of the dependent variables used in the estimation. This was done to achieve stationary series, meaning that their mean and variance do not change over time. Additionally, a logarithmic transformation was applied to reduce asymmetry and stabilize the variance. Moreover, this transformation allows for an interpretation of the coefficients in terms of rates of change. In our data panel we estimate two models: the first one is for a sample of 38 high-income countries. The second model estimates the same relationship for 33 lower and upper-middle- income countries. The World Bank classification of countries into high-income, upper-middle income and lower-middle income is used here. The low-income countries were excluded due to missing data points in most cases.

V. Main Results and Discussion

We estimate the following panel data model:

$$\text{LogCO2}_{it}$$

$$= \beta_0 + \alpha_i + \gamma_t$$

$$+ \beta_1 \text{LogRen}_{it} + \beta_2 \text{LogRID}_{it} + \beta_3 \text{LogImpTech}_{it} + \beta_4 \text{LogGDP}_{it} + \beta_5 \text{LogCO2}_{t-1,it} + \epsilon_{it},$$

The dependent variable is per capita CO2 emissions, and the independent variables are the percentage of energy generated from renewable energy sources, research and development expenditure as a percentage of GDP, technology imports, GDP per capita in constant 2015 dollars, and lagged CO2 emissions by one period. Annexes 1 and 2 display the descriptive statistics of the variables used in the analysis.

Table 1 shows the results for middle income countries. The estimated coefficients in the model exhibit the expected signs, and preliminary results indicate that the percentage of energy generation from renewable sources has a significant effect on reducing CO2 emissions. However, in the case of middle-income countries, it is observed that investment in research and development, technology imports, and the increase in production and income measured by GDP contribute to the increase in CO2 emissions over the analyzed period in the panel of countries used.

The dummy variable " Ratification Kyoto Protocol " is included in the analysis. However, it should be noted that the coefficients for the dummy variables in a fixed effects panel model are not reported due to the estimation approach used in these models. Fixed effects panel models require the inclusion of dummy variables to capture the specific effects of each panel unit (countries).

Dummy variables are used to control for constant differences across panel units, which means that a specific coefficient is not estimated for each category of the dummy variable. Instead, the estimation is based on within-unit differences over time. Therefore, the estimated coefficients are presented for the remaining independent variables, which represent the average effects on the dependent variable after controlling for the fixed effects (Ratification Kyoto Protocol).

Table 1. Estimate Coefficients to middle income countries (2009 -2019).

Balanced Panel: n = 33, T = 10, N 330

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Estimate	Estimate	Std. Error	t-value	Pr(> t)	
LogRen_diff1	-0,145	0.026	-5,691	3,07E-05	***
LogRID	0,017	0.011	1,655	0,099	.
LogImpTech_diff1	0,011	0.021	0,497	0,619	
LogGDP_diff1	0,607	0.121	5,008	9,54E-04	***
LogCO2_lag1	0,882	0.026	33,450	< 2,2e-16	***
Total Sum of Squares:	3,910				
Residual Sum of Squares:	0,746				
R-Squared:	0,809				
Adj. R-Squared:	0,785				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The preliminary results from Table 2 display the estimated coefficients for high-income countries. In this case, both investment in renewable energies and

research and development expenditure, variables associated with innovation, contribute to the reduction of CO2 emissions. Conversely, increases in production and technology imports stimulate an increase in emissions.

Table 2. Estimate Coefficients to High income countries (2009 -2019).

Balanced Panel: n = 38, T = 10, N = 380

Estimate	Estimate	Std. Error	t-value	Pr(> t)	
LogRen_diff1	-0,205	0.028	-7,189	4,223e-12	***
LogRID	-0,076	0.022	-3,331	0.000	***
LogImpTech_diff1	0,055	0.024	2,214	0,027	*
LogGDP_diff1	0,253	0.125	2,035	0,042	*
LogCO2_lag1	0,867	0.035	25,037	< 2,2e-16	***
Total Sum of Squares	2,474				
Residual Sum of Squares:	0,811				
R-Squared:	0,672				
Adj. R-Squared:	0,631				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

A comparative analysis reveals that investment in renewable energy sources in high-income countries leads to a greater reduction in CO2 emissions compared to middle-income countries. Additionally, in developed or high-income countries, innovation, as measured by research and development expenditure, contributes to reducing CO2 emissions. However, this relationship does not hold true for middle-income countries, as the estimated coefficient for investment in research and development in these countries was positive.

Our results demonstrate that increases in production levels, as measured by GDP, significantly raise CO2 emissions in middle-income countries. Meanwhile, technology imports have a comparatively smaller effect on emissions in middle-income countries.

In Table 3, a random effects panel model is estimated for the entire sample, considering both high-income and middle-income countries. The random effects model allows the inclusion of a dummy variable that accounts for the Kyoto Protocol ratification by these countries, defining it as a variable capturing the environmental policy effect pursued by the countries. The results show that both investment in renewable energy generation and research in innovation, measured through investment in research and development, contribute to the reduction of CO2 emissions. The model has been corrected for

heteroscedasticity, and the Breusch-Godfrey test for autocorrelation of residuals shows sufficient statistical evidence in favor of no autocorrelation.

Table 3. Estimate Coefficients all Sample (2009 -2019).

Balanced Panel: n = 71, T = 10, N = 710

Estimate	Estimate	Std. Error	t-value	Pr(> t)	
LogRen_diff1	-0,177	0,018	-9,586	2,2e-16	***
LogRID	-0,004	0,001	-1,400	0.161	
LogImpTech_diff1	0,041	0,016	2,547	0,010	*
LogGDP_diff1	0,118	0,022	5,313	0,000	***
LogCO2_lag1	0,984	0,003	311,844	0,000	***
(Protocol_kyoto)0	0,025	0,005	4,510	0,000	***
Total Sum of Squares	481,85				
Residual Sum of Squares:	01,914				
R-Squared:	0,996				
Adj. R-Squared:	0,995				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

It is evident from the results that the innovation path that middle-income countries need to follow to achieve a low carbon growth should be different from that of their developed counterparts. While it may be useful for high-income countries to undertake cutting-edge research, it is more prudent for middle-income countries to effectively utilize renewable energy sources. It must however be noted that reducing the dependence of non-renewable energy would be beneficial for both developed and developing countries. It is interesting to observe that the effect of import of technology is insignificant for middle-income countries, while it is positive for high-income countries. This may be because of the differential in technological prowess between the two groups of countries. When developed countries import from developing countries, they are indirectly contributing to emissions by adopting less-efficient technology.

In conclusion, our analysis shows that the inverse U relationship that the EKC suggests is not evident as per capita GDP has a positive and significant relationship with pollution in all the specifications, implying that the richer the country is the greater its per capita emissions are. Though innovation in the form of R&D and green technologies can combat GHG emission levels to some extent, the developed countries are still the main contributors to CO2 emissions.

This positive relationship is visible both in the case of middle-income as well as high-income countries.

VI. Conclusion

The discussion between economic growth and development has been extensively studied in the literature through the Environmental Kuznet's Curve (EKC), which postulates an inverted U- shaped relationship between economic growth and environmental degradation. The positive relationship between technological innovation and economic growth is well-established in the literature. Authors such as Slow (1957), Romer (1986), Schumpeter (1932), among others, have made significant contributions regarding the importance of technological development and innovation in economic growth. At the same time, innovation and technological development can contribute to reducing the effects of economic activity on the environment through the reduction in resource use and production methods that combat climate change.

However, the link between income growth and environmental pollution theorized in the form of the EKC hypothesis, is highly debated and shows mixed results in different empirical contexts. The inverse U-relationship between income growth and pollution that the EKC postulates also varies according to the variable of environmental degradation considered in the analysis. Differences between high-income countries and middle-income countries can create barriers for the latter to increase investment in research and development, innovation, or a more accelerated transition to renewable energy sources. However, recent studies show that innovativeness or income levels need not necessarily lead to better environmental consciousness and lower carbon emissions in high-income countries.

We argue that innovation is the channel through which the income-pollution linkage is primarily sustained. To test this relationship, we use a globally accepted and standardised measure of pollution- per capita carbon dioxide emissions. Countries in their early stages of development cannot afford to invest greatly in innovation due to the uncertainty and risk involved in it, which leads to higher levels of emissions in the initial phase. As countries mature and devolve a part of their resources for mitigation through investment in renewable sources of energy or promoting green technologies, GHG emissions begin to decline. As countries transcend the middle-income threshold, environmental consciousness increases and they have a greater ability to invest in indigenous and cutting-edge innovation to combat pollution. For such countries, additional investments in R&D together with a significant shift to renewable energy sources and highly efficient frontier technologies can fuel a reduction in carbon emissions.

Our results show that an increase in the proportion of renewable energy sources relative to total energy consumption has a greater effect on reducing

CO₂ emissions in high-income countries. This may be due to the rapid adoption of changes in technology used for renewable energy generation in these countries, taking advantage of technological advancements and cost reductions. In other words, technological change is faster in these countries.

On the other hand, research and development expenditure has different effects among the groups of countries studied. For middle-income countries, research and development expenditure contributes to an increase in CO₂ emissions, which could provide evidence in favor of the rising part of Kuznet's Curve for developing countries. In contrast, higher investment in research and development in high-income countries reduces CO₂ emissions, indicating evidence in favor of the declining part of Kuznet's Curve for developed countries.

For both groups of countries, an increase in high-technology imports (% of total imports) and gross domestic product (GDP) has a positive effect on the increase in CO₂ emissions, with GDP contributing more to emissions growth in middle-income countries.

In conclusion, our results underline the fact that middle-income and high-income countries should adopt different strategies to effectively reduce their carbon footprint. It may be beneficial for the developed countries to invest in in-house R&D to develop cutting-edge technologies that can combat carbon emissions and global warming. However, for the middle-income countries, it makes more sense to invest in renewable sources of energy and reduce their fossil-fuel dependence, rather than spend on indigenous R&D. The innovation policies in developing countries should hence focus on building regulatory sandboxes that incentivize the use of existing renewable energy sources in an effective manner to help them shift to a low-carbon growth trajectory

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Annex 1. Descriptive statistic, high-income countries.

Country	Per capita CO2 emissions				% of energy generated from renewable energy sources				Research and development expenditure as a percentage of GDP				High-technology imports (% of total imports)				GDP (Million constant US\$ 2015)			
	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max	Mean	Sd	Min	Max
Argentina	4.12	0.20	3.74	4.34	9.45	0.80	8.59	10.74	0.57	0.05	0.46	0.63	8.51	0.70	7.41	9.66	574.882	27.282	501.900	598.800
Armenia	1.83	0.21	1.47	2.19	9.41	2.34	6.56	13.15	0.23	0.03	0.18	0.29	4.18	0.80	2.98	5.40	10.249	1.426	8.330	12.870
Azerbaijan	3.19	0.25	2.68	3.54	2.59	0.86	1.62	4.45	0.21	0.02	0.18	0.25	3.54	0.88	2.41	5.44	50.296	2.867	44.950	53.610
Bolivia	1.77	0.21	1.39	2.00	10.89	3.28	7.27	16.21	0.18	0.04	0.11	0.24	3.85	0.46	3.15	4.47	31.289	4.888	24.270	38.190
Brazil	2.18	0.20	1.80	2.51	45.22	2.26	41.71	48.92	1.20	0.08	1.12	1.37	8.77	0.44	8.21	9.57	1.774.455	79.165	1.584.000	1.868.000
Bulgaria	5.97	0.36	5.46	6.76	16.52	2.55	11.62	19.60	0.70	0.14	0.49	0.95	5.32	0.43	4.71	6.20	50.824	3.428	46.820	57.440
China	7.03	0.53	5.80	7.61	12.54	1.02	11.34	14.45	1.98	0.19	1.66	2.24	21.37	1.83	18.00	23.76	10.440.364	2.456.950	6.828.000	14.300.000
Colombia	1.58	0.11	1.40	1.74	30.86	1.29	28.90	32.53	0.26	0.06	0.19	0.37	9.46	0.53	8.50	10.17	277.609	32.486	223.400	321.400
Costa Rica	1.60	0.04	1.54	1.66	37.76	1.67	35.70	40.72	0.47	0.07	0.37	0.56	12.94	5.12	7.20	18.47	54.759	6.624	44.470	64.380
Dominican Republic	2.21	0.14	2.04	2.50	16.21	1.07	13.98	17.34	0.22	0.04	0.17	0.30	4.16	0.54	3.35	4.76	68.555	12.539	51.650	89.290
Ecuador	2.43	0.11	2.27	2.62	14.00	2.13	11.79	17.73	0.42	0.05	0.33	0.49	5.99	0.64	4.49	6.64	93.664	8.846	77.190	101.700
Egypt, Arab Rep.	2.33	0.04	2.29	2.39	5.45	0.21	5.10	5.90	0.62	0.13	0.43	0.84	4.10	0.74	3.23	5.65	325.891	39.305	274.300	398.000
El Salvador	1.10	0.06	1.02	1.24	25.95	4.74	19.39	32.62	0.11	0.05	0.03	0.18	5.13	0.16	4.90	5.39	22.965	1.828	20.200	25.780
Guatemala	0.96	0.14	0.80	1.16	65.43	1.77	62.92	67.45	0.04	0.01	0.02	0.06	6.12	0.37	5.65	6.81	59.798	6.934	49.980	70.780
Honduras	1.02	0.04	0.96	1.07	50.86	2.63	45.92	53.63	0.16	0.02	0.12	0.18	5.63	1.00	4.79	8.36	20.505	2.468	17.000	24.360
India	1.57	0.17	1.28	1.79	34.24	1.56	32.41	37.41	0.72	0.06	0.66	0.83	7.61	1.70	5.31	9.72	2.011.091	438.046	1.416.000	2.686.000
Indonesia	1.91	0.19	1.62	2.30	28.36	5.42	19.09	38.18	0.14	0.09	0.01	0.27	7.76	0.60	7.00	8.90	825.618	141.079	619.300	1.049.000
Lebanon	4.40	0.28	4.01	4.83	4.93	0.85	3.96	6.18	0.38	0.06	0.28	0.44	2.65	0.40	2.18	3.19	47.819	2.906	41.810	51.100
Mexico	3.94	0.20	3.59	4.20	9.48	0.46	8.97	10.34	0.41	0.07	0.28	0.49	16.80	1.46	15.05	19.60	1.133.064	98.798	963.700	1.255.000
Moldova	2.88	0.22	2.51	3.33	21.76	5.98	4.84	26.07	0.32	0.08	0.24	0.53	3.61	0.35	3.10	4.03	7.595	1.003	6.025	9.155
Mongolia	6.10	0.60	5.11	7.14	3.54	0.53	2.97	4.46	0.19	0.07	0.09	0.30	4.10	0.95	3.46	6.45	10.638	2.457	6.724	14.170
Nepal	0.30	0.13	0.14	0.53	82.75	5.02	74.27	88.93	0.39	0.07	0.26	0.47	5.11	0.76	3.49	6.73	23.692	3.759	18.810	30.610
Nicaragua	0.79	0.04	0.73	0.85	52.13	2.08	48.91	54.56	0.10	0.01	0.08	0.11	4.22	0.94	2.55	5.53	11.903	1.574	9.366	13.960
Pakistan	0.78	0.07	0.71	0.92	45.59	2.08	42.09	48.13	0.28	0.07	0.20	0.45	4.17	0.67	3.07	4.95	264.200	37.708	218.800	324.400
Paraguay	1.02	0.19	0.80	1.31	62.04	1.84	59.24	65.36	0.09	0.04	0.04	0.15	18.76	4.68	11.53	27.01	34.739	4.746	26.810	40.840
Peru	1.67	0.12	1.42	1.83	29.15	2.10	27.12	32.92	0.10	0.03	0.06	0.16	8.37	0.81	7.43	9.69	181.491	24.759	138.700	215.000
Senegal	0.61	0.05	0.55	0.69	42.80	5.84	36.15	51.31	0.41	0.03	0.37	0.48	3.30	0.71	2.18	4.40	17.487	2.966	14.100	22.560
South Africa	7.84	0.26	7.53	8.21	10.57	0.60	9.77	11.77	0.70	0.05	0.62	0.76	8.29	0.52	7.47	9.25	337.382	19.022	302.500	359.500
Thailand	3.60	0.17	3.25	3.76	23.16	0.67	22.25	24.41	0.63	0.32	0.23	1.14	13.27	1.29	11.30	15.70	393.555	43.915	322.700	460.400
Tunisia	2.50	0.09	2.35	2.64	12.89	1.16	11.82	16.07	0.66	0.06	0.57	0.75	5.66	0.59	4.73	6.63	44.875	2.904	40.850	49.290
Turkiye	4.46	0.36	3.99	5.07	12.93	0.99	11.40	14.21	0.89	0.10	0.79	1.06	4.83	0.80	3.83	6.22	806.609	149.233	566.400	996.400
Ukraine	5.05	0.92	3.90	6.20	4.45	1.80	2.74	7.44	0.63	0.15	0.43	0.83	4.13	1.34	2.19	6.59	102.346	7.575	91.030	112.200
Vietnam	2.21	0.61	1.53	3.51	30.73	7.36	18.65	37.90	0.31	0.12	0.19	0.53	18.24	6.49	8.40	25.65	231.027	48.668	166.600	314.900

Annex 2. Descriptive statistic, high-income countries

Country	Per capita CO2 emissions				% of energy generated from renewable energy sources				Research and development expenditure as a percentage of GDP				High-technology imports (% of total imports)				GDP (Million constant US\$ 2015)			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Australia	16.43	0.96	15.25	18.22	8.97	0.88	7.15	10.13	2.05	0.22	1.83	2.37	9.78	0.58	8.86	10.37	1,320,273	113,096	1,156,000	1,492,000
Austria	7.59	0.39	7.13	8.37	33.64	1.55	31.15	35.67	2.94	0.19	2.60	3.13	5.35	0.29	4.94	5.97	382,991	18,086	355,900	414,200
Belgium	8.57	0.54	8.04	9.79	8.35	1.82	4.83	10.66	2.44	0.35	2.00	3.16	3.55	0.32	3.12	4.11	456,755	22,612	421,300	495,200
Canada	15.67	0.19	15.42	16.00	22.24	0.29	21.84	22.69	1.74	0.09	1.59	1.92	7.47	0.55	6.88	8.43	1,529,909	107,341	1,358,000	1,696,000
Chile	4.51	0.30	3.89	4.80	27.21	2.61	24.11	31.53	0.36	0.02	0.33	0.39	7.87	0.71	7.07	9.23	232,700	23,754	189,100	262,100
Croatia	4.17	0.28	3.83	4.72	30.82	2.31	27.16	33.60	0.84	0.10	0.74	1.08	4.96	0.40	4.21	5.52	51,704	2,669	49,010	57,210
Czechia	9.81	0.57	9.02	10.72	13.60	1.81	10.25	15.85	1.72	0.24	1.29	1.96	15.53	1.30	13.72	17.79	186,691	16,235	168,800	215,600
Denmark	6.73	1.20	5.11	8.68	29.18	5.99	19.33	37.52	2.97	0.07	2.89	3.09	7.61	0.33	7.02	8.07	302,009	18,718	278,700	332,600
Estonia	12.38	1.92	7.67	14.66	26.53	2.22	24.13	31.29	1.60	0.34	1.24	2.31	9.76	1.92	5.60	11.53	22,665	2,542	18,960	26,900
Finland	8.93	1.30	7.37	11.66	39.96	4.65	32.46	45.76	3.16	0.41	2.72	3.73	7.28	1.14	5.77	10.18	239,464	8,821	226,400	254,700
France	4.90	0.32	4.46	5.35	13.22	1.54	10.66	15.53	2.21	0.03	2.18	2.28	6.55	0.39	6.14	7.33	2,431,727	104,908	2,273,000	2,617,000
Germany	9.03	0.48	7.91	9.62	13.95	1.88	10.72	17.17	2.92	0.14	2.73	3.17	8.36	0.60	7.36	9.54	3,318,091	199,684	2,964,000	3,597,000
Greece	6.78	0.90	5.60	8.53	15.07	3.09	9.19	18.51	0.90	0.24	0.60	1.28	4.63	0.40	3.92	5.28	208,327	20,132	194,700	253,700
Hungary	4.55	0.26	4.12	4.79	14.78	1.46	12.29	17.18	1.29	0.13	1.13	1.51	15.15	3.30	12.38	21.20	124,073	12,048	111,900	147,400
Iceland	5.67	0.74	4.55	6.62	78.07	2.12	74.69	81.07	2.13	0.29	1.69	2.60	4.98	0.73	3.97	6.07	17,498	1,998	15,330	20,840
Ireland	8.01	0.50	7.25	8.94	8.26	2.26	5.30	12.34	1.40	0.19	1.17	1.61	8.90	1.60	7.50	13.25	266,800	62,325	208,300	371,300
Israel	8.15	0.92	6.88	9.62	5.07	2.37	2.88	9.08	4.34	0.38	3.92	5.14	9.38	0.94	8.73	11.46	296,727	38,408	238,400	358,500
Italy	5.90	0.61	5.31	6.84	15.32	2.03	11.90	17.27	1.32	0.09	1.20	1.46	5.47	0.88	4.81	7.73	1,872,636	35,917	1,822,000	1,918,000
Japan	9.21	0.46	8.54	9.91	5.79	1.14	4.51	7.69	3.21	0.07	3.10	3.37	11.72	1.03	10.14	13.01	4,376,000	169,830	4,053,000	4,580,000
Korea, Rep.	11.81	0.42	10.68	12.23	2.27	0.80	1.21	3.36	3.94	0.46	3.15	4.63	12.92	2.25	9.79	15.87	1,424,364	145,708	1,181,000	1,638,000
Latvia	3.77	0.19	3.44	4.06	38.99	2.75	33.07	42.60	0.60	0.09	0.44	0.72	7.76	1.72	5.44	10.00	26,602	2,587	22,990	30,750
Lithuania	3.93	0.17	3.70	4.20	27.61	5.11	20.09	33.78	0.92	0.08	0.78	1.04	4.48	0.80	3.61	5.76	40,448	4,645	33,840	48,200
Luxembourg	17.90	2.68	15.09	21.76	8.94	5.37	3.68	16.45	1.29	0.13	1.17	1.59	4.32	0.41	3.77	5.16	59,088	4,829	52,060	66,170
Netherlands	9.28	0.49	8.44	10.30	5.63	1.37	3.85	8.54	2.03	0.20	1.67	2.18	13.21	0.61	12.39	14.54	769,491	38,227	727,800	840,300
New Zealand	6.98	0.24	6.60	7.28	31.00	0.84	29.65	32.65	1.27	0.09	1.15	1.41	7.69	0.47	6.90	8.61	174,127	17,938	151,700	202,200
Norway	7.57	0.47	6.72	8.47	58.53	2.06	56.37	62.37	1.84	0.21	1.62	2.15	6.93	0.36	6.50	7.67	378,618	19,870	351,600	406,500
Poland	7.93	0.26	7.52	8.25	10.95	1.00	8.84	12.18	0.94	0.20	0.66	1.32	8.82	0.73	7.33	9.81	470,336	56,281	397,500	571,500
Portugal	4.74	0.30	4.34	5.33	27.49	1.98	24.42	30.46	1.38	0.11	1.24	1.58	5.41	0.60	4.68	6.59	205,055	8,871	194,300	222,400
Romania	3.82	0.19	3.59	4.17	23.11	1.10	21.09	24.40	0.46	0.04	0.38	0.50	7.49	0.74	6.77	9.30	178,936	21,085	155,000	218,000
Singapore	8.29	0.26	7.79	8.76	0.61	0.12	0.47	0.84	1.99	0.12	1.81	2.17	25.84	1.99	23.04	28.10	294,973	42,281	216,100	349,900
Slovak Republic	6.02	0.31	5.62	6.57	12.09	2.21	10.00	17.64	0.79	0.18	0.47	1.16	14.31	1.01	12.91	15.66	86,459	8,077	73,680	99,500
Slovenia	7.00	0.51	6.36	7.70	20.72	1.18	19.14	22.91	2.17	0.27	1.81	2.56	3.89	0.46	3.28	4.73	44,044	3,158	41,040	50,380
Spain	5.56	0.35	5.09	6.20	15.97	1.62	12.25	17.42	1.27	0.06	1.19	1.36	5.20	0.70	4.53	6.62	1,212,545	61,609	1,136,000	1,324,000
Sweden	4.16	0.52	3.41	5.13	49.00	2.95	44.70	52.88	3.26	0.10	3.10	3.40	9.95	0.71	8.99	11.34	491,627	38,725	428,100	549,800
Switzerland	5.00	0.49	4.36	5.78	22.64	1.83	19.97	24.99	2.99	0.12	2.85	3.15	4.35	0.90	3.50	5.88	682,955	42,534	616,300	747,100
Trinidad and Tobago	13.88	1.62	11.31	15.68	0.40	0.04	0.35	0.49	0.07	0.02	0.04	0.09	3.35	0.98	2.04	4.33	24,716	1,440	22,960	27,060
United Arab Emirates	19.65		19.65	19.65	0.11		0.11	0.11	0.49		0.49	0.49	10.99		10.99	10.99	278,400	-	278,400	278,400
United Kingdom	6.48	0.89	5.22	7.69	7.25	3.03	3.38	12.24	1.65	0.04	1.57	1.71	7.71	1.12	4.81	9.49	2,874,545	199,584	2,597,000	3,174,000
United States	15.84	0.87	14.67	17.43	9.01	1.00	7.35	10.42	2.83	0.14	2.68	3.17	13.52	0.65	12.81	14.40	17,827,273	1,299,862	15,950,000	19,930,000

Notes

¹ <https://unctad.org/news/blog-what-industry-40-and-what-will-it-mean-developing-countries#:~:text=However%2C%20only%20a%20few%20countries,lead%20in%20publications%20and%20patents.>

² https://www.wipo.int/global_innovation_index/en/2022/
https://edgar.jrc.ec.europa.eu/booklet/CO2_emissions_of_all_world_countries_2022_report.pdf

³ In the case of high-income countries, Qatar, Saudi Arabia, and Uruguay were omitted, while in the case of middle-income countries, the analysis excludes the following countries: Belarus, Cambodia, Iran, Islamic Rep., Kazakhstan and Kyrgyz Republic.

Environmental Regulations and Intra-BRICS Trade Flows: An Empirical Test of the Porter Hypothesis

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Abstract

While Governments around the world have taken a proactive response by implementing environmental regulations to cut emissions and make production more environmentally friendly, there is a growing concern that stringent environmental regulations may have both inhibiting and promoting effects on trade flows. On this basis, this study examines the impact of stringent environmental regulations on intra-BRICS trade flows, and also the validity of the Porter hypothesis for the bloc. Within the framework of the gravity model, a panel data on the five BRICS countries is used at a bilateral level. The three categories of bilateral export trade were analyzed for the period 2010-2021 using fixed and random effect models estimators. This study proxies environmental regulations using two country-specific and internationally-comparable measures: environmental policy stringency (EPS) and environmental performance indicators (EPI), both of which are computed based on environmental policy instruments, primarily related to climate and air pollution. Using EPS, the results show that stringent environmental standards have a promoting effect in the exporting countries while the inhibiting effect in the importing countries on intra- BRICS aggregate exports and its components (pollution-intensive exports and non-resource based exports trade). Further, the promoting effect of strict environmental standards in the exporting countries is lower relative to its inhibiting effect in the importing countries. This implies that the validity of Porter hypothesis for intra-BRICS trade flows could only hold if heterogeneity effects in terms of both the exporting and importing country-specific effects are not taken into consideration. However, Porter hypothesis is not valid using EPI. Policy recommendations are provided in the conclusion section.

Keywords: Environment, Regulations, Porter hypothesis, Intra-BRICS, Bilateral trade flows, Gravity model, and mixed methods.

1. Introduction

International trade has without a doubt been acknowledged by the international community as an effective tool for accomplishing the 17 Sustainable Development Goals (SDGs) and the 2030 Agenda for Sustainable Development¹ (United Nation, 2015). As a result, most countries, in particular, the developing and the emerging ones, aspire to achieve these goals by expanding their industrial base and increasing production activities, with a focus on both traditional labor-intensive and heavy industries². Unlike developed countries that have made the transition to producing environmentally-friendly goods, developing and emerging countries use low-end technologies and are more likely to produce pollution-intensive products which give rise to a number of global environmental problems such as climate change and pollution (Azam, 2016; Dai, Zhang & Zhang, 2021). In an attempt to cut emissions and make production more environmentally friendly, most governments around the world have taken a proactive response by implementing environmental regulations which may be used as a disguised form of protectionism (Berger et al., 2020; Qiang et al., 2022). The concept of environmental regulation is defined as a conventional tool for addressing environmental issues arising from international trade (Wang, Zhang & Zheng, 2016). According to Bommer and Schulze (1999), if stricter environmental quality standards are put in place, international trade could improve the quality of the environment. To address these global environmental issues, there is growing concern about implementing more strict environmental regulations.

In the theoretical literature, there are two strands of arguments on whether countries with relatively strict environmental regulations lose international competitiveness, particularly in pollution-intensive industries. The first strand of the argument is explained by the pollution haven hypothesis (PHH), which posits that differences in environmental standards between countries lead to a reallocation of polluting industries from those with stringent environmental regulations to those with weak policies. As a result, developing countries with lax environmental policies have become a pollution haven for those with strict environmental policies, exporting "dirty" goods and importing "clean" ones. The developed countries, on the other hand, improve environmental quality by developing a comparative advantage in the production of clean goods (Arouri et al., 2012). The second argument advanced by Porter and Linde (1995), popularly known as Porter hypothesis, however, subjected the assertion of the PHH to a static view and challenged on the basis that a country with stricter environmental regulations can gain from improved quality of environment and is likely to develop new comparative advantages in environmentally more sensitive industries. According to them, the long-run benefits associated with

strengthening environmental regulations may outweigh the short-run losses of such a country (Harris, Kónya, & Mátyás, 2002; Azam, 2016). This is because firms operating in such a country will be triggered to engage in technological innovation, which may boost their productivity and export competitiveness in the long-run (Qiang et al., 2022).

Based on these arguments, the findings of a number of empirical studies have made it clear that the relationship between environmental regulations and trade is indefinite (inconclusive) due to their disparate findings. For instance, studies (such as Van Beers & Van den Bergh, 1997; Hwang & Kim, 2017; Yeo & Deng, 2019; Berger et al., 2020; Dai, Zhang & Zhang, 2021; among others) support the pollution haven hypothesis by concluding that stricter environmental policies inhibit trade. The findings of studies (such as Silajdzic & Mehic, 2017; Wang, Zhang & Zeng, 2016; Yu & Sun, 2017; and Wang, Huang & Yu, 2019) confirm the Porter hypothesis with evidence that environmental regulations tend to promote international competitiveness due to green protectionism. However, the findings of Harris, Kónya and Mátyás (2002) and Arouri et al. (2012) conclude that environmental regulation has no discernible impact on the development of export trade.

In terms of trade and investment cooperation, the BRICS countries have made a significant progress. Specifically, intra-BRICS trade in goods has grown faster than BRICS total foreign trade and global trade. As a result, the BRICS countries' share of mutual exports in overall exports grew from 8.9% in 2010 to 9.4% in 2021. The share of mutual imports in overall BRICS imports increased from 11.1% in 2010 to 12.6% in 2016 but steadily dropped to 10.6% in 2021 (UN comtrade, 2022). For all member countries, intra-BRICS trade is expanding and the number of traded commodity positions is gradually increasing. Against the above background, important questions arise. What impact do environmental regulations have on intra-BRICS trade flows? Is the Porter hypothesis valid for environmental regulations and intra-BRICS export trade relationship?

The contributions of this study to the existing literature are four fold. First, almost all the previous studies reviewed in this area measured environmental regulations using either market-based or non-market based environmental policy instruments. None of these studies considered weighting the regulations under each and aggregating them into a single indicator. As a result, their results are mixed and inconclusive, implying the need for more studies. This study is unique in that it uses the environmental policy stringency (EPS) index, which is a novel data set that tracks environmental regulations on both market-based and nonmarket policy instruments. Also, this study checks for robustness using environmental performance indicators (EPI) as alternative measure of environmental regulations which is not common in the literature. Second, some of the studies reviewed (Wang, Zhang & Zeng, 2016; Silajdzic & Mehic, 2017; and Qiang et al., 2022) confirmed the validity of the Porter hypothesis. The conclusion of these studies cannot be relied upon as they failed to account for

exporter and importer-specific effects, making it difficult to determine the relative impact of stringent environmental regulations from both ends (i.e., exporting and importing countries) on exports. This present study accounts for heterogeneity effects and the results show that the promoting effect of strict environmental standards in the exporting countries is lower relative to its inhibiting effect in the importing countries. This implies that the validity of Porter hypothesis for intra-BRICS trade flows could only hold if heterogeneity effects in terms of both the exporting and importing country-specific effects are not taken into consideration. Third, this study uses time-variant variables and as well employed an augmented gravity model with the aid of fixed effect and random effect models because it helps to solve the prevailing issues relating to endogeneity, heterogeneity, and simultaneity that crop up in a panel data analysis. Most of the previous studies used panel ordinary least squares (OLS), poisson pseudo maximum likelihood (PPML), quantile regression, which could not address the above mentioned issues and could render the estimates inefficient. Finally, the study disaggregates the analysis to reflect the full and pre- COVID-19 periods, and to the best of my knowledge, no such study focusing on the BRICS countries exists in the literature. The objective of this study is to explore the impact of stringent environmental regulations on intra-BRICS trade flows, as well as the validity of the Porter hypothesis for the bloc.

After the foregoing introductory section, section 2 presents stylized facts on the trend of environmental regulations indicators and intra-BRICS trade performance. Section 3 covers a literature review, and section 4 focuses on methodology and estimation techniques. Section 5 presents the empirical results with a discussion, while section 6 concludes the paper with policy recommendations.

2. Overview of Environmental Regulations Indicators and Intra-BRICS Trade Flows

This section presents the indicators of environmental regulations for the BRICS countries. Also, the section analyse the performance of intra-BRICS trade flows.

2.1 *Environmental Regulations Indicators*

The OECD Environmental Policy Stringency Index (EPS)

EPS is a country-specific and internationally-comparable measure of the stringency of environmental policy. It is computed based on the degree of stringency of 13 environmental policy instruments, primarily related to climate and air pollution. The index has a scale of 0 (least strict) to 6 (most stringent). Figure 1 shows that, between 2010 and 2020, only China and India among the BRICS countries maintained a somewhat upward trend in the strictness of their environmental policies. Considering the average EPS score index from 2010 to 2020, all BRICS countries have a score lower than the average of 3. This

demonstrates that the BRICS countries have a lax approach to environmental policy.

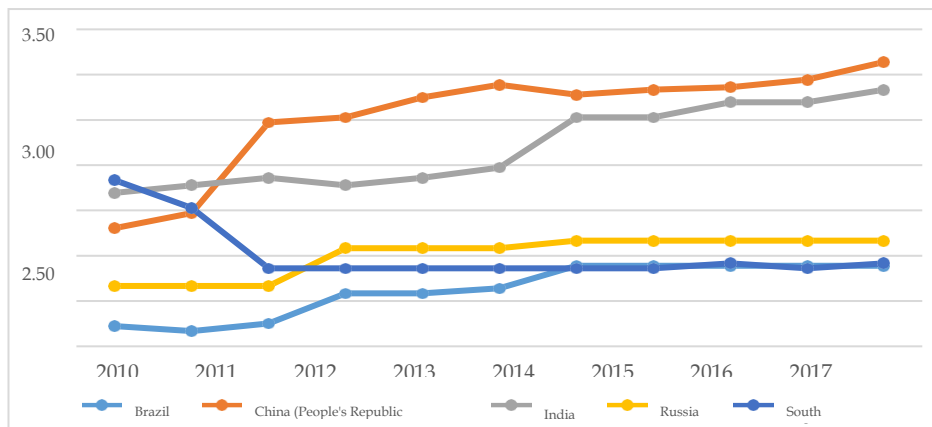


Figure 1: Environmental Policy Stringency (EPS) Index.

Source: Extracted from OECD.Stat

Environmental Performance Index

Following the global concern about environmental degradation, the gathering of global stakeholders encouraged several countries to take action to enhance environmental standards. This is in support of efforts to meet the UN Sustainable Development Goals and transition society to a more sustainable future (Wolf et al. 2022). The Environmental Performance Index (EPI) ranks countries based on how well they address the environmental challenges that they confront. EPI indicators provide a way to spot problems, set targets, track trends, understand outcomes, and identify best policy practices. EPI is measured based on 32 performance indicators across 11 main issues, such as air quality, biodiversity and levels of climate change. A higher EPI score represents stricter environmental regulations and vice-versa. Figure 2 shows the EPI scores for BRICS countries over a period of 2010-2022.

Figure 2 shows that between 2010 and 2014, the BRICS countries had relatively low EPI scores, which reflects the low stringency of their environmental policies. These countries were below the world average score of 50, except Brazil with a score of 63.4 in 2010 and 60.9 in 2012, respectively. In 2016, the entire BRICS countries had a relatively fair scores, as none of them had below the world average of 50. Between 2018 and 2022, however, these countries were maintaining a relatively low environmental policy stringency, thus lagging behind their peers in the world.

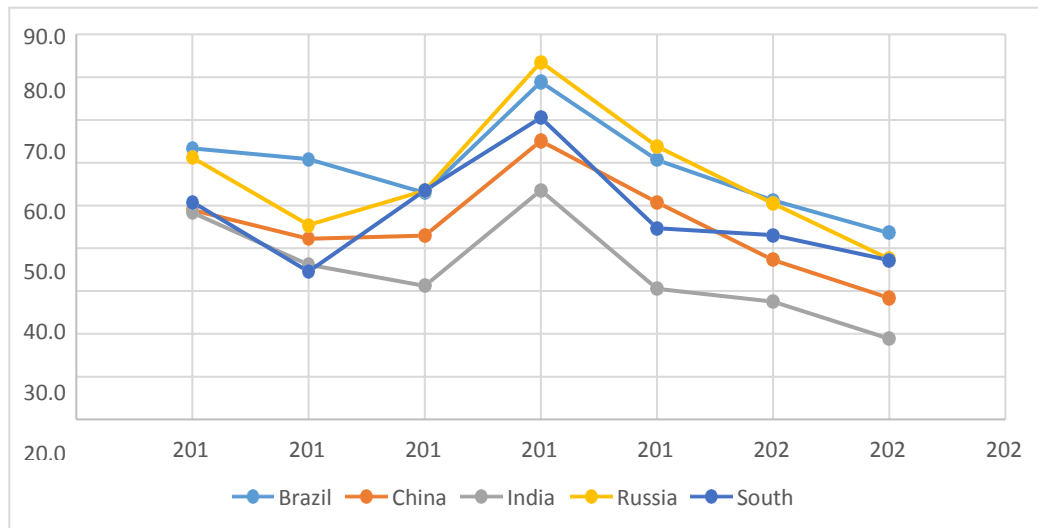


Figure 2: Environmental Performance Index (EPI) Scores

Source: Environmental Performance Index (EPI) reports

2.2 Analysis of intra-BRICS Trade Flows

As observed in Table 1, intra-BRICS share of global exports and total trade has been increasing since the forum (i.e., the economic bloc) was renamed in 2010, but it fell dramatically in 2016. Again, from 2018 upward, both the share of global exports and total trade peaked and increased gradually through 2021. The same pattern was observed for intra-BRICS share of world imports and total trade.

Table 1: Intra-BRICS Trade Flows Analysis

	2010	2012	2014	2016	2018	2020	2021
Intra-BRICS exports as a share of world exports	2.65	2.79	2.95	2.12	2.90	3.51	4.30
Intra-BRICS imports as a share of world imports	3.29	3.88	3.81	3.56	4.09	4.35	4.80
Intra-BRICS exports as a share of total trade	1.32	1.39	1.47	1.06	1.44	1.75	2.14
Intra-BRICS imports as a share of total trade	1.65	1.95	1.91	1.79	2.06	2.19	2.41

Source: Author's calculation based on UN comtrade database, 2022. Note: All 2-digit (AG2) and 3-digit (AG3) SITC commodities are reported.

Table 2 shows the intra-BRICS exports and imports as a share of total trade from the bloc. It is clear from this table that between 2010 and 2021, China has consistently been the largest exporter of goods among the BRICS countries, and its share of exports from the bloc increased from 22.73% in 2010 to 23.68% in 2021. It is also observed from the table that its export share alone was higher than the average of all the five countries in the bloc during the period. Brazil has the second largest share of exports among the other BRICS countries, while South Africa has the least share of exports. Table 2 also shows that China has consistently been the largest importer of goods among the BRICS countries, with a share higher than the average BRICS imports share. Between 2010 and 2021, India has the second largest import share, followed by Russia, with South Africa having the lowest share in the bloc. With respect to pollution-intensive products, Table 2 also shows that China has the largest share both in terms of exports and imports while South Africa has the least share in the bloc.

Table 2: Intra-BRICS Exports and Imports as a Share of Total Trade from the bloc

Table 2: Intra-BRICS Exports and Imports as a Share of Total Trade from the bloc														
Year	Exports							Imports						
	2010	2012	2014	2016	2018	2020	2021	2010	2012	2014	2016	2018	2020	2021
Brazil	8.75	8.41	7.93	9.24	10.36	10.54	9.43	7.79	7.43	7.89	6.49	6.61	6.45	6.71
China	22.73	20.15	23.77	15.57	18.67	22.84	23.68	22.08	26.06	24.24	24.67	26.79	26.74	24.68
India	4.24	3.93	3.62	3.14	3.45	3.16	3.81	12.17	11.76	11.63	16.28	13.42	10.77	11.08
Russia	5.97	7.47	6.65	7.63	6.72	6.01	8.24	10.10	9.59	9.23	11.43	8.60	8.82	7.91
South Africa	2.68	1.76	1.62	1.51	2.02	1.85	1.84	3.50	3.44	3.43	4.05	3.36	2.81	2.62
Average	8.87	8.34	8.72	7.42	8.24	8.88	9.40	11.13	11.66	11.28	12.58	11.75	11.12	10.60
Share of Pollution Intensive Products of Total Trade														
Brazil	0.31	0.24	0.28	0.46	0.44	0.44	0.28	1.02	0.94	1.20	0.85	0.89	0.89	1.15
China	2.20	2.12	2.37	2.58	1.91	2.09	2.48	1.89	1.92	1.52	1.81	1.81	2.21	1.85
India	0.87	0.86	0.89	0.53	0.73	0.64	0.74	1.47	1.34	1.58	1.73	1.53	1.28	1.30
Russia	0.94	0.94	0.50	0.48	0.84	0.77	0.88	0.59	0.57	0.54	0.56	0.57	0.56	0.51
SA	0.29	0.19	0.21	0.30	0.19	0.21	0.20	0.33	0.36	0.38	0.39	0.31	0.28	0.31
Average	0.92	0.87	0.85	0.87	0.82	0.83	0.92	1.06	1.03	1.04	1.07	1.02	1.04	1.02

Source: Author's calculation based on UN [comtrade](#) database, 2022. Note: All 2-digit (AG2) and 3-digit (AG3) SITC commodities are reported.

3. Literature Review

3.1 Empirical Literature Review

There have been numerous empirical studies conducted on the impact of environmental regulations on trade flows. Existing studies on the impact of environmental regulations or stringency on trade in goods is inconclusive. Evidence can be found in some of the studies conducted across a sample of countries and as well for specific countries. For instance, Van Beers and Van den Bergh (1997) employed the ordinary least square (OLS) technique while exploring the impact of relatively stringent environmental regulations on a country's trade flows. They found that stricter (high environmental standard)

regulations had a significant negative impact on bilateral trade flows between OECD nations. Across 19 OECD countries, Hwang and Kim (2017) classified the manufacturing sector into three groups (high, medium and low) based on energy intensity while analyzing the effect of environmental regulations on trade performance of each group under static and dynamic conditions. To account for unobserved heterogeneity, fixed and random effects models were used and their results revealed a significant negative effect of energy tax on exports under the static condition while, a significant positive effect under the dynamic condition. However, the positive effect does not offset the negative effect, as the latter overshadows the former. In the same vein, the findings of Yeo and Deng (2019) suggested that the nature or specificities of trade policy in place have an impact on trade flows between Pakistan and its dominant trading partners. For instance, strict environmental policies and high costs of goods and services reduce trade flows, while free trade policy is seen as an effective way to stimulate trade. In another dimension, Berger et al. (2020) examined the trade effects when environmental provision is incorporated in Preferential Trade Agreements (PTAs). Their findings demonstrate that PTAs have a stimulating effect on trade flows. However, the inclusion of environmental provisions in PTAs has a significant trade-restrictive impact, which adversely affects developing country exports in terms of trade flows to developed countries.

Dai, Zhang, and Zhang (2021) explored the impact of environmental regulations on trade in environmental goods listed in Asia-Pacific Economic Cooperation (APEC) and the Organization for Economic Co-operation and Development (OECD) from 1989 to 2013. The authors used the z-score approach proposed by Kheder and Zugravu (2012) to proxy environmental regulations, and found that more stringent environmental policies inhibit trade, with greater impact on environmental goods listed in APEC compared to those listed in OECD. In a country-specific study, Hering and Poncet (2014) examined the impact of environmental policy on Chinese exports. According to their findings, sectoral exports were reduced between 1997 and 2003 as a result of stringent regulations on sulfur di oxide (SO₂) emissions, particularly for more polluting industries. Similar findings were reported for all manufacturing sectors in the Czech Republic by Kiuila (2015).

Another strand of the literature provides evidence that environmental regulation may promote international competitiveness due to green protectionism. For instance, Costantini and Mazzanti(2012) investigated how environmental regulation and innovation have affected the EU's export competitiveness by testing both the strong and narrowly strong versions of the Porter hypothesis. Their findings support the two versions of the Porter hypothesis, since environmental policy initiatives appear to promote export dynamics rather than weaken EU competitiveness in international markets. This implies that environmental regulation and innovation have a significant positive impact on EU exports. Azam (2016) analyzed bilateral trade relations

between China and its 40 main trading partners in 2009 using spatial generalized method of moment (GMM) and OLS estimators. The author reported positive effects of both domestic and foreign strictness of environmental regulations on trade. Similarly, the findings of Silajdzic and Mehic (2017) confirm the Porter hypothesis. They found a strong positive and significant impact of the environmental taxes on exports of pollution-intensive industries among Central and Eastern European countries (CEEC). This suggests that exports of the least regulated transition economies that specialize in pollution-intensive industries tend to bear a greater burden of environmental taxes, though they tend to benefit from differences in compliance with environmental regulations among EU countries.

With respect to the country-specific study, Qiang et al. (2022) found that environmental regulations have a restraining effect on export trade in the short-run, but with the existence of innovation efficiency in the long-run, the effect of environmental regulations will transform to one that promotes export trade, thus confirming the existence of Porter hypothesis in China. More so, several other studies, particularly in China have also found a significant positive impact of environmental regulation on trade (Wang, Zhang & Zeng, 2016; Yu & Sun, 2017; Wang, Huang, & Yu, 2019).

Contrary to the foregoing, some cross-country and country-specific analyses have demonstrated that environmental regulation has no discernible impact on the development of export trade (Harris, Kónya & Mátyás, 2002; and Arouri et al., 2012). Harris, Kónya, and Mátyás (2002), for example, examined the potential impact of environmental policy on bilateral foreign trade flows for a group of 24 OECD countries between 1990 and 1996. Based on a triple-indexed fixed-effects model, their findings suggest that environmental costs have no actual impact on foreign trade, either positive or negative.

Existing studies on the impact of environmental regulations on trade have demonstrated some elements of divergence, as their findings and conclusions vary. Some of these studies were conducted across a sample of countries, while some focused on a particular country. Aggregate trade data within the panel framework were utilized by these studies. On the methodology adopted, the majority of these studies employed a gravity model, with the exception of Wang, Zhang and Zeng (2016) and Qiang et al. (2022), who used the econometric approach.

3.2 Measures of Environmental Regulations

Measuring environmental regulations is difficult due to a lack of appropriate proxies that can capture the general policy stringency such as sophistication of regulatory structure, strictness of enforcement, quality of environmental institutions and available environmental information, and natural resource subsidization. As a result, numerous studies have employed various indicators,

the majority of which have been criticized for being inadequate and unreliable. However, the adoption of these indicators largely depends on the type of industrial activity that the economy engages in, as well as the level of development of the economy or region under study. Table 3 shows the various indicators used in the literature.

Table 3: some of the indicators used in the literature for measuring environmental regulations

Author(s)	Indicators used
Van Beers and Van den Bergh (1997)	Energy intensities and recycling rates
Harris, Konya, and Matyas (2002)	Six indicators based on relative energy consumption supply
Hwang and Kim (2017); Costantini and Mazzanti (2012) ; (Kiuila (2015); Silajdzic and Mehic (2017)	Three environmental indicators based on energy intensity (environmental taxes, energy taxes and emissions trading system).
Arouri <i>et al.</i> (2012)	CO2 emissions (proxied by gross domestic product and energy consumption)
Azam (2016)	Environmental performance indicators (EPI)
Wang, Zhang and Zeng (2016)	Quantified the environmental regulation level (ERL) by computing the principal component analysis (PCA) for abatement rate of waste water, purification rate of atmospheric pollution, and the recycling-rate of solid waste
Yeo and Deng (2019)	Computed environmental policy stringency based on Walter and Ugelow (1979) EPS index and redefined on a scale of 1= tolerant to 7 = strict.
Berger <i>et al.</i> (2020)	Used environmental provision as contained in the trade and environment database (TREND) to capture contractual arrangement for exporter and importer.
Dai, Zhang, and Zhang (2021)	Adopted the z-score method proposed by Kheder and Zugravu (2012) for the three comprehensive environmental indicators (cumulative number of all the pieces of environmental legislation ratified by a country, intensity of environmental laws, and energy efficiency (GDP/total units of energy used))
Qiang <i>et al.</i> (2021)	Constructed an environmental regulation intensity (ER) index for pollutant emission level, prediction and export trade symbol.

4. Methodology

In international trade literature, the gravity model is often used as a veritable tool in analyzing bilateral trading relations. Originally, the model was adopted by Tinbergen (1962), Poyhonen (1963) when analyzing bilateral trade flows patterns amongst the European countries and later by Linnerman (1966) while exploring the factors that affect Egypt's bilateral export flows to its main trading partners. Nevertheless, the model has a lot of controversies. For instance, its theoretical background was first put into doubt but subsequently justified by Anderson (1979) for differentiated goods based on their origin. Also, in Bergstrand (1989) for the factorial model, Deardorff (1998) for the H-O model, and Helpman et al. (2008) in the context of firm heterogeneity. Besides, the model has been validated by recent theoretical and empirical studies (Frankel, 1997; Feenstra et al., 1998; Evenett & Keller, 2002; Anderson & Van Wincoop, 2003) through the inclusion of other important determinants of bilateral trade (i.e., multilateral trade resistance variables). This model has also been used by several empirical studies to analyze the link between environmental regulations (stringency) and trade flows (Van Beers & Van den Berge, 1997; Harris, Kónya, & Mátyás, 2002; Jug & Mirza, 2005; Arouri et al., 2012; Dai, Zhang, and Zhang, 2021).

In order to analyze the impact of environmental regulation on trade flows, this study follows the framework of Anderson and van Wincoop (2003), who provided a theoretical refinement of the traditional gravity model (i.e., theory based gravity model) to include multilateral trade resistance variables (i.e., barriers to trade that each country faces with all its trading partners). According to Anderson and van Wincoop (2003), bilateral trade flows depend both on bilateral and multilateral trade barriers of the two countries involved in a trade relationship. The "theory based" gravity model (an improved conditional general equilibrium model) has been estimated in different ways the gravity equation of the form;

$$X_{ij} = K \frac{Y_i Y_j}{Y^w} \left(\frac{\tau_{ij}}{\Pi_i P_j} \right)^{1-\sigma} \quad (1)$$

Where; $\tau = (R_{ij}^q)^{\eta}$ (2)

Where X_{ij} is nominal exports from country i to j , Y_i and Y_j is the nominal income (GDP) of exporter i and importer j , respectively, Y^w is nominal world income (total world GDP), τ_{ij} is the bilateral trade costs, η is the elasticity of substitution among goods, Π_i and P_j are outward and inward multilateral resistance variables, respectively. In addition, R_{ij}^q ($q = 1, \dots, Q$) is a set of observables to which bilateral trade frictions/barriers are related.

The expression in equation (1) is the gravity equation which, when rearranged looks similar to the gravitational force equation.

$$X_{ij} = K \frac{Y_i Y_j}{\tau_{ij}^{\sigma-1}} \quad (3)$$

$$\text{Where } \tau_{ij} = \frac{1}{Y^w} \left(\frac{1}{\Pi_i P_j} \right)^{1-\sigma}$$

In log-linear form, equation (1) can be rewritten as:

$$\log X_{ij} = -w \log Y + \log Y_i + \log Y_j + (1-\sigma) \log \tau_{ij} + (\sigma-1) \log \Pi_i P_j$$

The expression in equation (4) relates to bilateral exports which is positively to the size of the countries and negatively to the trade barriers between countries. Bilateral trade barriers, τ_{ij} , also referred to as “bilateral resistance”, which include tariff as well as non-tariff barriers, but also factors such as environmental policy stringency. The K term includes the price indices of the two countries – it should however be noted that while Π_i and P_j can be interpreted as price indices in the model, they should not be interpreted as price indices in general, rather should be thought of as nonpecuniary trade costs that a country has with all its trading partners. These “multilateral” resistance terms are often unobservable but could be subsumed by country fixed effects (Anderson and Van Wincoop, 2003).

4.1 Model Specification

In this present study, the traditional standard gravity model is modified to include strictness of environmental policy variables, while controlling for both multilateral resistance and heterogeneity effects, following the work of Harris, Kónya, and Mátyás (2002) and Arouri et al. (2012) is specified as:

$$\ln \exp_{ijt} = \delta_0 + \delta_1 \ln y_{it} + \delta_2 \ln y_{jt} + \delta_3 \ln gdp_{it} + \delta_4 \ln gdp_{jt} + \delta_5 trf_{ijt} + \delta_6 \ln reer_{it} + \delta_7 \ln reer_{jt} + \delta_8 \ln iq_{it} + \delta_9 \ln iq_{jt} + \delta_{10} \ln eps_{it} + \delta_{11} \ln eps_{jt} + \varepsilon_{ijt} \quad (5)$$

Where z equals total trade, pollution intensive and non-resources based sectoral trade, i indexes countries and t denotes time. The dependent variable ($\exp_{ijt}$) in equation (5) represents exports of commodity z from country i (a member of BRICS country) to country j (each of other BRICS members) at year t ; y_{it} and y_{jt} signify the gross domestic product (GDP) of the exporting (i) and importing countries (j) at time t ; gdp_{it} and gdp_{jt} denote the GDP per capita of country i and j at time t ; trf_{ijt} is bilateral weighted average level applied MFN tariffs rates at time t ; $reer_{it}$ and $reer_{jt}$ denote real effective exchange rate for both exporting and importing countries at time t ; iq_{it} and iq_{jt} signify institutional quality for both exporting and importing countries at time t ; eps_{it} and eps_{jt} denote environmental policy stringency for both exporting and importing countries at time t ; while ε_t represents error term at time t .

4.2 Definition and Measurements of Variables

The precise definitions of the key variables used in the above model can be discussed as follows:

In the literature, there are debates about the use of variables, particularly, export and import. Though justifications for the use of any of these variables are always provided. Following the work of Arouri et al. (2012), bilateral export is employed as the dependent variable in this analysis. The rationale for its adoption is based on the objective of this study, which is to test whether stringent environmental regulations could promote intra-BRICS bilateral exports based on the Porter hypothesis³. The model as represented in equation (5) was estimated for three categories of bilateral export trade:

- a. Total bilateral exports ($TEXP_{ijt}$); this measures the total exports of country i to country j in year t in current US dollars. The bilateral export data in Thousands of US dollars are obtained from the United National Commodity Trade Statistics (UN COMTRADE database). These current export figures are deflated by the United States GDP deflator (2015 is the base year) in order to obtain real values.
- b. Bilateral exports in pollution-intensive sectors, i.e., aggregation of all sectors categorized as 'dirty' industries ($DEXP_{ijt}$). Based on the classification of UNIDO (1982) and Low (1992a), the following industries on the basis of SITC (version 3) are classified as 'dirty' sectors: 51 (organic chemicals); 52 (inorganic chemicals); 59 (chemical materials); 64 (paper paperboard); 67 (iron and steel); 68 (non-ferrous metals); 69 (metal manufactures); 251 (pulp and waste paper); 334 (petroleum products); 335 (residual petroleum products); 562 (fertilizers);

634 (veneers, plywood); 635 (wood manufactures); and 661 (lime, cement, construction materials).

- c. Bilateral exports in pollution-intensive sectors that are related to non-resource based (i.e., 'footloose' sectors -FLEXP). The following sectors were considered: 59 (chemical materials); 67 (iron and steel); 69 (metal manufactures); and 661 (lime, cement, construction materials).

Gross domestic product (*gdp*); in the literature, GDP has mostly been used to measure the economic size of trading partners, though there are diverse opinion on whether it should be measured in terms of purchasing power parity (PPP) or official exchange rate. According to Cassim (2001), PPP is considered a better measure of relative standards in that it reflects the purchasing power of domestic goods of countries involved in a trade relationship. Hence, the PPP version of GDP is used for the analysis in the study. In a gravity model, bilateral trade flows between trading partners is expected to be greatly influenced by their respective GDPs, such that the GDP of both exporters (gdp_{it}) and importers (gdp_{jt}) are expected to positively affect trade

Flows $\square$ i.e., $\square_1, \square_2 \square 0$. The series for GDP are obtained from World Development Indicators (WDI, 2022).

GDP per capita (*gdppc*); this measures the level of development of countries and enables us to determine the prosperity of BRICS countries based on their respective population sizes. In this study, the inclusion of GDP per capita is to test the effect of the proclaimed similarity of factor endowment on trade among BRICS countries. Therefore, the coefficients of GDP per capita of both exporters ($gdppc_{it}$) and importers ($gdppc_{jt}$) are expected to positively influence intra-

BRICS trade flows $\square$ i.e., $\square_3, \square_4 \square 0$. The series for GDP per capita are also obtained from World Development Indicators (2022).

Tariff (*trf*); this is a trade policy barrier measure which is usually imposed by the importing countries. Tariff as a trade resistance factor representing trade costs. This study uses an adjusted tariff rate $\square_1 \square t_{ijt} \square$ by substituting the variable 'distance' in the standard gravity model by the cost of transporting goods from country *i* to *j*, which is equivalent to one plus tariff rate applied to the goods (Sadikov, 2007). High tariffs do not only impact adversely on trade, production and consumption patterns but also worsen the welfare of both the citizens of the countries that impose them and their trading partners. It also generates a wedge between local and global prices, while directing demand towards substitutes produced locally, thus restricting bilateral trade flows (Kowalski, 2005). So, its coefficient is expected to be $\square$ i.e., $\square_5 \square 0$. Tariff data is sourced from World Development Indicators (2022).

Real effective exchange rate (*reer*); this is another component of trade policy barrier which reflects the underlying relative movement of prices at home and

abroad. This study uses REER because it represents the weighted average of a country's currency relative to a basket of other major currencies and the inclusion is to test the effect of its volatility on intra-BRICS trade flows. An increase in exporter's REER / a decrease in importer's REER (appreciation of exporter's currency) is associated with higher trade costs, thus reducing the incentives to trade. On the other hand, a decrease in exporter's REER / an increase in importer's REER (depreciation of exporter's currency) tends to reduce trade costs. The coefficient of exporter's REER ($reer_{it}$) is expected to be negative (i.e., $\beta_6 \leq 0$), while that of the importer ($reer_{jt}$) to be positive (i.e., $\beta_7 \geq 0$). The series for REER are obtained from Global Economic Monitor (GEM, 2022).

Institutional Quality (inq); this measures the channels through which weak or inadequate institutions impede trade. In this study, the quality of institutions is proxied by regulatory quality index taken from the World Bank Governance Indicators (see Kaufmann, Kraay & Mastruzzi, 2011). It varies from -2.5 to 2.5 with higher values corresponding to placing less burden of government regulations. The coefficients for both exporter (inq_{it}) and importer (inq_{jt}) are expected to be positive [i.e., $\beta_8, \beta_9 \geq 0$] based on the hypothesis that improved institutional setup of the trading partners' results in higher bilateral trade flows.

Environmental Policy Stringency (eps); this is the principal variable of interest in this analysis. Stringency is defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior (OECD, 2021). The index is computed based on the degree of stringency of 13 environmental policy instruments, primarily related to climate and air pollution. The index ranges from 0 (not stringent) to 6 (highest degree of stringency). As for the coefficient of environmental policy stringency for exporter and importer, $\beta_{eps_{it}}$ and $\beta_{eps_{jt}}$ are expected to have positive impact [i.e., $\beta_{10} \geq 0$; $\beta_{11} \geq 0$] on the basis of the Porter hypothesis.

Environmental Performance Index (epi); this is another key variable which is used for robustness check of the initial analysis. EPI also represents the degree of strictness of the environmental regulations in the exporting and importing countries, respectively. The data belong to the family of index numbers, with the larger number denoting high stringency of environmental policy. Based on the Porter hypothesis, it is also expected that the environmental performance index of exporter (epi_{it}) and importer (epi_{jt}) to have a positive impact.

A summary of the variables discussed above and their respective sources is presented in Table 10 in the appendix. The entire data used in this study covers 12 years (2010 to 2021). The choice of this period is due to data availability and to bring the bilateral trade data close to the year in which the bloc was formed with the representation of its five members (i.e., in 2010 when BRIC was renamed as BRICS, after which South Africa became a full member). Data

covers the five (5) BRICS countries (Brazil, Russia, India, China, and South Africa).

4.3 Estimation Techniques

The empirical models analyzing the impact of environmental regulation on bilateral trade are estimated using both the fixed effect model (FEM) and the random effect model (REM) estimators⁴. The choice of these techniques is motivated by two main rationales that are exposed thus. First, FEM and REM estimators are mostly relevant when the structure of the panel analysis is such that the time period (T) is greater than the number of cross-sectional units (N). Considering the present study, the time periods (T) (2010–2021 or 12 years) exceeded the cross-sectional units (N), which is (5 countries). Second, since this study is a panel in nature, the prevailing issues relating to endogeneity, heterogeneity, and simultaneity mostly crop up and are best addressed through the instrumental variables employed in the FEM and REM estimators. If these problems are present in a panel model and not addressed, the estimates will be inefficient (Salim, Kabir & Mawali, 2011). This study further conducts Hausman test so as to confirm the most suitable out of the fixed or random effects models. The Hausman test examines whether the error terms are correlated with explanatory variables. The random effect model (REM) is more efficient, particularly under the null hypothesis of zero correlation between error term and explanatory variables. Though, fixed effects model (FEM) tends to give consistent estimate provided the null hypothesis is rejected. These techniques have been used by a number of empirical studies on trade- environment relationships (see Mulatu, Florax, & Withsgen, 2004; and Ederington & Minier, 2003).

Thus, the FEM and REM estimators were used to analyze the three categories of bilateral export trade (aggregate, “dirty” and “footloose”) among the BRICS countries (intra-BRICS export flows). Finally, the models were estimated to cover the full periods (period 2010-2021) and pair-wise period i.e. pre-COVID-19 period (2010-2019). Conversely, post-COVID-19 was not estimated due to short period of time (i.e., 2020-2021). The rationale for splitting the sample period is to be able to assess the differing impact of environmental regulations on intra-BRICS trade flows for each period, as the COVID-19 pandemic has heterogeneous impact on trade across countries and sectors (industries) during the period.

5. Empirical Results and Discussions

5.1 Descriptive Statistics

The descriptive statistics for the variables used in the analysis are shown in Table 4. The result of the analysis reveals that intra-BRICS aggregate, dirty, and non-resource based exports averaged US\$280.38 million, US\$27.54 million, and US\$8.88 million between 2010 and 2021, respectively. These values are

relatively higher than the average prior to the period of the COVID-19 pandemic (2010-2019). This implies that the values of intra-BRICS bilateral trade flows in all the three export categories (aggregate, “dirty” and “footloose”) are relatively higher following the occurrence of COVID-19. For environmental regulations indicators, the average, maximum and minimum values of environmental policy stringency (EPS) recorded after the incidence of COVID-19 (periods between 2020 and 2021) are relatively higher than before (2010-2019). The case is different for environmental performance indicators (EPI), with average and minimum values greater prior to COVID-19 (See Table 4). Considering the two indicators, the analysis shows that the BRICS countries have a lax approach to environmental policy. Furthermore, the correlation analysis results presented in Table 9 in the appendix show that none of the explanatory variables had strong relationships. The mean-variance inflation factors (VIF) score is 3.28, which is much lower than the acceptable 10.0 threshold. This leads us to the conclusion that multicollinearity does not exist (Hsiao, 2003).

Table 4: Descriptive Statistics

Variable	Full period					Sub-period (i.e., period before COVID-19)				
	Obs	Mean	St.dev	Min	Max	Obs	Mean	St.dev	Min	Max
total_exp	240	280384.7	368080.7	996.59	1717223	200	266264.9	339269.7	996.59	139487
dirty_exp	240	27537.76	35418.9	183.70	206449.4	200	26326.38	33475.86	183.70	163952.8
nrb_pi_exp	240	8880.62	13378.6	25.13	68596.8	200	8243.30	12514.81	25.13	54259.09
gdp_x	240	3443.4	4263.2	311.6	15801.9	200	3275.3	3941.7	311.6	14296.3
gdp_m	240	3443.3	4263.2	311.6	15801.9	200	3275.3	3941.7	311.6	14296.3
gdppc_x	240	6862.1	2969.8	1238.0	11188.3	200	6761.9	2903.8	1238.0	10155.5
gdppc_m	240	6862.1	2969.8	1238.0	11188.3	200	6761.9	2903.8	1238.0	10155.5
reer_x	240	92.39	16.35	57.52	127.96	200	93.54	15.04	69.0	127.96
reer_m	240	94.17	16.88	57.52	127.96	200	95.17	15.51	69.0	127.96
eps_x	240	1.51	0.86	0.17	3.14	200	1.45	0.82	0.17	2.94
eps_m	240	1.51	0.86	0.17	3.14	200	1.45	0.82	0.17	2.94
mst_x	240	-0.17	0.27	-0.56	0.45	200	-0.16	0.28	-0.56	0.45
mst_m	240	-0.17	0.27	-0.56	0.45	200	-0.16	0.28	-0.56	0.45
ept_x	240	51.27	13.40	27.6	83.52	200	53.13	13.39	30.57	83.52
ept_m	240	51.27	13.40	27.6	83.52	200	53.13	13.39	30.57	83.52
trf_adj	240	8.05	2.09	4.3	12	200	8.08	2.02	4.3	12

Source: Author's computation.

5.2 Analysis of environmental regulations on intra-BRICS aggregate exports

The results of the fixed and random effects models using the augmented gravity model are presented in Table 5. Model 1 shows the estimates for the full period (2010-2021), while model 2 presents the estimates for the pair-wise period (2010-2019). In each of the models estimated, the F-test conducted reveals the presence of heterogeneity as shown in Table 5. To control for unobserved heterogeneity between country pairs and to account for exporter and importer-specific effects, the Hausman test is used as a model selection criterion to choose between fixed effect (FE) and random effect (RE) models. For the two models in Table 5, the RE model is preferred based on the Hausman test statistics. Under the two models (i.e., the full period and pair-wise period analysis), the estimated results reveal that among the significant explanatory variables in the model, only GDPPC of the importer is inconsistent with the

expected sign. However, GDPPC of exporter is statistically insignificant under the two models.

In terms of the traditional variable of the gravity model, the estimates of the two models (1 & 2) in Table 5 reveal that GDP measured by the economic size of both exporting and importing countries exerts a positive and significant impact on intra-BRICS aggregate exports. From the estimated results, the differing impact is clearly shown as the coefficient of importers' GDP exerts a higher impact than that of the exporters on aggregate exports. This finding is consistent with previous studies (Arouri et al., 2012; Azam, 2016; and Silajdzic & Mehic, 2017), who found that economic size (i.e., GDP of both exporting and importing countries) is a critical factor of bilateral trade. As regards the GDP per capita that measures the level of development of countries, the RE estimates of the two models in Table 5 show that per capita GDP of importing countries is statistically significant, though negative. This shows that the five countries that constitute BRICS are classified as middle-income countries. As a result, bilateral trade flows within the bloc may be hindered to some extent due to their level of development as importers. The estimates of the two models also indicate the impact of tariffs as a deterrent to intra-BRICS bilateral exports, with the importing countries' tariff rate having a significant negative impact. These findings are consistent with those of Hwang and Kim (2017), who found a significant negative effect of tariffs on bilateral trade flows. Comparing the two periods under consideration, the estimates further show that due to high tariffs imposed by members of the bloc, intra-BRICS aggregate exports reduced more during the entire period (0.22%) than before the COVID-19 pandemic (0.19%).

Under the two models, the estimates of environmental policy stringency (EPS), a proxy for environmental regulations, are positive and statistically significant in the exporting countries. This suggests that, despite the imposition of stringent environmental regulations in the exporting country, intra-BRICS aggregate exports are not adversely affected. This may be because the members of the BRICS are well-endowed with resources, giving them a competitive edge in the more environmentally sensitive industries. Therefore, the results of this analysis negate the hypothesis that stricter environmental regulations reduce exports and have a negative impact on global competitiveness, while supporting the hypothesis that such strict environmental regulations do not reduce competitiveness but instead tend to promote the competitiveness of industries in the BRICS economies due to green protectionism. This result is in line with the findings of Costantini and Mazzanti (2012); Wang, Zhang and Zeng (2016); Silajdzic and Mehic (2017); Yu and Sun (2017); Wang, Huang, and Yu (2019); and Qiang et al. (2022), who all found evidence confirming the Porter hypothesis. By comparing these estimates under the two periods, the findings show that imposition of strict environmental regulations by exporters increased intra-BRICS aggregate exports more during the full period (0.47%) than before the COVID-19 pandemic (0.35%).

For the importing countries, however, the estimates of the two models reveal significant negative impact of environmental regulations. This implies that intra-BRICS aggregate exports could be impaired perhaps due to trade barriers imposed on importations by members of the bloc with lower environmental standards. This also suggests that importing countries prefer domestically produced goods over those from countries with high environmental standards. Thus, a comparison of the estimates for the two periods with respect to both countries shows that strict environmental standards in the importing countries have a greater impact on reducing intra-BRICS aggregate exports than the increase that stringent environmental standards in the exporting countries could bring (See Table 5). This result contradicts those of Arouri et al. (2012), who found a significant positive impact of stringent environmental regulations in the importing countries on aggregate exports.

Table 5: Analysis of environmental regulation on intra-BRICS aggregate exports

Full Period (2010-2021)			Period before COVID-19 (i.e., if year =2019)	
Model 1			Model2	
DependentVariable: AggregateExports	Fixed Effects Model	Random Effects Model	Fixed Effects Model	Random Effects Model
lgdp_x	-7.721* (4.087)	1.219*** (0.097)	-8.290 (5.105)	1.293*** (0.102)
lgdp_m	1.609*** (0.184)	1.708*** (0.155)	1.454*** (0.151)	1.571*** (0.136)
lgdppc_x	11.659** (4.622)	-0.051 (0.111)	11.029* (5.971)	-0.125 (0.115)
lgdppc_m	-1.154*** (0.269)	-1.405*** (0.208)	-0.948*** (0.217)	-1.230*** (0.173)
lreer_x	-6.126*** (1.808)	-3.363*** (0.841)	-5.239** (2.065)	-3.206*** (0.879)
lreer_m		1.043 1.457** (0.590)	0.690 (0.770)	1.381** (0.654)
eps_x		-0.341 0.477*** (0.142)	-0.115 (0.231)	0.355*** (0.134)

eps_m	-1.028*** (0.334)	-1.335*** (0.240)	-0.712*** (0.276)	-1.083*** (0.209)
inst_x	1.510* (0.909)	0.427* (0.258)	1.633 (1.154)	0.673** (0.266)
inst_m	1.312*** (0.419)	1.796*** (0.321)	1.153*** (0.387)	1.640*** (0.307)
trf_adj	-0.179*** (0.060)	-0.217*** (0.047)	-0.148*** (0.052)	-0.186*** (0.044)
Constant	-6.738 (9.961)	14.159*** (4.491)	-1.098 (14.353)	12.986*** (4.404)
F-test	3.77*** (0.0055)		2.39 * (0.0526)	
Hausman test		2.03 0.9984)		4.39 (0.9570)
Number of groups	5	5	5	5
Number of observations	235	235	195	195
R-square	0.531	0.985	0.612	0.988

Notes: standard errors are in parentheses while ***, **, and *, respectively represent $p < 0.01$, $p < 0.05$, and $p < 0.1$

Source: Author's computation

A fall in REER represents depreciation which is associated with lower trade costs (a gain in trade competitiveness) and vice-versa. Exportable goods become more affordable and competitive as a result of the depreciation of the exporter's currency relative to the currencies of the importers, thus increasing its demand in the foreign markets. Similarly, exportable goods become more competitive when the currencies of importers appreciate relative to those of exporters. This is supported by the estimates of the two models in Table 5 showing a significant negative coefficient of exporter's REER while positive coefficient of importer's REER, with higher impact during the entire period relative to the COVID-19 period. These estimates suggest that a 1% depreciation of the exporter's currency may boost intra-BRICS aggregate exports by 3.4% and 3.2%, respectively and by 1.5% and 1.4% if the importing country's currency appreciates by at least 1%. The RE estimates under the two periods show that the qualities of institutions for both exporting and importing countries are all found to be positive and exert a significant impact on intra-BRICS aggregate exports. From the estimates, it is understood that development of well improved and standardized institutions in the exporting country, with similar case in the importing countries could enhance intra-BRICS aggregate exports. Although, there is differing impact as maintaining an improved institutions in the importing countries tends to boost intra-BRICS aggregate exports more than having a sound institution in the exporting country.

5.3 Analysis of environmental regulation on intra-BRICS sectoral exports

The results of the gravity models estimated to discern the impact of environmental regulations on intra-BRICS exports of pollution-intensive sectors ('dirty' industries) and exports of non-resources based sectors (footloose) are presented in Tables 6 and 7 for both the full and pair-wise periods.

'Dirty' Exports

The impact of environmental regulations on intra-BRICS exports of pollution-intensive sectors ('dirty' industries) is estimated for both full and pair-wise periods as shown in Table 6. Based on Hausman test statistics, the RE model is chosen for the two periods. According to the RE estimates, the GDP of exporting and importing countries play an important role in promoting intra-BRICS 'dirty' exports, with importing country GDP having a higher impact. Also, GDP per capita of importer, tariff, exporters' REER and institutional quality of exporting country all exert significant negative impact, while institutional quality of importing country has a significant positive impact on intra-BRICS 'dirty' exports. Similar to the estimates of aggregate exports, the relative stringency of environmental regulations under the two periods shows that strictness in the exporting country significantly increases intra-BRICS 'dirty' exports, while strictness in the importing country appears to have a significant negative impact. A comparison with respect to the two periods shows that, due to strict environmental standards in the exporting country, intra-BRICS 'dirty' exports increased more during the full period (0.97%) than before COVID-19 (0.88%). However, due to strict environmental standards in the importing country, it decreased more during the full period (1.73%) than before COVID-19 (1.49%) (See Table 6).

Table 6: Analysis of environmental regulation on intra-BRICS exports of pollution-intensive sectors ('dirty' industries)

Full Period (2010-2021)			Period before COVID-19 (i.e., if year <=2019)	
Dependent Variable:	Model 1		Model 2	
	Fixed Effects Model	Random Effects Model	Fixed Effects Model	Random Effects Model
Dirty Exports				
lgdp_x	-1.594 (4.326)	0.709*** (0.114)	-0.251 (5.601)	0.784*** (0.125)
lgdp_m	2.240*** (0.197)	2.273*** (0.183)	2.168*** (0.182)	2.197*** (0.178)
lgdppc_x	5.442 (4.882)	0.015 (0.131)	3.125 (6.548)	-0.067 (0.141)
lgdppc_m	-1.910*** (0.289)	-2.024*** (0.247)	-1.876*** (0.269)	-1.983*** (0.235)
lreer_x	-4.615** (1.905)	-2.823*** (0.990)	-3.642 (2.232)	-2.924*** (1.078)
lreer_m	-0.633 (0.766)	-0.411 (0.693)	-1.019 (0.866)	-0.635 (0.797)
eps_x	-0.258 (0.261)	0.971*** (0.167)	-0.130 (0.257)	0.878*** (0.166)
eps_m	-1.610*** (0.356)	-1.730*** (0.285)	-1.376*** (0.336)	-1.495*** (0.274)
inst_x	0.080 (0.960)	-0.965*** (0.303)	-0.093 (1.250)	-0.711** (0.326)
inst_m	3.380*** (0.446)	3.653*** (0.378)	3.485*** (0.440)	3.686*** (0.389)
trf_adj	-0.234*** (0.063)	-0.232*** (0.056)	-0.199*** (0.060)	-0.186*** (0.056)
Constant	2.713 (10.482)	22.300*** (5.302)	9.491 (15.966)	23.615*** (5.652)
F-test	5.85*** (0.0002)		5.42*** (0.0004)	
Hausman test	12.11 (0.3555)		16.62 (0.1197)	
Number of groups	5	5	5	5
Number of Observations	235	235	195	195
	0.529	0.970	0.577	0.965

Notes: standard errors are in parentheses while ***, **, and *, respectively represent $p < 0.01$, $p < 0.05$, and $p < 0.1$

Source: Author's computation.

In terms of the relative impact of strict environmental standards for both importing and exporting countries on intra-BRICS 'dirty' exports, the results also show that strict environmental standards in the importing countries reduced intra-BRICS 'dirty' exports more than the increase associated with stringent environmental standards in the exporting countries (See Table 6). This result is contrary to the findings of Arouri et al. (2012), who found significant positive impact of stringent environmental regulations in the importing countries on 'dirty' exports.

'Footloose' Exports

Similar to aggregate and dirty exports estimations, the RE model is chosen for analyzing the impact of environmental regulations on exports of non-resources based sector for both full and pair-wise periods, as shown in Table 7. The estimates of non-resources based exports are similar to those under aggregate and dirty exports. There are just two differences: first, in addition to other significant variables in the model, GDP per capita of exporting countries has a significant impact on 'footloose' exports but negative. Second, the impact of strict environmental standards both in the exporting and importing countries is higher for 'footloose' exports than for aggregate and dirty exports, respectively (See Table 7).

Looking at the comparison analysis of the two periods, the results show that stringent environmental standards in the exporting country increased intra-BRICS 'footloose' exports more during the full period (1.45%) than before COVID-19 (1.32%). However, strict environmental standards in the importing country reduced it by 2.93% during the full period and by 2.68% before COVID-19 (See Table 7). This result contradicts the findings of Arouri et al. (2012), who found no significant impact of stringent environmental regulations both in the exporting and importing countries on 'footloose' exports.

Table 7: Analysis of environmental regulation on intra-BRICS exports of non-resources based sectors ('Footloose' exports)

Full Period (2010-2021)			Period before COVID-19 (i.e., if year ≤ 2019)	
Model 1			Model2	
Dependent Variable:	Fixed Effects Model	Random Effects Model	Fixed Effects Model	Random Effects Model
NRB Exports				
lgdp_x	3.368 (6.235)	1.15*** (0.174)	6.06 (8.753)	1.336*** (0.205)
lgdp_m	2.648***	2.669***	2.448***	2.47***

	(0.37)	(0.355)	(0.362)	(0.344)
Notes: standard errors are in parentheses while ***, **, and *, respectively				
dppc_x	2.62 (7.126)	-0.334* (0.197)	-1.433 (10.429)	-0.501** (0.221)
lgdppc_m	-2.942*** (0.555)	-3.039*** (0.51)	-2.884*** (0.554)	-2.964*** (0.499)
lreer_x	-8.873*** (3.259)	-7.14*** (1.985)	-8.967* (4.624)	-8.168*** (2.347)
lreer_m	1.026 (1.188)	0.569 (1.047)	1.323 (1.444)	0.925 (1.256)
eps_x	-0.478 (0.393)	1.448*** (0.288)	-0.251 (0.398)	1.322*** (0.288)
eps_m	-2.989*** (0.676)	-2.933*** (0.577)	-2.751*** (0.679)	-2.68*** (0.564)
inst_x	1.589 (1.42)	1.075** (0.451)	2.059 (2.151)	1.492*** (0.495)
inst_m	3.259*** (0.71)	3.422*** (0.647)	3.186*** (0.72)	3.313*** (0.674)
trf_adj	-0.42*** (0.104)	-.402*** (0.095)	-.356*** (0.102)	-.324*** (0.094)
Constant	10.383 (15.375)	44.389*** (10.67)	24.264 (24.615)	47.583*** (11.826)
F-test	6.37*** (0.0001)		5.03*** (0.0007)	
Hausman test		15.67 (0.1540)		15.14 (0.1763)
Number of groups	5	5	5	5
Number of observations	235	235	195	195
R-square	0.192	0.955	0.674	0.952

represent p<0.01, p<0.05, and p<0.1

Source: Author's computation.

5.4 Robustness Analysis

In order to check for robustness of the above analysis, this study conducted another set of analyses using environmental performance indicators (EPI) as a proxy for environmental regulations. Across the models specified for the three categories of bilateral exports (i.e., aggregate, dirty and footloose) and for both full and pair-wise periods, the results of the analyses consider the RE model more appropriate based on Hausman test statistics. Thus, only the results of the RE model are presented in Table 8. On the three categories of bilateral exports, the estimates under the two periods reveal that the GDP of exporting and importing countries, GDP per capita of exporting countries, and institutional

quality of importers all exert significant positive impact on intra-BRICS trade flows. However, importing countries' GDP per capita, tariffs, and exporters' REER exert significant negative impacts (See Table 8).

Concerning environmental regulations, as measured by environmental performance indicators, the results show a significant negative impact in the exporting countries across the specifications. This suggests that high degree of strictness of environmental standards in the exporting countries significantly lowers the productivity of BRICS countries (due to high production cost), thus inhibits their competitiveness in the three categories of export trade flows mentioned earlier. This result negates the Porter hypothesis based on the fact that it has no promoting effects on productivity and exports competitiveness, but rather support the hypothesis that strict environmental standards has an inhibitory effects. This result contradicts the findings of Azam (2016), who measured environmental regulations using EPI and found that strict environmental standards has a significant positive impact on aggregate exports in the exporting countries.

However, in the importing countries, the estimates show a significant positive impact of strict environmental standards. This connotes that importing countries prefer to buy from countries with stricter environmental standards. This result is consistent with the findings of Azam (2016), who reported a significant positive impact of stringent environmental standards on aggregate exports in the importing countries.

6. Conclusion and Policy Recommendations

Table 8: Panel random effects estimation on the impact of environmental regulation on intra-BRICS trade flows

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	ltotal_exp2		ldirty_exp2		lnrb_pi_exp2	
	Full Period (2010- 2021)	Period before COVID-19	Full Period (2010- 2021)	Period before COVID-19	Full Period (2010- 2021)	Period before COVID-19
<u>lgdp_x</u>	1.318*** (0.137)	1.333*** (0.139)	0.983*** (0.211)	1.083*** (.141)	1.347*** (0.229)	1.53*** (0.195)
<u>lgdp_m</u>	1.478*** (0.168)	1.424*** (0.158)	2.165*** (0.260)	1.732*** (.14)	1.717*** (0.220)	1.377*** (0.163)
<u>lgdppc_x</u>	0.548** (0.227)	0.322 (0.204)	0.948*** (0.344)	0.279 (.187)	0.610** (0.296)	0.065 (0.214)
<u>lgdppc_m</u>	-2.911*** (0.555)	-2.460*** (0.453)	-4.831*** (0.916)	-2.449*** (.349)	-4.137*** (0.761)	-2.691*** (0.436)
<u>lreer_x</u>	-3.958*** (1.312)	-2.922** (1.234)	-3.938* (2.094)	-2.543* (1.321)	-4.232* (2.548)	-4.354** (2.082)
<u>lreer_m</u>	0.458 (0.899)	0.070 (0.930)	-2.026 (1.339)	-1.725* (.882)	-1.233 (1.258)	-0.680 (1.041)
<u>lepi_x</u>	-4.585*** (1.060)	-3.493*** (0.838)	-7.687*** (1.672)	-3.826*** (.731)	-7.015*** (1.555)	-4.617*** (0.976)
<u>lepi_m</u>	5.689*** (1.312)	4.090*** (1.026)	9.622*** (2.111)	3.995*** (.838)	8.570*** (1.887)	5.067*** (1.079)
<u>inst_x</u>	-0.032 (0.441)	0.419 (0.412)	-1.792*** (0.649)	-.805** (.384)	0.552 (0.577)	1.376*** (0.440)
<u>inst_m</u>	2.768*** (0.597)	2.584*** (0.545)	5.576*** (0.936)	3.809*** (.467)	3.827*** (0.788)	2.663*** (0.545)
<u>trf_adj</u>	-0.179*** (0.062)	-0.133** (0.055)	-0.246** (0.097)	-.041 (.051)	-0.219*** (0.082)	-0.046 (0.059)
<u>Constant</u>	24.391*** (7.701)	21.485*** (7.253)	41.214*** (11.907)	26.379*** (6.951)	36.632*** (12.137)	30.926*** (9.939)
<u>Hausman test</u>	7.26 (0.7778)	2.72 (0.9939)	15.70 (0.1527)	10.07 (0.5243)	12.11 (0.3551)	12.66 (0.3162)
<u>Number of groups</u>	5	5	5	5	5	5
<u>Number of observations</u>	235	195	235	195	235	195
<u>R-square</u>	0.998	0.999	0.998	0.950	0.981	0.944

Notes: standard errors are in parentheses while ***, **, and *, respectively represent $p < 0.01$, $p < 0.05$, and $p < 0.1$

Source: Author's computation.

6. Conclusion and Policy Recommendations

This study explores the impact of stringent environmental regulations on intra-BRICS trade flows, as well as the validity of the Porter hypothesis for the bloc. Within the framework of the gravity model, a panel data on the five BRICS countries is used at a bilateral level. The three categories of bilateral exports ('aggregate', 'dirty' and 'footloose' trade) were analyzed for the period 2010-2021 using fixed and random effect models estimators. This study proxies environmental regulations using two country-specific and internationally-comparable measures: environmental policy stringency (EPS) and environmental performance indicators (EPI), both of which are computed based on environmental policy instruments, primarily related to climate and air pollution. Using EPS, the findings show that stringent environmental standards have a promoting effect in the exporting countries while the inhibiting effect in the importing countries on intra- BRICS aggregate exports and its components (pollution-intensive exports and non-resource based exports trade). Across the three categories of export trade, the findings also reveal that the impact of strict environmental standards both in the exporting and importing countries is higher for 'footloose' exports than for aggregate and dirty exports, respectively. In addition, the promoting effect of strict environmental standards in the exporting countries is lower relative to its inhibiting effect in the importing countries. This implies that the validity of Porter hypothesis for intra- BRICS trade flows could only hold if heterogeneity effects in terms of both the exporting and importing country-specific effects are not taken into consideration.

Using EPI as a measure of environmental regulations, the results show a significant negative impact in the exporting countries across the specifications. This suggests that high degree of strictness of environmental standards in the exporting countries significantly lowers the productivity of BRICS countries (due to high production cost), thus inhibiting their competitiveness in the three categories of export trade flows. This result negates the Porter hypothesis based on the fact that it has no promoting effects on productivity and exports competitiveness, but rather support the hypothesis that strict environmental standards has an inhibitory effects.

Based on the results obtained in this study, environmental policy should not be viewed as a rival context, particularly by the importing countries. Thus, there is a need for BRICS countries to comply with environmental stringency by insisting on a more unified regulatory framework to preserve the environment while maintaining economic efficiency. The findings of this study confirmed that the long-run benefits associated with strengthening environmental regulations may outweigh the short-run losses, particularly in the exporting countries. It is therefore important that the BRICS countries provide the right incentives through implementing environmental regulations accompanied by effective innovation and technology policy. Such provision may foster cleaner

technologies and sustainable use of energy and resources, while minimizing the risk of relying on suboptimal technologies, and thus promoting competitiveness.

Appendix 1

Table 9: Results of Correlation Analysis

	lgdp_x2	lgdp_m2	lgdppc_x	lgdppc_m	lrer_x	lrer_m	eps_x	eps_m	inst_x	inst_m	epi_x	epi_m	trf_adj
lgdp_x	1.000												
lgdp_m	-0.240	1.000											
lgdppc_x	0.071	-0.005	1.000										
lgdppc_m	-0.005	0.071	-0.235	1.000									
lrer_x	0.501	-0.047	-0.250	0.005	1.000								
lrer_m	-0.193	0.660	0.013	-0.182	-0.033	1.000							
eps_x	0.676	-0.139	-0.361	0.127	0.571	-0.269	1.000						
eps_m	-0.139	0.676	0.127	-0.361	-0.201	0.716	-0.156	1.000					
inst_x	-0.498	0.102	0.130	-0.060	-0.203	0.133	-0.316	-0.174	1.000				
inst_m	0.102	-0.498	-0.060	0.130	0.022	-0.238	0.012	-0.316	-0.174	1.000			
epi_x	-0.114	0.024	0.522	-0.137	-0.304	0.109	-0.458	0.122	0.009	-0.002	1.000		
epi_m	0.024	-0.114	-0.137	0.522	0.113	-0.321	0.122	-0.458	-0.002	0.009	0.375	1.000	
trf_adj	0.053	-0.237	-0.002	-0.021	0.176	-0.474	0.107	-0.543	-0.027	0.237	-0.074	0.174	1.000

Source: Author's computation.

Table 10: Definition, Measurement, and A’priori Expectation of the Variables used in equations (5)

Abbreviation of Variables	Explanation of Variables	Measurement	Expected relationship (sign)	Data source
EXP	Export	Trade value of export in 1000 USD		UN COMTRADE database
GDP	Gross Domestic Product	GDP at market prices (constant 2015 US\$).	+	WDI
GDPPC	GDP per capita	GDP per capita (constant 2015US\$)	+	WDI
TRF-adj	Adjusted tariff	1 + Bilateral weighted average level applied MFN tariffs rates (%)	-	WDI, World bank database. https://data.worldbank.org/indicator/TM.TAX.TCOM.SM.AR.ZS
REER	Real effective exchange rate	Real effective exchange rate	+/-	World Bank General Economic Monitor (GEM)
INQ	Institutional quality	Regulatory quality	+/-	Computed from data available in WGI
EPS	Environmental policy stringency	Environmental policy stringency	+	OECD.stat
EPI	Environmental performance index	Environmental performance index	+	http://epi.yale.edu

Source: Author’s Compilation from Literature Review

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Notes

¹ This Agenda covers a wide range of indicators which comprise three interrelated goals of sustainability: improve economic, social and environmental conditions worldwide (Berger et al., 2020).

² Heavy industries include steel, petrochemicals, fertilizers, and paper, whereas traditional labor-intensive industries include textile and apparel.

³ Testing whether Porter hypothesis could hold for intra-BRICS export trade

⁴ FEM assumes that in a gravity equation, unobserved heterogeneous is constant over time and in different way affects each individual country in a panel analysis, while REM assumes absence of correlation imposed between individual effects and the regressors (see Gómez-Herrera, 2013).

Energy mix and economic growth in sub-Saharan Africa: Evidence from a threshold model

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Abstract

This paper is concerned with the effects of the energy mix on economic growth in sub-Saharan African countries. We constructed an energy mix diversification index (EMDI) for Sub-Saharan Africa (SSA). Using the EMDI, we then analyse the effects of total energy consumption on economic growth. Splitting total energy consumption into renewable and non-renewable energy consumption, their respective effects on economic growth were analysed. Finally, the effects of EMDI on economic growth within SSA over the period from 1980 to 2019 was analysed. Also, the pool mean group (PMG) estimator and the panel threshold model developed by Seo and Shin (2019) were used in order to determine the threshold level of energy consumption that increases economic growth. Robustness check was done by using the Dynamic common correlated effect (Dynamic CCE) estimation techniques. Thus, our findings showed that, total energy consumption, non-renewable energy consumption, electricity consumption and energy mix diversification tend to increase economic growth in SSA in the long-run. However, it was realised that renewable energy consumption tends to have a mitigating effect on economic growth when the threshold level of 0.0453 is exceeded. It was also realised that the threshold rate of EMDI favourable for economic growth in SSA is 0.376. Therefore, in order to enhance energy transition, policymakers should endeavour to formulate policies that will encourage investments in the main sources of renewable energy.

1. Introduction

Energy plays a very important role in the world today. It serves as a catalyst for investment in industrial development, resulting in job creation and economic growth in most countries of the world. Energy policy today seeks to mitigate climate change and achieve sustainable development without exposing the poor all over the world to perpetual poverty is the main challenge of energy policy today (Harjanne and Korhonen, 2019). Primary energy is energy available in a raw state, before any transformation. It can be available in a stock form (coal, crude oil, natural gas, uranium.) it is also known as non-renewable energy. Primary energy also exist in a flux form (solar, wind or hydro energy), otherwise known as renewable energy (Percebois, 1989).

For domestic and industrial purposes, some countries can formulate policies which can either encourage only the consumption of fossil fuels or the consumption of both renewable and non- renewable energy, a package referred to as energy mix (Donev et al. 2021). The concept of the energy mix has been featuring in economic literature and political discourses since the adoption of the United Nations Sustainable Development Goals (SDGs) in September 2015 and the COP21 in December of the same year.

Among the seventeen sustainable development goals, goal number 7 aims at promoting clean and affordable energy, while goal number 9 seeks to build resilient infrastructure, promoting sustainable industrialisation and encouraging innovation. These goals are essential to developing countries in sub-Sahara Africa, considering that investment in infrastructure can boost economic growth (Aschauer, 1989a and 1989b; Barro, 1990). It is important to note that energy infrastructure, industrialisation and investment in public infrastructure can greatly enhance economic growth and development. "Countries that invest more in public infrastructure have a competitive advantage in attracting economic activity" (Halstead and Deller, 1997; Palei, 2015). The lack of infrastructure, industrialisation and innovation constitute a major difficulty to the development of African countries, given that, firms as the prime movers of economic growth and development, make use of public infrastructure as well as private labour or capital in their production processes. It is clear from the above that energy, investment in both local and foreign, trade openness as well as innovation can increase country's economic growth.

Several empirical studies have investigated the causal effects of energy consumption on economic growth (Templet, 1999; Behname, 2012; Apergis and Payne, 2010; Menyah and Wolde-Rufael, 2010; Wandji, 2013; Shahbaz et al. (2013); Najid and Liangsheng, 2019). Of all these studies, none has so far targeted the effect of energy mix on economic growth. Consequently, following Rubio-veras and Munoz-delgado (2019) based upon the Herfindahl- Hirschman

Index (HHI), we constructed an energy mix diversification index (EMDI) and analysed its effects on economic growth in Sub-Sahara African countries.

The objective of this empirical paper is to highlight the effects of energy mix on economic growth in sub-Saharan African countries. To do so, a step by step approach was used. Firstly, an energy mix diversification index (EMDI) for SSA was constructed. Secondly, the effects of total energy consumption on economic growth were analysed. Then, total energy consumption was split into renewable and non-renewable energy consumption and their respective effects on economic growth were analysed. The third step was to analyse the effects of the energy mix diversification index on economic growth. More specifically, we study the long and short run effect of energy mix on economic growth in SSA over the period 1980 to 2019. This was done using the ARDL modelling through the pool mean group (PMG) estimators developed by Pesaran et al (1999). Furthermore, the panel threshold model developed by Seo and Shin (2019) was used to highlight an eventual non-linear relationship and determine the threshold level of energy consumption. To do so, we partitioned our time span (initially 40 years) into 8 periods of 5 years each, making the number of countries (N) higher than the number of years per country

(T). In this way, the sample of the study will be consistent with the $N(36) > T(8)$ criterion (Asongu, 2017). For robustness check, the Dynamic common correlated effect (Dynamic CCE) estimation techniques (Pesaran and Chudik, 2015) was used.

The rest of the paper will include literature review in section two, data and methodology in section three, results and discussion in section four, policy implications in section five and conclusion in section six..

2. Literature review

In this section, we will address issues related to both renewable and non-renewable energy because we are working on energy mix.

The economic theory nowadays deals mainly with energy transition, clean energy, energy mix and sustainable development (Azevedo et al., 2019; Markovska et al., 2016). In order to tackle the problem of sustainability and alleviating poverty in the world, the United Nations formulated 17 Sustainable Development Goals (SDG) for the period 2015-2030. Many of these SDGs, such as decent jobs, income, pollution and ecosystems are directly linked to energy, so much so that it exercises a strong influence on the difficulties and opportunities in the world of today (Büyükoğkan et al., 2018). Most vibrant economies today are standing tall due to reliable sources of energy. The use of more renewable energy would adequately reduce Africa's economic vulnerability to the adjustable and rising prices of imported fuels. It is for this

reason that Aliyu et al. (2017) agrees that energy efficiency, access to renewable energy for off-grid, small scale application can have a positive influence to energy crisis, sustainable development, climate change and poverty alleviation.

Energy security is very essential in poverty alleviation (OECD/IEA, 2010), that is why access to energy for off-grid and small-scale application is actually being debated in developing countries. The objective of the United Nations Sustainable Energy for All initiative (SE4All) is to provide electricity to the 1.1 billion people in developing countries by 2030. Knowing that it is mainly in the rural areas that access to energy is still very low, mini-grids play a crucial role in accomplishing the SE4All's goal because, access to electricity will benefit many households (Peters et al., 2019) given that connection cost in grid roll-out programs is high in sparsely populated areas (IEA, 2010; Bos et al., 2018).

From the above mini-grid, the distribution of wind and solar energy enables local communities to become energy providers, thereby upsetting the monopoly of major power utilities and also serving as a source of local income as highlighted by Harjanne and Korhonen (2019). It is for this reason that developing economies must ensure that proper energy policies are formulated and great attention paid to SDG 7 and SDG9.

Researchers in the domain have proven that of renewable energy expansion in the market, it has been proven that renewable energy consumption is suitable for sustainability (Aliyu et al., 2017) as well as creates more job opportunities. However, renewable energies need to be subsidised in order to enhance competitiveness with non-renewable energies (Lund, 1999). Over the past fifteen years, the cost of producing electricity from renewable sources has reduced by at least 50%. This notwithstanding, renewable energies are still more expensive than fossil fuels that have long been existing. Fossil fuel also have the advantage that the cost of their installed infrastructures has been amortised. So far, the introduction of renewable energy has to a great extent been provided through feed-in tariffs and other comparable schemes (Djørup et al., 2018). These schemes are often referred to as subsidies, implying that they are temporal necessities until renewable energy technologies mature. Furthermore, Djørup et al. (2018) argue that, the feed-in tariffs presently fill the gap between long term production costs and market prices derived from short term marginal costs. This gap seems to be a permanent condition, while, the transition continues over the next 3-4 decades.

On the other hand, other studies have examined the interaction of renewables energies expansion and oil price; and their findings show that high hydrocarbon prices tend to improve the position of renewable energy sources (Bird et al., 2005; Van Ruijven and Van Vuuren, 2009; Reboredo, 2015), whereas low oil prices have the opposite effect. In addition, Sylva et al. (2018) pointed out that the wealth of a country plays a significant role in determining the use of renewables. A higher level of income means higher potential or more

resources to enhance RE growth. More income will enable countries to handle the costs of developing RE technologies and ensuring higher support for the costs of public policies in promoting and regulating renewables. It is for this reason that Aliyu et al. (2017) concluded that energy efficiency, access to renewable energy for off-grid, small scale application are primordial to the successful resolution to energy crisis, sustainable development and the fight against climate change. The important role of energy in the production process is now known in the economic theory. Basically, classical and neo-classical economists do not directly integrate energy as a factor of production in the production process (Alam, 2006). These authors focus mainly on labour and capital. Adam Smith for instance stated that the value of a good depends only on the quantity of work needed to produce it. It is following the work of Stanley Jevons in 1865, on the impact of coal depletion on the industrial development in the United Kingdom that energy will be considered as a main factor in the production process (Stern and Cleveland, 2004; Missemmer, 2012).

Following the 1973 oil crisis and its consequences on the world economies, energy as a factor of production became more relevant to economic research (Jaffe and Stavins, 1995; Milliman and Prince, 1989). Further studies therefore integrated the effects of energy consumption such as oil and gas on economic activities (Behname, 2012). While Stern (1999) divided factors of production into two groups: reproducible factors like labour and capital and unreproducible factors like energy.

The debate went on with Berndt and Wood arguing that energy and capital are complementary while Griffin and Gregory are of the opinion that energy and capital are substitutes to each other (Ozatalay et al., 1979) these arguments led to the conclusion that economic growth depends on the number of factors of production and technical progress (Percebois, 1989). It is at this point that the causal relationship between energy and economic growth was developed.

There is clear proof that there is a causal relationship between economic growth and energy consumption. The very first study of causal relationship between energy consumption and economic growth (Kraft and Kraft, 1978) showed that an increase in income will lead to more energy consumption in the USA. The study covered the period from 1947-1974 and was based on concrete statistical tests developed by Sim (1972). Because the first oil price shock fell within that period, Akarca and Long (1980) criticised the result of Kraft and Kraft. Using the same techniques but reducing the period of study to 18 years (1950-1968), Akarca and Long proved that there is no causal relationship between energy consumption and economic growth. This result was later confirmed by Yu and Hwang (1984) in the USA. Besides, Jumbe (2004) pointed out that energy consumption, especially electricity, is essential for economic development because it facilitates the efficiency of production inputs. To arrive at this, he used the Granger causality and error correction model over the period 1970-1999 in Malawi.

After these pioneer works on the causal relationship between energy and economic growth, many other empirical studies were done using different methods and producing different results. Adams et al. (2016) categorised these varying results into four main groups: -the conservation, growth, neutrality, and feedback hypothesis. **The energy conservation hypothesis** is based on the idea that economic growth is likely to result in an increase in energy consumption. To support this hypothesis, Omri and Kahouli (2014) and Esso (2010) used the Generalized Method of Moments (GMM) estimation technique and the bounds testing approach respectively to confirm that economic growth positively affects energy consumption.

The growth hypothesis is about the fact that energy consumption is the pivot of economic growth. Adopting the same variables used by Apergis and Payne in 2010, Behname (2012) used cointegration test, the Hausman test and the Granger causality test over the period 1995-2010 to prove that in Western Europe, there is a long and short term causal relationship from renewable energy consumption to economic growth. The Granger causality test indicated that the relationship was bidirectional. The same author in a similar study in northern Europe proved that the causality was rather unidirectional, implying that energy positively affects GDP growth. Menyah and Wolde-Rufael (2010) on their part examined the relationship for South Africa over the period 1965–2006 and reported a unidirectional causality resulting from energy consumption to economic growth. In addition, Wandji (2013) did similar studies for Cameroon covering the period 1971–2009 and reported that 1% energy consumption leads to 1.1% increase in economic growth.

Furthermore, Silva et al. (2012) using the unit root tests and the VAR method, studied the impact of renewable energy consumption on economic growth and CO₂ emission in a panel of 4 countries (the USA, Denmark, Portugal and Spain). They concluded that renewable energy would not have any significant effect on growth in the short run (except in the US), but that it would exponentially reduce the emission of CO₂. For the Italian economy, Magnani and Vaona (2011) tested the spillover effects of renewable energy generation applying panel cointegration and Granger non-causality within the framework of GMM systems. Their results showed that renewable energy generation can promote economic growth; consequently, policies to promote renewable energy should be formulated.

The feedback hypothesis stands for a bi-directional causality between energy and economic growth, meaning that an increase in energy consumption will lead to more economic growth and vice versa. Here, Apergis and Payne (2010b), using the variables of capital formation, GDP, labour and renewable energy consumption, showed that, there is a bi-directional causality between economic growth and renewable energy consumption in Eurasia. They had the same results for OECD countries in 2010 (Apergis and Payne, 2010a). The same empirical exercise was undertaken by Apergis and Payne (2011, 2012a) to find

the causal relationship between renewable energy consumption and economic growth using the data of Central American countries over the period of 1980–2006. The estimated results revealed a bidirectional causality between the two variables, which also confirms the feedback hypothesis.

According to Adams et al. (2016), the **neutrality hypothesis** explains a situation where there is no correlation between energy consumption and economic growth. The empirical work of Akarca and Long (1980) confirmed this explanation by citing other studies such as, Tang and Abosedra (2014) who argue that energy conservation policies or energy crisis will not have any significant impact on economic growth. This because energy consumption represents a very small percentage of the GDP and therefore is not expected to have any effect on the growth rate (Yu and Choi, 1985). Also, Soytaş et al. (2007) studied the cases of US and Turkey and reported that there is no significant relationship between energy consumption and economic growth.

In view of the above, this paper supports the growth hypothesis which state that an increase in energy consumption will result to more economic growth. From our findings in section 5, we will either confirm or reject this hypothesis. This hypothesis is chosen because SSA is endowed with enormous energy resource potentials so much so that an optimal use of this energy will have a positive effect on economic activities. Before testing this hypothesis, an energy diversification index for SSA will be constructed.

3. Data and methodology

In this section we discuss the construction of the energy mix diversification index, followed by the specification of the theoretical baseline model which highlights the effect of energy mix on economic growth. Finally the presentation of the data and the estimation procedure of our model are done.

3.1 Construction of the energy mix diversification index (EMDI)

To construct the energy mix diversification index (EMDI) of SSA, we use the method of Rubio-veras and Munoz-delgado (2019) which is based on the Herfindahl-Hirschman market share concentration index (HHI). The HHI is generally applied to the analysis of market concentration. It is measured by the sum of the squares of the market shares of each energy source over a given period, which corresponds to the formula:

$$HHI_t = \sum_i^t P_i^2 \quad (5)$$

Where P_i is the share of the energy source i in the energy mix. Smaller values of the HHI indicate greater diversification, with 0 being the minimum concentration and 1 being the maximum concentration (in case the shares are

expressed as fractions, where the aggregation of all the portions sum one i.e., 10% would be considered as 0.1). Accordingly, the concentration of the energy mix in a given year has been calculated using the HHI, and we named it Energy Mix Concentration Index (EMCI). For each country, we built a matrix containing the share of each energy source in the total energy consumption of every year from 1980 to 2019, for countries of SSA. For our calculations the energy sources are aggregated at the upper level possible following the classification originally made in Kander et al. (2014): coal, natural gas, oil, nuclear and renewable energy. Thus rewriting equation (5) becomes:

$$EMCI_t = \sum_i^t P_i^2 \quad (6)$$

Once we have the energy mix concentration index developed by Rubio-veras and Munoz- delgado (2019), we subtract it to one to obtain the energy mix diversification index (EMDI). Hence, equation (6) becomes:

$$EMDI_t = 1 - \sum_i^t P_i^2 \text{ or } 1 - EMCI_t \quad (7)$$

Where t is the considered year and i are:

- Coal
- Natural gas
- Oil
- Nuclear
- Renewable energy

The closer the index calculation is to 1, the more the country's energy consumption tends to be diversified towards many energy source. For instance, the calculation of the EMDI for SSA countries from 1980 to 2018 shows an average of 0.42 with a minimum of 0 and a maximum of 1. Overall, the average value of EMDI is closer to 0 than to 1, meaning that a great majority of sub-Saharan African countries are not diversifying their energy consumption, many of these countries have just one or two energy sources for their economy. For example, the value of EMDI for Chad and Guinea-Bissau is 0 from 1980 to 2013, meaning that these two countries were using only one energy source to fuel their economies. In the next section, we intend to analyse the effect of this energy mix on economic growth. To do so, we use an extended Cobb- Douglas production function as shown in the following theoretical baseline model.

3.2 Data

This study is done on a panel of 36 sub-Saharan African countries listed in appendix 3. The other SSA countries were dropped because of lack of data. The timespan is running from 1980 to 2018. The data is collected from the International Energy Statistics Database of U.S. Energy Information Administration (EIA) and World Development Indicators (WDI) of the World Bank databases (2022). The dependent variable is real GDP per capita (GDPpc) collected from WDI. Our explanatory variables of interest are: total energy consumption (TENcon), non-renewable energy consumption (NRE), Renewable energy consumption (RE), electricity consumption (ElecCon), and energy mix diversification index (EMDI). These variables are all collected from the International Energy Statistics Database of U.S. Energy Information Administration (EIA), except Electricity consumption collected from WDI. As for control variables, we use the most common in the literature (e.g., Shahbaz et al. (2013), Le (2016), Shahbaz et al. (2018), Le and Nguyen (2019)), namely: Total trade value per capita, used as the proxy of Trade Openness (TO), collected from WDI. Domestic credit provided by private sector per capita used as a proxy of Financial Development (FD) from WDI. INV is domestic investment measured by Gross fixe capital formation per capita, from WDI. In a nutshell, all these variables are summarised in table1 of appendix 1.

Regarding the correlation matrix analysis in table 2 (appendix 2), the result indicates that energy mix index as well as all the others forms of energy (total energy consumption, non-renewable energy consumption, renewable energy consumption and electricity consumption) are positively and significantly correlated to real GDP at 1% significant level. Based on the econometric analysis in the sections below, we will verify this relationship in depth.

3.3 Theoretical baseline model

In order to investigate the impact of energy security on economic growth, an extended Cobb- Douglas production function, which was used in many previous studies (e.g., Shahbaz et al. (2013), Le (2016), Shahbaz et al. (2018), Le and Nguyen (2019)), is used as our baseline model, as follows:

$$Y = AK\alpha_1 L\alpha_2 EM\alpha_3 e^{\mu} \quad (1)$$

Where: Y is real domestic output, K is capital, L is labour, EM is energy mix, A is technological factor, and e is error assumed N(i.i.d). α_1 , α_2 and α_3 represent the elasticities of output to capital, labour, and energy mix, respectively. For the model (1), the extended Cobb-Douglas production function with constant returns to scale is employed ($\alpha_1 + \alpha_2 + \alpha_3 = 1$).

According to Shahbaz et al. (2013) and Le and Nguyen (2019), the technology in the extended Cobb-Douglas production function is allowed to be endogenously determined by the levels of trade openness and financial development. In fact, a vast of literature has highlighted the roles of financial development in determining output (Durusu-Ciftci et al., 2017; Ibrahim and Alagidede, 2018; Le

and Tran-Nam, 2018; Le et al, 2016b; Ruiz, 2018), which are transmitted through two main channels (Le, 2016): (i) the accumulative channel through its induced effects on the accumulation of physical and human capital (Pagano, 1993), and (ii) the allocative channel by its positive effects on the effectiveness of resource allocation (King and Levine, 1993a,b). Furthermore, the higher level of financial development in an open economy creates a more favourable environment for FDI inflow, leading to higher technological and managerial skill transfers (Alfaro et al., 2004; Azman-Saini et al., 2010; Hermes and Lensink, 2003).

The growth effects of trade openness have been well studied following endogenous growth models (Rivera-Batiz and Romer (1991a); Rivera-Batiz and Romer (1991b)), which argue that trade openness tends to enhance economic growth by improving domestic productivity through innovation and technology development (Shahbaz et al., 2013; Le, 2016; Le and Tran-Nam, 2018). Openness to trade also creates economies of scale through specialization (Amable, 2000). Trade openness plays a vital role for most free market economies since it increases domestic rivalry, creating pressures for innovations to achieve higher efficiency (Hadhek and Mrad, 2015). As a result, trade openness has favourable effects on technological advancement and its diffusion (Le, 2016; Le et al, 2016a,b).

Therefore, the roles of trade openness and financial development are explicitly incorporated in the technological progress of the extended Cobb-Douglas function as follows:

$$A_t = \partial TO^\varnothing FD^\theta \quad (2)$$

In which: ∂ is the constant time-invariant, TO and FD represent trade openness and financial development, respectively. $\varnothing$ and θ are the elasticities of technology to trade openness and financial development, respectively. In fact, finance might play a significant role in the linkage between energy security and economic growth (see Yoshino et al., 2018). Lack of private sector finance is identified as one of the key obstacles to development of renewable energy projects. Easing finance for investment in green energy projects is thus a major challenge for the transition to low-carbon energy provision (Stern, 2015; Mazzucato and Semieniuk, 2018; Yoshino et al., 2018). With the assumption as $\alpha_1 + \alpha_2 + \alpha_3 = 1$, equation (2) is put into equation (1) as follows:

$$Y_t = \partial TO^\varnothing FD^\theta K^{\alpha_1} L^{1-\alpha_1-\alpha_3} E M^{\alpha_3} \quad (3)$$

The impact of labour is kept constant by dividing both sides of equation (3) for the population to transform this equation in per capita terms. We include one additional control variables in the baseline model, namely gross fixe capital

formation (INV). This variable, which is a proxy of domestic investment, might impact economic growth, as well as demand and supply shifts of energy and oil, and thus might influence the linkage between energy security and economic growth (Taghizadeh-Hesary and Yoshino, 2018).

Based on this extended theoretical framework, the linearized Cobb-Douglas production function from equation [3] for panel data sample is expressed as follows:

$$GDP_{pc\ it} = \alpha_t + \beta_1 EM_{it}^j + \beta_2 TO_{it} + \beta_3 FD_{it} + \beta_4 INV_{it} + \varepsilon_{it} \quad (4)$$

In which: GDP_{pc} is real GDP per capita. *EM* is the energy mix index. Trade openness (TO) is total trade value per capita. Financial development (FD) is domestic credit provided by private sector per capita. INV is domestic investment measured by Gross fixe capital formation per capita. *EM_j* is energy consumption, it changes according to the type of energy that is used, where $j = \{TENcon, NRE, RE, ElecCon, \text{ and } EMI\}$, TENcon is total energy consumption, NRE non-renewable energy consumption, RE Renewable energy consumption, ElecCon electricity consumption, EMDI energy mix diversification index. All the variables are transformed into logarithmic forms, except for EMDI. Variables' definition, calculation, data source, and description are shown in Table 1. The expected signs of $\beta_1, \beta_2, \beta_3, \text{ and } \beta_5$ are to be positive. In order to estimate the previous model in equation (4) we use de Pool mean group estimator (pmg) of ARDL modelling.

3.4 Econometric approach

The procedure for estimating long run models like ARDL model generally requires three steps, namely: panel unit root tests, panel cointegration test and the specification of the model.

3.4.1 Panel unit root tests

The panel unit root test is well known for its high power over normal time series and cross- sectional data (Al-mulali, 2012). Three types of panel unit root tests, the Levin, Lin and Chu (2002, LLC) test, the Breitung (2001) test and the Im et al, (2003; IPS) test will be used in this study as these are the most widely used tests in the literature. Both tests assume that there is a general panel unit root process, so that the autoregressive coefficients are the same in all cross sections.

3.4.2 Panel cointegration

As with panel unit root tests, panel cointegration tests are much more powerful than normal time series cointegration (Al-mulali, 2012), Pedroni's test will be used in this study to examine whether the long-run relationship exists between the variables. Pedroni performed several tests to test the null hypothesis of no cointegration in the panel data model. This test allows for considerable heterogeneity. Pedroni's cointegration test can be organised into two groups, the first group involves averaging the test statistics for the absence of cointegration in the time series across the cross-section, while in the second group the averaging is done piecewise so that the limiting distributions can be based on the limits of the piecewise numerator and denominator terms,

$$Y_{it} = \alpha_i + \delta_{it} + \sum_{j=1}^k \beta_j X_{j,it} + \varepsilon_{it} \quad (9)$$

Where

$$t = 1, \dots, T; i = 1, \dots, N; j = 1, \dots, k;$$

$$t = 1, \dots, T; i = 1, \dots, N; j = 1, \dots, k;$$

Y and X are assumed to be integrated of order 1, i.e. I(1). The parameters α_i and δ_{it} are individual entity and time effects, respectively, which can be negated if desired.

Under the null hypothesis of no cointegration, the residuals ε_{it} will be I(1). To perform the cointegration test, we need to obtain the residuals from equation (9) and then test whether the residuals are I(1)

3.4.3 Panel ARDL estimation: Pool Mean Group (PMG) approach

Four estimation methods are often used to estimate panel data models: pooling, aggregating, averaging group estimates, and cross-section regression. As for the averaging group estimates (mean group estimator) suitable for larger T, it consists of averaging separate estimates for each group in the panel. According to Pesaran and Smith (1995), this estimator provides consistent estimates of the parameters' averages. Pirotte (1999) also shows that the mean group estimator provides efficient long-run estimators for a large sample size. It allows the parameters to be freely independent across groups and does not consider potential homogeneity between groups. On the other hand, especially for larger T, Pesaran and Smith (1995) showed that the traditional procedures for estimation of pooled models, such as the fixed effects, instrumental variables, and generalized method-of-moments (GMM) estimators proposed, by among others, Ahn and Schmidt (1995), Anderson and Hsiao (1981, 1982), Arellano (1989), Arellano and Bover (1995) can produce inconsistent, and potentially very misleading estimates of the average values of the parameters in dynamic

panel data models unless the slope coefficients are in fact identical, a possible problem that is exacerbated when the period is long.

Pesaran et al. (1999) proposed an intermediate estimator that allows the short-term parameters to differ between groups while imposing equality of the long-term coefficients between countries. One advantage of the PMG is that it can allow the short-run dynamic specification to differ from country to country while making the long-run coefficients constrained to be the same. Furthermore, unlike the Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS), the PMG estimator highlights the adjustment dynamic between the short-run and the long-run. The reasons for assuming that short-run dynamics and error variances should be the same tend to be less compelling. Not imposing equality of short-run slope coefficients allows the dynamic specification to differ across countries. Finally, it generate consistent estimate of the mean of short-run coefficients by taking the simple average of individual unit coefficients.

Therefore, the long-run relationship between energy mix and economic growth is expected to be identical from country to country but the short-run coefficients are expected to be country- specific. The null hypothesis of the homogeneity in the long-run coefficients can be verified with the Hausman test.

With a maximum of q lags for all variables, the autoregressive distributed lag, ARDL ($p, q, q, \dots, q$) model proposed by Pesaran et al. (1999) is as follows:

$$y_{it} = \sum_{j=1}^p \delta_j y_{i,t-j} + \sum_{j=0}^q \beta'_{ij} X_{i,t-j} + \varphi_i + e_{ij} \quad (18)$$

Where:

y_{it} is the dependent variable,

X_{it} is the $k \times 1$ vector of explanatory variables which are either $I(0)$ or $I(1)$,
 φ_i is the unit-specific fixed effects

p and q are maximal lag orders; $i = 1, \dots, N$; $t = 1, 2, \dots, T$
 e_{ij} is the error term

The re-parameterised ARDL($p, q, q, \dots, q$) error correction model is specified as:

$$\Delta y_{it} = \theta_i [y_{i,t-1} - \lambda'_i X_{i,t}] + \sum_{j=1}^{p-1} \xi_j \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij} \Delta X_{i,t-j} + \varphi_i + e_{ij} \quad (19)$$

Where:

$\theta_i = -(1-\delta_i)$ is the group-specific speed of adjustment coefficient, it is expected to be negative,

λ'_i is the vector of long run relationships

ECT = $[y_{i,t-1} - \lambda'_i X_{i,t}]$ the error correction term

ξ_{ij}, β'_{ij} are the short-run dynamic coefficients

By substitution in our own case the model is as follow:

$$\Delta GDP_{it} = \theta [GDP_{i,t-1} - \lambda'_i X_{i,t}] + \sum_{j=1}^{p-1} \xi_{ij} \Delta GDP_{i,t-j} + \sum_{j=0}^{q-1} \beta'_{ij} \Delta X_{i,t-j} + \varphi_i + e_{ij} \quad (20)$$

With $X = \begin{pmatrix} EMDI_t^z \\ INV \\ TO \\ FD \end{pmatrix} \quad z = \{TENcon, NRE, RE, ElecCon, and EMDI\},$

Finally, to estimate the previous model, we use the PMG estimator developed by Pesaran et al (1999).

The panel ARDL model can only permit us to know the short-run and long-run effect of energy mix on economic growth, yet in case of negative effect, it would be relevant to know if the negative effect is throughout or there is a break at a certain moment. In order to assess this, we use the threshold model developed by Seo and Shin (2019). This model will enable us to highlight an eventual non-linear relationship. To do so, we partition our timespan (initially 40 years) into 8 periods of 5 years each, making the number of countries (N) higher than the number of years per country (T). Hence, the sample of the study is consistent with the $N(36) > T(8)$ criterion (Asongu, 2017)

3.4.4 Threshold model specification

To examine the potential non-linear relationship between energy mix and economic growth, we follow the spirit of Chen et al (2020) by employing a dynamic panel error correction threshold regression model, which is a sample split form of the model (20) and can be expressed as follow:

$$\Delta y_{it} = \alpha_0 + \beta_1^T X_{it} + e_{it}, \quad q_{it} \leq \gamma \quad (21)$$

$$\Delta y_{it} = \alpha_0 + \beta_2^T X_{it} + e_{it}, \quad q_{it} > \gamma \quad (22)$$

Where,

X_{it} is a $k \times 1$ vector containing all the regressors of the model (20),

q_{it} is the threshold variable

γ is the threshold level.

Therefore, model (20) can be regarded as a special case of the threshold model with either $q_{it} \leq \gamma$ or $q_{it} > \gamma$ for all $i = 1, \dots, N$ and $t = 1, \dots, T$

For compactness, (21) and (22) can be integrated as a single form as follow:

$$\Delta y_{it} = \alpha_i + \beta_2^T X_{it} + \delta^T X_{it} I(q_{it} \leq \gamma) + e_{it}, \quad (23)$$

Where $I(\cdot)$ is the indicator function representing the sample splitting, and $\delta = \beta_1 - \beta_2$. Hence, the indicator function in the non-linear specification defined in Eq. (23) describes the sample split by only one threshold level.

There are several other threshold regression methods (e.g., Hansen (2000), Caner and Hansen (2004), Kremer et al. (2013), and Kourtellous et al. (2016)). But, we choose to use the first- difference (FD) GMM method of Seo and Shin (2019) to estimate model (23). Because the FD- GMM method studies a dynamic threshold panel model and allows the endogeneity in both regressors and threshold variables whereas other methods either rely on the exogenous threshold variable or not applying for the dynamic panel. To do so, we partition our timespan (initially 40 years) into 8 periods of 5 years each, making the number of countries (N) higher than the number of years per country (T). Hence, the sample of the study is consistent with the $N(36) > T(8)$ criterion (Asongu, 2017)

In the line with Arellano and Bond (1991), we consider the following moment conditions to estimate (20) and (23),

$$\begin{aligned}
(\Delta e_{it} y_{it-r}) &= 0; E(\Delta e_{it} TO_{it-r}) = 0; E(\Delta e_{it} INV_{it-r}) = 0; \\
(\Delta e_{it} FD_{it-r}) &= 0; E(\Delta e_{it} EMCI_{it-r}) = 0; E(\Delta e_{it} ENT_{it-r}) = 0; \\
(\Delta e_{it} NRE_{it-r}) &= 0; E(\Delta e_{it} RE_{it-r}) = 0
\end{aligned}$$

To test the presence of a threshold effect, we use a sup-Wald test proposed by Seo and Shin (2019). Following Hansen (1996), the critical values are generated by a bootstrap method.

4. Results and Discussion

In this section, we are going to examine the short and long-run equilibrium relationship between economic growth, energy mix, capital (INV), trade openness, and financial development. This examination will be done using cross-sectional dependence test (CD test), unit root tests and panel cointegration tests to infer the degree of integration of the variables in model (4). The results obtained with the linear GMM estimation technique and the results with the threshold estimation method are then discussed.

4.1. Cross-sectional dependence and unit root tests

Table 3: Results of Cross-sectional Dependence (CD) test

Variable	CD-test	p-value
logGDPpc	31.209***	0.000
logTENcon pc	22.427***	0.000
logNREpc	23.029***	0.000
logREpc	18.371***	0.000
logElec	30.537***	0.000
EMDI	22.75***	0.000
logTOpc	53.883***	0.000
logFDpc	28.533***	0.000
logINVpc	44.692***	0.000

Notes: Under the null hypothesis of cross-section independence, $CD \sim N(0,1)$ P-values close to zero indicate data are correlated across panel groups

The results in Table 3 prove the existence of cross-sectional dependence in GDP per capita (GDPpc), capital formation (INV), trade openness (TO), financial development (FD), total energy consumption (TEN), non-renewable energy consumption (NRE), renewable energy consumption (RE), electricity consumption (Elec), and Energy mix diversification index (EMDI) at 1% significance level.

Given the fact that the variables are cross-sectionally dependent, it is inappropriate to use the first generation panel unit root tests that are based on the cross-sectional independence assumption (Maddala and Wu, 1999; Choi, 2001; Levin et al., 2002; Im et al., 2003), since they would suffer from size distortions and the ignorance of cross-section dependence (Pesaran, 2015). Therefore, to account for the presence of cross-sectional dependence in the variables, we use the cross-sectionally augmented panel unit root test in presence of cross section dependence (CADF) proposed by Pesaran (2006).

Table4: Results of Panel unit root tests (Pesaran's CADF)

Variable	Pesaran's CADF test (level)	Pesaran's CADF test (1st defference)
logGDPpc	0.378 (0.647)	-8.719 (0.000)***
logTENconpc	0.138 (0.555)	-11.478(0.000)** *
logNREpc	-0.114 (0.455)	-11.374(0.000)** *
logREpc	0.205 (0.581)	-8.310(0.000)** *
logElec	1.086 (0.861)	-6.262(0.000)** *
EMDI	-1.953 (0.025)**	
logTOpc	-1.818 (0.035)**	
logFDpc	-3.654 (0.000)***	
logINVpc	-2.184 (0.014)**	

Note: () are p-values, *** 1% significance, ** 5% significance, * 10% significance

The Pesaran's simple panel unit root test in presence of cross section dependence is used in both level and first-order difference. From the results in table 4, when we use variables at level, we fail to reject the null hypothesis of the unit root at the 5% significance level for logGDPpc, logTENpc, logNREpc, logREpc, logElec. However, we reject the null hypothesis of the unit root at the 5% significance level for EMDI, logTOpc, logFDpc, INVpc, making them I(0). When we obtain the first-order differences of the five variables that are not I(0), the null hypothesis of non-stationarity can be rejected at the 1% significance level for these variables, making them I(1). No variable is I(2), consequently the ARDL regression can be implemented conveniently. Before running this regression, we need to assess the long-run relationship through the panel cointegration test.

4.2 Panel cointegration tests

Given the existence of cross-sectional dependence in all our variables, we use the cointegration tests proposed by Pedroni (1999, 2004) to check whether there exists a long-term relationship between the variables. Since the cointegration test proposed by Pedroni (1999) allows for heterogeneity and is developed to deal with cross-sectionally dependent data (Pedroni, 2004). Table 5 gives the results of panel cointegration tests.

Table5: Results of Panel cointegration tests

Model	Statistic	P-value
Model with logTENpc	1.7270	0.0421**
Model with logNREpc	1.7734	0.0381**
Model with logREpc	2.9554	0.0016***
Model with logElec	0.4410	0.3296
Model with EMDI	3.3507	0.0004***

Five sets of co-integration tests are conducted according to the type of energy considered. When we use the model with total energy consumption (logTENpc), the null hypothesis of no cointegration is rejected at a significance level of 5%, meaning that there is a long-run relation between economic growth and total energy consumption. The same result is obtained when we use the models with renewable energy consumption (logREpc) and energy mix index (EMDI) at 1% significance level. However, we fail to reject the null hypothesis of no cointegration when we use the model with electricity consumption (logElec).

4.3 Results of the effect of energy mix on economic growth

In this section, model (20) and model (23) are estimated to determine the long-run linear and non-linear relationships, respectively. We present the results of the effects of each type of energy consumption on economic growth. In the case where a negative effect is highlighted, we use the panel dynamic threshold regression to determine the threshold level necessary for a positive effect.

4.3.1 The effect of total energy consumption on economic growth in SSA

Table 6 presents the results of the PMG regression of the long-run and short-run coefficients of the economic growth model using total energy consumption (logTEN) as the main input. It also shows the convergence parameter (adjustment coefficient). The cointegration equation is estimated, following Pesaran et al (1999), and does not include trends. The convergence parameter allows adjustment from short-run to long-run, where there is homogeneity in energy consumption and economic growth coefficients across countries. From the results in table6 the adjustment coefficient (-0.00295) has the expected sign.

This result proves that there is an adjustment dynamic from short-run to long-run in energy consumption and economic growth across sub-Saharan Africa countries.

The estimates provide more interesting results. First, we notice that the short-run and long-run coefficients of total energy consumption are positive and significant at the 1% level. This result indicates that a 1% increase in energy consumption leads to an increase of almost 1.5% in economic growth in the long run. This result is consistent with the growth hypothesis whereby an increase in energy consumption will result to more economic growth (Behname (2012); Apergis and Payne (2010); Menyah and Wolde-Rufael (2010); Wandji (2013)). On the other hand, trade openness and financial development have negative effects on economic growth in the short-run but in the long-run, the effect of trade tends to change to positive while the effect of financial development remains negative. The coefficient of trade is significant at 1% level in the long-run indicating that trade openness increases economic growth in SSA in the long-run. This result is consistent with the literature and also with our theoretical base model. However, the effect of local investment on economic growth tends to be mitigated in the long-run despite the positive effect in the short-run, meaning that more capital is still needed for public investment in sub-Saharan economics

Table 6: PMG regression results with total energy consumption as main variable of interest

	(1)	(2)
VARIABLES	ECT1	SR
ECT1		-0.00295 (0.00379)
D.logTENconpc		0.0579*** (0.0193)
D.logTOpc		-0.0150 (0.0169)
D.logFDpc		-0.0108 (0.0101)
D.logINVpc		0.0430*** (0.0136)
logTENconpc	1.409*** (0.375)	
logTOpc	2.058*** (0.678)	
logFDpc	-0.142 (0.136)	

logINVpc	-1.640*** (0.515)	
Constant		0.0338 (0.0416)
Observations	1,212	1,212

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.3.2 The effect of non-renewable energy consumption on economic growth in SSA

Table 7 presents the results of the PMG regression of the long-run and short-run coefficients of the economic growth model with non-renewable energy consumption (logNRE) as the main variable of interest, the remaining variables are mainly considered as control variables. Hence, non-renewable energy consumption has a positive effect on economic growth at a 1% significance level in both the short-run and long-run, their coefficients are respectively 0.0581 and 1.938. This result implies that in sub-Saharan Africa countries, a 1% increase in non-renewable energy consumption is associated with 1.938 % increase in economic growth in the long-run. This outcome is consistent with the growth hypothesis whereby energy consumption leads to higher economic growth (Behname (2012); Apergis and Payne (2010); Menyah and Wolde-Rufael (2010); Wandji (2013)). Because the signs of the short-run and long-run coefficients are all positive and significant, it indicates a linear relationship between non-renewable energy consumption and economic growth in SSA. Therefore, it is needless to run the model (23). Besides, the adjustment coefficient (-0.00374) of the linear model has the expected sign, confirming the long-run dynamic between renewable energy consumption and economic growth. The effect of the control variables remain the same like in the first model.

Table 7: PMG regression results with non-renewable energy consumption as main variable of interest

VARIABLES	(1) ECT2	(2) SR
ECT2		-0.00374 (0.00296)
D.logNREpc		0.0581*** (0.0220)
D.logTOpc		-0.0119 (0.0164)
D.logFDpc		-0.0138 (0.0102)
D.logINVpc		0.0469*** (0.0148)

logNREpc	1.938*** (0.663)	
logTOpc	0.188 (0.228)	
logFDpc	-0.251 (0.228)	
logINVpc	-1.530** (0.706)	
Constant		-0.0348 (0.0314)
Observations	1,212	1,212

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.3.3 The effect of renewable energy consumption on economic growth in SSA

Table 8 presents the results of the PMG regression of the long-run and short-run coefficients of the economic growth model with renewable energy consumption (logRE) as the main variable of interest, the remaining variables are mainly considered as control variables. Hence, renewable energy consumption has a negative effect on economic growth at a 1% significance level in both the short-run and long-run dynamic. This outcome is an evidence of lack of renewable energy infrastructures in the majority of sub-Saharan African countries. In these countries, investments are not done in the main sources of renewable energy like: wind energy, tidal energy, geothermal energy, solar energy and nuclear energy. The negative effect of renewable energy consumption is likely to result from non-sufficient use of these main renewable sources. On the contrary, the type of renewable energy mostly used in sub-Saharan African countries is biomass. This energy from waste cannot adequately feed heavy industries that drive economic growth.

Table 7': PMG regression results with renewable energy consumption as main variable of interest

VARIABLES	(1) ECT3	(2) SR
ECT3		-0.00717 (0.00994)
D.logREpc		-4.25 (26.95)
D.logTOpc		-0.00667 (0.0183)
D.logFDpc		-0.0144 (0.0105)
D.logINVpc		0.0447*** (0.0163)

logREpc	-8.912***	
	(2.660)	
logTOpc	-0.361***	
	(0.0685)	
logFDpc	0.140***	
	(0.0358)	
logINVpc	0.724***	
	(0.107)	
Constant		0.111
		(0.140)
Observations	1,212	1,212

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Given the mitigating effect of renewable energy consumption on economic growth in SSA, we will run the threshold regression of model (23) in order to find the threshold level of renewable energy consumption at which the effect on economic growth is positive.

Table 8: Non-linear Dynamic Panel threshold regression results when renewable energy consumption is used as a threshold variable

VARIABLES	(Low) logGDPpc	(High) logGDPpc
Threshold (r)	0.0453**	
Lag_y	(0.0204)	-0.154
	0.654***	
logREpc	(0.100)	(0.166)
	15.74*	-14.44*
	(8.179)	(7.921)
logTOpc	-0.115***	0.116***
	(0.0423)	(0.0430)
logFDpc	-0.00789	0.127
logINVpc	(0.0362)	(0.0901)
	0.0815** (0.0342)	0.249***
		(0.0670)
cons	1.567	1.567
	(0.0670)	(0.0670)
Observations	26	26

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Model (23) is estimated to determine an eventual non-linear relationship and the threshold level of renewable energy consumption that mitigates economic growth behaviour in SSA. The result in table 8 reports an inverted U shape relationship between renewable energy consumption and economic growth in SSA. We obtain a significant threshold (0.0453) of renewable energy

consumption level (see the p-values reported in Table 8 where the null hypothesis of the linear relationship is rejected at the 5% level). The findings with the threshold model suggest that the growth of renewable energy consumption (i.e., logREpc) significantly and positively affects economic growth if and only if countries use a renewable energy below the threshold level of 0.0453. Note that renewable energy in majority of SSA countries is dominated by biomass, consequently, this threshold is more relevant to the use of biomass. If countries use biomass above this threshold level, the effect of renewable energy consumption on economic growth is insignificant, which is similar to the findings obtained from the linear estimations.

4.3.3 The effect of electricity consumption on economic growth in SSA

Table 9 presents the results of the PMG estimation of the long-run and short-run coefficients of the economic growth model with electricity consumption (logElec) as the main variable of interest, the remaining variables are mainly considered as control variables. Hence, electricity consumption has a positive effect on economic growth at a 1% significance level in long-run. A 1% increase in electricity consumption is associated with 2.469 % increase in economic growth in the long-run. This outcome is consistent with the growth hypothesis whereby energy consumption leads to higher economic growth. Because the signs of the short-run and long-run coefficients are all positive, it indicates a linear relationship between electricity consumption and economic growth in SSA. Therefore, it is needless to run the model (23). Besides, the long-run adjustment coefficient has the expected negative sign although not significant. Still from this model, trade openness has a positive effect on economic growth in the long-run. However, the effect of financial development is mitigated in the long run.

Table 9: PMG regression results with electricity consumption as main variable of interest

VARIABLES	(1) ECT4	(2) SR
ECT4		-0.00253 (0.00675)
D.logElec		0.0429 (0.0455)
D.logTOpc		0.00915 (0.0233)
D.logFDpc		-0.00511 (0.00956)
D.logINVpc		0.0474*** (0.0172)
logElec	2.469*** (0.906)	

logTOpc	0.118 (0.207)	
logFDpc	-0.280 (0.193)	
logINVpc	-0.709* (0.416)	
Constant		-0.0130 (0.0126)
Observations	572	572

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Overall, the financial system of many countries in SSA is dominated by informal. Household in general prefer to deal with meeting houses than the formal banking system.

4.3.4 The effect of energy mix diversification index on economic growth in SSA

Table10 reports the results of the PMG estimation of the long-run and short-run coefficients of the economic growth model with energy mix diversification index (EMDI) as the main variable of interest, the remaining variables are mainly considered as control variables. Hence, EMDI has a positive (0.737) effect on economic growth in SSA in the long-run. This effect arises as a result of diversification in energy consumption. Many SSA countries are using more than one energy source for their energy need in the economy, generally hydro and thermal central sources.

Table 10: PMG regression results with energy mix concentration index as main variable of interest

VARIABLES	(1) ECT5	(2) SR
ECT5		0.00198 (0.00322)
D.EMDI		-0.422

		(0.353)
D.logTOpc		-0.00325
		(0.0176)
D.logFDpc		-0.0110
		(0.00989)
D.logINVpc		0.0414***
		(0.0138)
EMDI	.737	
	(0.736)	
logTOpc	2.527***	
	(0.610)	
logFDpc	1.041***	
	(0.235)	
logINVpc	-1.324***	
	(0.344)	
Constant		-0.0467
		(0.112)
Observations	1,212	1,212

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

This diversification towards two or more sources of energy seem favourable to economic growth in the long-run. Given the mitigating effect of energy mix on economic growth in the short-run, we will run the threshold regression of model (23) in order to find the threshold level of energy mix diversification at which the effect on economic growth is positive

Table 11: Non-linear Dynamic Panel threshold regression results when energy mix diversification index is used as a threshold variable

	(Low)	(High)
VARIABLES		
Threshold (r)	0.376***	
LaglogGDPpc	0.678***	-0.196
	(0.179)	(0.158)
EMDI	0.605	1.509
	(0.695)	(0.995)
logTOpc	-0.791**	0.816**
	(0.320)	(0.320)
logFDpc	0.321*	-0.370*
	(0.167)	(0.195)
logINVpc	0.527***	-0.638***
	(0.199)	(0.212)
cons		-2.586
		(2.048)

*** p<0.01, ** p<0.05, * p<0.1

4.4. Robustness analysis

Table 12: Dynamic Common Correlated Effect regression results

VARIABLES	(1) D.logGDPpc	(2) D.logGDPp c	(3) D.logGDPp c	(4) D.logGDPp c	(5) D.logGDPp c
L.logGDPpc	-0.387***	-0.387***	-0.432***	-0.418***	-0.348***

	(0.0534)	(0.0497)	(0.0511)	(0.0576)	(0.0533)
logTENconpc	0.0392 (0.0376)				
logTOpc	0.0189 (0.0178)	0.0175 (0.0180)	0.0256 (0.0231)	0.0265 (0.0252)	0.0135 (0.0179)
logFDpc	-0.0255** (0.0128)	-0.0264** (0.0121)	-0.0253* (0.0134)	-0.00205 (0.0131)	-0.0184 (0.0113)
logINVpc	0.0418** (0.0207)	0.0429** (0.0211)	0.0359* (0.0183)	0.0149 (0.0168)	0.0349* (0.0190)
logNREpc		0.0466* (0.0271)	-81.50		
logREpc					
logElec			(54.68)	0.00974	
EMCI				(0.0615)	0.583 (0.703)
Constant	0.150 (1.488)	-0.187 (1.296)	0.495 (0.802)	1.425 (0.953)	-0.512 (1.148)
Observations	1,191	1,191	1,191	533	1,191
R-squared	0.469	0.482	0.483	0.456	0.514
Number of groups	34	34	34	17	34

Table 12 presents the results of the robustness analysis obtained from the Dynamic Common Correlated Effect regression. We evaluate the effect of each type of energy on economic growth using this method. From the outcome in table 12, total energy consumption positively affects economic growth, its coefficient (0.0392) is positive although not significant. Similarly, non-renewable energy consumption significantly and positively (0.0466) influences economic growth in SSA at 10% percent significant level. As for renewable energy consumption, it negatively (- 81.50) influences economic growth in SSA. Electricity consumption and energy mix index positively affect economic growth in SSA, their coefficients are respectively 0.00974 and 0.583. Overall, the results obtained here are all consistent with those obtained in the empirical analysis from the PMG estimation. Therefore, we can validate and accept our results. We conclude that, total energy consumption, non-renewable energy consumption, electricity consumption and energy mix tend to increase economic growth in the long-run in SSA. However, we found that renewable energy consumption tends to have a mitigated effect on economic growth when the threshold level of 0.0453 is exceeded.

5. Policy implication

Energy as one of the main factors of economic growth, is not yet adequately being supplied in developing countries such as SSA countries. Given that access to energy is less than 60% in SSA, not more than ten million people especially those in the rural areas can enjoy social services. Consequently, if renewable energy can be adequately developed and extended, it would boost the activities of small and medium size enterprises. For instance, small businesses like documentation centres, metal and welding workshops, hair dressing and barbing salons among others would spring up in the rural areas of SSA. Living standards will improve remarkably if renewable energies are expanded, more business will boom and profit margin will increase. If small and medium size enterprises begin to flourish, the poverty level in SSA will diminish in accordance with SDGs. This can only be possible through public-private partnership investment where more subsidies is granted to the private sector. Therefore, we are suggesting a Public-private partnership for an optimal investment scheme in local power mini- grids in SSA. Such energy policy will enhance the achievement of SDGs and their targets. Resilient energy infrastructure will act as a precondition for the building of resilient infrastructure and promotion of inclusive and sustainable industrialisation.

6. Conclusion

The aim of this paper is to find out whether energy mix increases economic growth in sub-Saharan African countries. The work tried to ascertain if there is any non-linear relationship between energy mix consumption and economic growth when a threshold model is employed. The procedure was to construct an energy mix diversification index for sub-Saharan Africa countries. Then, using the pool mean group regression, the effects of total energy consumption, renewable and non-renewable energy consumption on economic growth were analysed. Finally, an assessment of the effects of electricity and energy mix index on economic growth was done. Also, after grouping and calculating mean periods of 5 years, making our sample N(36) and T(8), the panel threshold regression was used to highlight the non-linear relationship between renewable energy consumption and economic growth given its mitigating effect on economic growth. The conclusion was that, total energy consumption, non-renewable energy consumption, electricity consumption and energy mix tend to increase economic growth in the long-run in SSA. It was however realised that renewable energy consumption tends to have a mitigating effect on economic growth when the threshold level of 0.0453 is exceeded. Furthermore, a significant threshold level of 0.376 of energy mix diversification was obtained for economic growth.

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Appendix 1: Table 1- Statistical descriptions, and data sources.

Variable	sources	Obs	Mean	Std. Dev.	Min	Max
GDPpc	WDI	1425	1789.88	2416.393	167.246	16989.959
TOpc	WDI	1328	.0000711	.0003	2.85e-08	.003
FDpc	WDI	1362	.0000111	.00004	0	.0004
INVpc	WDI	1306	.0000155	.0000588	-5.59e-07	.001
TENconpc	US.EIA	1440	.361	.703	.008	5.114
NREpc	US.EIA	1440	.333	.695	.008	5.114
REpc	US.EIA	1440	.029	.043	-.006	.302
ElecCon	WDI	679	522.959	974.535	17.567	4851.692
EMDI	US.EIA	1440	.4181447	.2386484	0	1

Appendix 2: Table 2- Correlation matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) GDPpc	1.000								
(2) TOpc	0.675 (0.000)	1.000							
(3) FDpc	0.720 (0.000)	0.959 (0.000)	1.000						
(4) INVpc	0.566 (0.000)	0.882 (0.000)	0.893 (0.000)	1.000					
(5) TENconpc	0.881 (0.000)	0.717 (0.000)	0.730 (0.000)	0.553 (0.000)	1.000				
(6) NREpc	0.867 (0.000)	0.727 (0.000)	0.739 (0.000)	0.565 (0.000)	0.998 (0.000)	1.000			
(7) REpc	0.378 (0.000)	-0.050 (0.070)	-0.006 (0.813)	-0.061 (0.026)	0.206 (0.000)	0.146 (0.000)	1.000		
(8) ElecCon	0.625 (0.000)	0.129 (0.001)	0.246 (0.000)	0.120 (0.003)	0.971 (0.000)	0.979 (0.000)	0.123 (0.001)	1.000	
(9) EMCI	0.063	0.277	0.295	0.290	0.103	0.136	-0.510	0.070	1.000

The case of cable cars and innovation in public transportation services in the Metropolitan Zone of the Valley of Mexico

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Abstract

In metropolitan contexts of excessive population growth, mobility is essential for the development of economic, social and cultural activities. However, urban dynamics present negative externalities resulting from vehicular congestion with economic and socio-environmental impacts. The study of the dynamics between science, technology and development in Latin American contexts from the perspective of the socio-technical approach is relevant to analyze this type of problems, not only because of the resignification of analytical categories that allow understanding the importance of certain innovations in the face of complex problems, but also because they incorporate the analysis of the costs and benefits of the equitable distribution of a public or collective good; trying to identify the state capacities that favor a set of technological, institutional, socio-environmental changes. The approach allows describing and explaining the socio-technical trajectories and the degree of tensions and interactions between the relevant social actors, which result in the collective construction of technological, organizational and institutional devices to solve the problem. This article presents the context, the aims and some findings of our current research on cable cars in the Metropolitan area of the Valley of Mexico, seen as a socio-technical innovation in public transportation services.

Keywords: Public transport, urban mobility, Sustainability, Innovation in public services.

Introduction

Mexico City and its metropolitan area constitute the sixth largest metropolis in the world, after Tokyo, Seoul, Delhi, Bombay and São Paulo [1]. In Mexico, Metropolitan Commissions created since the early 1990s emerged to discuss and propose interurban projects, based on intergovernmental agreements between the federal government, the different administrative entities and local governments that form the Metropolitan Zone of the Valley of Mexico [2]. In 2016, after a political reform process that endowed the Mexican capital with greater autonomy, the principles of development, democratic planning and good governance were constitutionalized [3]; however, government administrations continue to face divergent challenges in terms of land use planning and the resolution of problems such as urban mobility, urban solid waste, air quality, connectivity, service infrastructure, drinking water, drainage and wastewater treatment, among other problems.

The Metropolitan Zone of the Valley of Mexico (hereinafter MZVM) is the largest industrial, commercial and service concentration in the history of Mexico. At the national level, it generates a third of the gross domestic product and 38% of the industrial sector, it receives the most important capital flows and is home to more than half of the country's top five hundred companies [4]. Although in many cases only the central offices are located there, but not the production plants.

Historically, cities have been growing, especially since the Industrial Revolution, until they became what is known today as the Megalopolis. These are territorial delimitations that transcend the merely urban, where a complex network of infrastructure and communications converge, and may include heterogeneous spaces such as forests and semi-rural areas, industrial and high-density urban housing zones, residential suburbs, areas dedicated to recreation and tourism, etc. [2]. Mexico's development has made the urban system more complex, in which a process of megalopolization around the federal capital, Mexico City, stands out [5]. Thus, as in all the so-called megalopolises, transportation in this context becomes a relevant issue since it mobilizes the economic, social and political life of citizens.

One of the main challenges of megacities is to provide the infrastructure and services to guarantee the different activities of urban life, including the mobility of their inhabitants. In fact, the displacements allow productive and commercial activities to be carried out, which is why the various transportation options are crucial.

For the purposes of this research, it is convenient to specify the concept of public transportation, given that there are two main meanings. The first is understood as that part of transportation that is totally or partially owned by the public sector, and is therefore managed and financed by the State. The

second meaning, considers the user to whom the service is provided; in this case it includes the means of transport in which passengers are not owners of these (cars), being granted by third parties (public or private companies). Thus, public transport helps the movement of people from one point to another, paying a fee established according to the route [6]. In our research we will use and try to find points of convergence of these concepts.

The objective of our research is to analyze the influence of the state capacities on the implementation of innovations in public transport and urban mobility services in the Metropolitan Zone of the Valley of Mexico, in order to analyze positive and negative externalities (economic and socio-environmental). By state capacities we mean that the agency capacity of the State (investment, management, planning) with regards to innovations in public transport are relevant to achieve improvements in public service. It is expected that state capacities will influence the construction of the socio-technical trajectory of such innovations through greater intergovernmental articulation, a clear public agenda with policies for mobility and transport, greater adoption of new technologies, greater citizen participation and inclusion, etc.

Schools or different streams of the socio-technical approach have emerged that introduce analytical concepts to address complex problems. Thus, it was considered appropriate for this research to integrate two of these schools: the Dutch current of transitional studies and the Latin American current, and to select some of their key central concepts. Our conceptual perspective takes up the socio-technical approach, trying to combine the multilevel perspective of the Dutch school of technological transitions, whose exponent is Geels (2005) [7], from which other analyses derive such as Geels and Schot (2007), Bergek (2008), Schot & Geels (2008), Geels and Kemp, Geels (2010), Victor, Geels and Sharpe (2019), with the Latin American perspective addressed by references such as Dagnino, Thomas and Davyt (1996), Thomas (2000, 2008, 2012), Thomas, Lalouf and Garrido (2014) [8], Lepratte (2014), Bortz, Thomas (2018), Cancino (2022). On the other hand, we are interested in taking up again the concept of state capacities, which we can define following Repetto (2004) as "the ability of government agencies to translate through public policies the highest possible levels of social value or public value; where its exercise has attributes of coordination, flexibility, innovation, quality, sustainability and evaluability" [9].

Our research proposal seeks to contribute to the Latin American socio-technical analysis, an analytical approach that has prioritized the approach to social technologies or other issues related to the inclusive and sustainable development of our societies.

From our point of view, it is relevant to know and understand the socio-technical trajectories of certain innovations in the public transport and urban mobility service, which presumably seek to solve several of the problems mentioned above. Innovation in public service consists of the "design and

implementation of a new or significantly improved public service or delivery method that, by generating use value for users, generates public value for citizens in general" [10]. However, for the case of the megalopolis that Mexico City represents, innovation in the public transport and urban mobility service has specific implications given the multimodalities of the service that have been implemented over time; in addition to issues related to the environmental problems involved in the use of transportation.

The conceptual and methodological approach

To address the relationship between state capacities and innovations in public services, particularly in transportation and urban mobility for the case study in metropolises or complex population enclaves, the use of the analytical framework known as the socio-technical approach has been considered relevant; it has had a strong presence in discussions of transitional processes of technologies in the face of the emergence of problems arising from climate change, also in the emergence of social technologies, debates between imaginaries or socio-technical controversies of new technologies, etc.

The social studies of science and technology, born under the figures of Merton (1937) and Bernal (1939), constitute a problematic field given that they discuss the pertinent analytical frameworks for approaching the specificities of local phenomena, and, on the other hand, they try to operationalize concepts that allow recording and valuing the events of developing countries [8].

Hölsgens (2022) explains the multivel perspective through the existence of a certain socio-technical regime that is defined around technology (for example, the regime of mobility through the automobile; also the regime of food production and consumption). These regimes are intrinsically stable, since there are forces at play that complement each other; so manufacturers within the socio-technical regime need suppliers; they need customers or users; they need public policies. Conversely, in turn, public policies need manufacturing companies, since they create jobs; etc. However, the socio-technical regime can be disrupted or destabilized by pressures from the socio-technical landscape, i.e. the macro context (climate change; wars; emergency or catastrophe situations). These pressures align with elements of the regime that have begun to show signs of exhaustion or crisis [11].

Moreover, the socio-technical regime may open up as innovations in technological niches challenge the existing regime. Transitions to a possible new regime may involve competing technologies. Geels and Schot (2010: p:12) define transitions as "processes of co-evolution that require multiple changes in sociotechnical systems" [12], this may include changes in certain practices; interactions between different social groups, new rules of the game, etc.

The socio-technical system is analyzed from the observation of resources, actors, institutions and rules; these elements give dynamism and organicity to

the system. Interactions between actors are based on rules at different levels and with different degrees of autonomy. The different social actors build rules that express aspirations or expectations of the technologies. The rules can be formal, cognitive or normative or regulatory. Geels (2004) seeks to understand how processes of stabilization or technological change occur in certain sectors; what are the conditions of stability and how change expands after the emergence of what he calls radical innovation niches; that is, changes that spread to the rest of the system and in turn modify the rules in different areas [13]. The alternatives for approaching innovation include micro analysis, case studies, or meso analysis of socio-technical systems. Under this approach, sociotechnical systems include three levels: landscape (macro); regime (meso) and niche (micro).

An attempt will be made to find points of convergence of this multilevel perspective with the interactive model of innovation, whose central characteristic is that it considers the interactions and back-and-forth effects between the phases that occur during the innovation process, from the search for available knowledge to the generation of the new knowledge demanded. The relationship between science and technology is considered bidirectional, with mutual feedbacks in all phases. The interactive model identifies relevant social actors such as R&D institutions, companies, public organizations, universities, non-governmental organizations, cooperatives, end users and their interrelationships in terms of knowledge, learning, capabilities and problem-solution relationships [14].

We believe that socio-technical analysis can be used to approach the object of study in a more integrated manner and in relation to various dimensions. As Thomas (2008) points out, the analysis of socio-technical trajectories developed in Latin America has made it possible to understand the local capacity to convert conditions of socio-technical dynamics into synergistic dynamics, making viable from the renewal of technologies aimed at import substitution to competitive participation in international markets for knowledge-intensive goods [15].

From the ontological point of view, for the case studies, it is assumed that there are multiple realities. An attempt will be made to report them based on the evidence and the perspective of the protagonists. The research techniques include case studies, with direct observation (primary data) and indirect observation (secondary data), collection of documentary data, official statistics, interviews with the protagonists of the mobility projects, expert judgments; they bring us closer to the ideas of the topics involved, as they are collected it will be possible to construct the analytical categories, applying a triangulation between the socio-technical approach and policy analysis.

For this research, the case of the very recently created public transportation cable car lines in the MZVM has been selected. Although cable cars were

designed for tourist purposes more than a century ago, their adoption as a means of public transportation is less than a decade old, since their introduction in the city of Medellin, Colombia. From a socio-technical approach, our proposition is that cable car for urban transportation presents several features that confer it the character of innovation, such as: a new mode of transportation that requires state-of-the-art technologies for managing the flow of passengers and cabins, a novel interaction with existing modes of transportation, a new relationship of users with technology and urban mobility, and so on.

The research is an exploratory case study, with a flexible research design, where the first part is based on documentary analysis and unstructured interviews to get an approach to the context and the specificities of the case in a situated key.

Preliminary results

The transportation system as a public service poses challenges for the different actors, from the municipalities and their public institutions involved, the private companies providing services, the workers, their unions and the users with their practices and needs, given that the service provided has a multimodal character in the Valley of Mexico, where there is a passenger transportation network, Metro public transportation system, light rail, trolleybus, Metrobus, bicycle paths, cablebus, microbuses, cabs, motorcycle cabs, motorcycle cabs, bicycle cabs, eco-bicycles, etc. . To consider some data from the National Institute of Statistics and Geography (INEGI) (Table 1), the Metro mobilizes more than 4.5 million people per day [16]. In Mexico City, users are mostly from the lower middle class and use the Metro and Bus service.

Table 1
Passengers transported. Mexico City, 2019.

Denomination	2019											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Metro public transportation system (Millions)	132.3	122.7	134.6	124.7	133.9	128.5	130.6	141.4	131.8	145.7	138.0	130.4

Passenger transportation network (Millions)	12.0	12.1	13.4	11.7	13.4	12.9	13.0	13.8	13.8	15.4	13.9	11.9
Light rail (Thousands)	2,460	2,461	2,656	2,386	2,548	2,327	1,834	2,093	2,096	2,367	2,216	1,862
Metrobus (Thousands)	29,55 9.8	28,65 8.6	31,23 9.6	28,52 0.1	31,23 7.2	29,81 0.4	30,45 7.5	32,52 1.8	30,95 9.6	34,25 1.6	33,29 9.1	31,21 7.3
Trolleybuses (Thousands)	3,757	3,541	3,833	3,509	3,559	3,267	3,490	3,787	3,534	3,701	3,546	3,414

Source: [16]. Based on data from Mexico City Government. Sistema de Transporte Colectivo Metro. Government of Mexico City. Passenger Transportation Network. Government of Mexico City. Servicio de Transportes Eléctricos. Government of Mexico City. Decentralized Public Organization Metrobús.

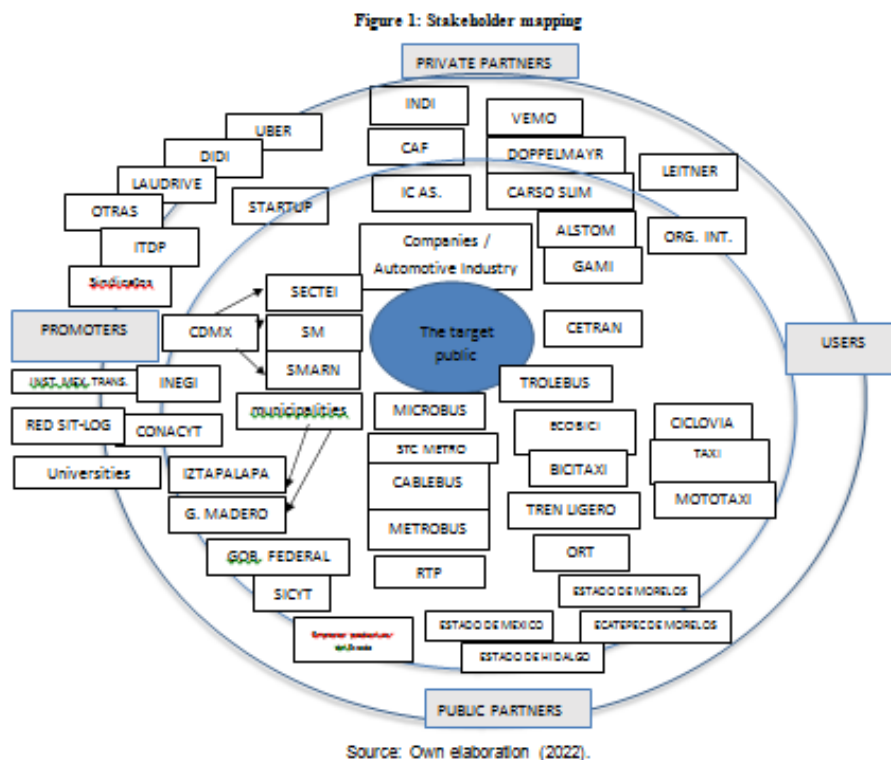
The diversification of the modalities of public transportation service reached a milestone with the creation of the Metro. However, its management has gone through critical moments, such as the need to expand routes to contiguous municipalities belonging to the State of Mexico, labor conflicts and even tragic accidents. The most recent serious accident occurred in May 2021, on line 12 of the Metro in a section built by a consortium of companies formed by Ingenieros Civiles Asociados, Carlos Slim's Grupo Carso and the French company Alshtom. This has not been the only accident in the Mexican transportation system, however, it leads to the identification of relevant social actors that can be distinguished in socio-technical trajectories of certain artifacts related to transportation and urban mobility. Figure 1 shows the different actors involved in the mobility of the megalopolis that we have been able to identify.

Historically, different options to the transportation and urban mobility problem converge in the MZVM. Institutionally, at present, different actors are directly and indirectly involved. From the Federal State with its Secretariat of Infrastructure, Communications and Transportation; to the Secretaries of Mobility, in Mexico City or in the State of Mexico, and the competent agencies in the service of more than 70 municipalities. Decentralized organizations such as the Collective Transportation System, Metrobus, Passenger Transportation Network, Electric Transportation Service, Transportation Regulatory Body, Ecobici, Taxi, etc. The public sector also includes the Mexican Institute of

Transportation, which with the participation of CONACYT created the SiT-LOG Network, a specialized transportation network. The National Institute of Geography and Statistics (INEGI) provides indicators of the national and local transportation system.

For their part, several companies participate in the bids for the public works required to update the public transportation and urban mobility service. Mexican and transnational companies with French, Spanish and Chinese shareholders and capital stand out, for example, which have participated in the various infrastructure works created.

Transportation and urban mobility have undergone significant transformations through different development projects, incorporating greater electromobility. In the mid-2000s, the Bus Rapid Transit (BRT) system was installed and Metrobús was born, which is a large-capacity bus that runs on specific lanes of several kilometers. This coincided with the entry into force in 2005 of the Kyoto Protocol, which Mexico had ratified a few years earlier



In addition, the suburban electric train of the Valley of Mexico (2008), designed with the contribution of the Spanish company CAF (Construcciones y Auxiliar de Ferrocarriles S.A.). On the other hand, it is noted that the Interurban Train Mexico-Toluca, which will have 30 trains of 5 cars, manufactured by the same Spanish company, has been under construction since 2014.

In times of digitalization of services, private mobility business alternatives have emerged with applications such as Uber, DiDi, Cabify, Beat, Mi Taxi, among others. The case of the digital application Laudrive stands out, a Mexican startup with a gender focus, with more than 350 drivers, who only provide services to women and the drivers of the vehicles are also only women. Inclusion and gender policies are also observable in the various modes of transportation: the cases of exclusive cars for women and children in the Metro (for two decades), the Metrobus and the Trolleybus stand out. The pink buses or the Atenea bus service, which includes an exclusive service for women, children, people with special needs and senior citizens.

At the level of interconnections between different territorial spaces in the Valley of Mexico, the Modal Transfer Centers called CETRAN also stand out, where various means of public and concessioned transportation such as Metro, buses, minibuses and cabs, among others, are connected.

A recent innovation in the MCMA has been the incorporation of cable car lines for public transportation and urban mobility, although the city of Zacatecas in 1979 inaugurated the first cable car for tourist purposes. There are also tourist cable cars in Chihuahua, Durango, Puebla, Taxco and Guanajuato. In 2016, the first cable car was built as a means of public transportation called Mexicable in the Municipality of Ecatepec de Morelos in the State of Mexico, which is the most populated in the country and adjacent to Mexico City. As a result of this example, the government of Mexico City planned the construction of two lines similar to the one in Ecatepec de Morelos.

Knowing the state capacities in the case of the socio-technical trajectories of the existing cable car lines allows us to glimpse to what extent they represent innovations in the public transport service. Line 1 of the so-called Cablebús, which starts at Indios Verdes station and ends in Cuautepec (Alcaldía Gustavo A. Madero), inaugurated in March 2021, is predominantly used by the working class and domestic employees, with a capacity to transport up to 4,000 passengers per hour in each direction. Cuautepec is a densely populated neighborhood in the municipality of Gustavo Madero.

Cablebús Line 2, which crosses the Sierra de Santa Catarina, in the Iztapalapa district of eastern Mexico City, has a capacity to transport 200,000 people per day through 308 cabins, each with a seating capacity for 10 people. Travel time is reduced from one hour and 13 minutes by bus or minibus to 40 minutes by cable car, from terminal to terminal. It connects areas of high marginalization and population density in Iztapalapa, and for its construction reclaimed public spaces were used.

It is worth mentioning that transnational companies such as the Austrian company Doppelmayr, which also has other works in Bolivia, Colombia and other countries, participated in the construction of the MZVM cable cars,

together with the Mexican company Gami, Ingenierías e Instalaciones del Grupo Indi, a team specialized in these infrastructure works.

The socio-technical approach allows us to delve into the ideological factors that are relevant to the object of study. Particularly, in this case, which has been crossed by ideological-political conflicts. There have been trials of transportation policies, with power struggles and income distribution of the services provided. Battles between concentrated economic groups and historical actors of the transportation system that appeal to inclusion. The unions of drivers and workers in the sector have been key players and have put forward radical positions in the negotiations of labor relations [17]. The socio-technical approach could address the impacts of these dynamics on socio-technical trajectories in the case of public transport, its vestiges and discontinuities in recent history.

Discussion

The problem of megacities is related to the time spent on transportation, the economic cost and the impact on the family budget of their inhabitants, which affect their quality of life [16]. In addition, there is the amount of downtime in transportation, the man-hours lost, the health problems associated with transportation stress, the problems of pollution due to concentration and vehicular blockage, among others [18].

Numerous studies have been conducted on the economic and social value of mobility in metropolitan contexts. The Mexican Institute for Competitiveness (IMCO) and the non-governmental organization Sin Tráfico (ST) point out in their Report (2019: 23) that "in Mexican cities, lost income opportunities for public transport users represent 69 billion pesos per year, while for those who use cars they represent 25 billion pesos annually. In total, congestion costs us 94 billion pesos a year" [19]. According to the aforementioned report, the Valley of Mexico has a total congestion cost value for automobile trips notably higher than other cities in the country. For his part, Aguirre (2017) released a research report in the scope of the Senate of the Republic where he places Mexico City as the city in the world with the highest traffic (59% percentage of additional transfer time) [20].

The initial premise and diagnosis could reflect that there has been an increase in available resources, the number of actors involved, training and research related to certain problems; however, this does not translate into an increase in the production capacity of technological solutions. For the most part, technology is imported in various sectors (that which is incorporated or disincorporated) in the Mexican case, as well as in the rest of the peripheral economies.

Innovations in public transport services involve various aspects such as infrastructure, sustainability, electromobility, networks and international

cooperation, importation of technologies and/or own developments, modification of public spaces and commitment to the users involved. Analytically, it is necessary to provide a precise empirical content to the concept of innovation in public transport services by relating the influence of state capacities. In this sense, the socio-technical analysis applied to the case of cable cars will provide a mapping of actors, sequencing of the operation or non-operation of artifacts and the identification of environmental, technological, legal, political, economic and socio-cultural factors involved, the rules of the game and their contribution to the solution of the mobility problem; and the approach to state capacities will allow discerning the way in which the local government mobilizes resources and creates institutional rules for the implementation of the new public transport system.

During the Institutional Revolutionary Party (PRI) government until 2018, there was a boom in the promotion of innovation policies in public service, with a merchandized and neoliberal vision on a national scale [21]. Since the political alternation and the arrival of the National Regeneration Movement (MORENA) to the federal government, there are some dissidences in terms of policies, resignification of axes distributors of public resources and new public policy agendas. These tensions could also be addressed through the socio-technical approach.

Faced with the rise of the sustainability paradigm in the face of the problems derived from climate change, it is necessary to contribute to the development of analytical frameworks that explain the processes of technological transitions on a larger scale in Latin American contexts.

The currents of the socio-technical approach can be considered as general theories; which obliges us to specify other categories of other analytical approaches that allow us to explain why innovation in services is produced in these territories.

After the empirical phenomenological definition, the precision of certain categories was considered in order to drill into this reality and to be able to abstract it, with the interest of answering Why does innovation in public transport and urban mobility services occur or how does it occur in complex contexts such as the metropolitan one?

In order to deepen the relationship between state capacities and the innovations that occur in public services such as transportation and urban mobility, it is necessary to establish the articulation of these analytical approaches with the selected socio-technical studies by identifying the central concepts to be used.

The categories associated with the use value for users of public transport and mobility services generate a specific type of use value. Samayoa, Cavalle and Gallego (2021) delve into four typologies of associated values: for the user (time efficiency, adaptation to their activities), in relation to the environment

(reduction of polluting emissions and impact on the production of the automotive industry), in relation to society as a whole (reduction of vehicular congestion and impact on road infrastructure) and from an economic perspective (impact on productivity and economic growth) [22]. For the case of transportation and urban mobility, undoubtedly, the demands imposed by climate change and the promotion of policies in favor of creating new conditions that favor sustainability, at global, regional and local levels, are elements to be considered.

In the Mexican context, these processes mark disjunctions around policies, conceptions of the city or metropolitan life, traditions and a culture of the metropolitan that has not yet been fully defined.

If state capacities are based on the socio-technical dynamics in which managers and officials and their public institutions or organizations participate, the regulatory framework (one of the dimensions of the socio-technical regime) regulates and can foster or hinder the development of these capacities. Another point of contact between the two approaches could be raised here: which of the capacities would make it possible to open these "windows of opportunity" for change?

First, by observing the characteristics of the public agenda and the public transport space in this context, we can identify the available resources and their relationship with innovations in public service. The socio-institutional dimension will bring us closer to knowing the human, financial, technological and scientific resources available in the agencies involved in the management of public transport and urban mobility in metropolitan contexts. These metropolitan contexts, complex by their nature, require the search for inter-institutional coordination, that is to say, to know the intergovernmental relations, their logics, their actors, their results; immersed in ideological disputes about the most appropriate conception of city or metropolis. The incorporation of new technologies is central given the pressures of the socio-technical landscape and the adaptation of existing public services to the new changes required.

What elements of the prevailing transport service have been going into crisis, and what capabilities would allow identifying the use value and public value of innovation in public service? How do state capabilities foster the development of technological niches in transport and specifically in the ropeway?

The growth of problems related to habitat and mobility, environmental pollution, vehicular congestion in metropolitan contexts, has required attention to the use value of users (accessibility, travel time, safety, comfort, efficiency, etc.) and the public value of citizens in general (environmental sustainability, social inclusion, economic impact, legitimacy and aesthetic impact) of public services as pointed out by Arguelles and Villavicencio (2018) [10].

In this sense, the state capacities present provide some stability; but they also provide legitimacy to the decisions that emerge from both the pressures of the socio-technical landscape and the new conditions imposed by innovations.

For the analytical approach to the case study of innovation in public services such as the cable car, it was considered relevant to identify and select the concepts that converge in their meaning between the socio-technical studies limited to the Dutch school of technological transitions and the Latin American school of socio-technical studies, and their relationship with the approach of state capabilities.

The contributions of Latin American socio-technical studies provide us with inputs to understand the scope of public policies, i.e. the State's action on mobility that leads to the design and implementation of modern, efficient and sustainable transportation solutions; they also allow us to observe the creation of value of use in users and the public value of public transportation in citizens in general.

Four central analytical concepts were selected from the Dutch School of technological transitions and the multilevel perspective: socio-technical landscape, socio-technical regime, institutional rules and technological innovation niche.

-Socio-technical landscape implies the external context where the different relevant social actors of the systems involved interact, where regime or niche actors have a low degree of influence; the landscape puts pressure on the regime and opens windows of opportunity for innovation; here we will observe political ideologies, global trends, macroeconomic indicators, natural resources; for example, lithium nationalization processes or other renewable energy development strategies for our research case.

-Socio-technical regime is contemplated when considering historical and cultural aspects, where relevant social actors or large groups of actors interact (such as: the educational and scientific, technological, industrial, users, political and legal and cultural systems), with the presence of alliances or coalitions integrated by hegemonic actors, are the central protagonists. Within the framework of stabilization processes, there are several processes where power relations are present.

Technological innovation niches where opportunities for the development of specific innovations can be observed, in some cases political or state support can favor these innovations. Here we find coincidence with the concept of backward mapping observed in Latin American socio-technical studies.

The concepts of socio-technical trajectory, dynamics and socio-technical alliances are selected by the Latin American School of socio-technical studies.

-Socio-technical trajectory consists of the "process of co-evolution of products, productive and organizational processes, and institutions, user-producer relationships, learning processes, problem-solution relationships, etc.; it allows ordering causal relationships between heterogeneous elements in temporal sequences (...)." [8]

-Socio-technical dynamics is defined as the "set of patterns of interaction of technologies, institutions, policies, rationalities and forms of ideological constitution of the actors. These patterns change over time, in the sense that changes in the logics of socio-political systems arise" [8].

-Socio-technical alliance is understood as "a coalition of heterogeneous elements (network of elements) involved in the process of construction of functioning-non-functioning of an artifact or a technology. A socio-technical alliance is the result of a movement of alignment and coordination of artifacts, ideologies, regulations, knowledge, institutions, social actors, economic resources, environmental conditions, materials, etc., that make viable or impede the stabilization of the socio-technical adequacy of an artifact or a technology and the assignment of sense of functioning" [8] [23].

Conclusions

The complexity of the problem of mobility and public transport in the MZVM provides the opportunity to use the socio-technical approach for the description, explanation and interpretation of innovations in public services carried out in these contexts.

At the macro level, socio-technical studies of urban mobility and public transport immerse us in the identification and description of the normative and socio-institutional framework, to take into account, on the one hand, norms of local scope such as mobility and public transport laws, Mexico City development plans or land use plans, implicitly carry ideas of the city or the relationship between territory and society; and on the other hand, international agreements that propose ideas of the greening of social life, with diverse patterns such as the reduction of polluting gas emissions and the promotion of new policies such as electromobility.

At the meso level, the public transportation system includes multimodality of the service for a geographically extensive territory and with diverse degrees and trajectories of urbanization; with influences from diverse subsystem arrangements, including industrial and market relations, the education and research system, among other subsystems. This forces us to identify different relevant social actors at play.

At the micro level, the identification of innovation niches resulting from the influence of the factors involved at the other levels, leads us to identify characteristics of innovation in the specific public service.

Therefore, the socio-historical contextualization of the public transport system as a socio-technical regime will be relevant.

At an empirical level, it is interesting to carry out a comparative exercise between the two existing cable car systems: the Mexicable of Ecatepec and the Cablebus of Mexico City. The former has been in operation for 5 years, while the latter is barely one year old. This comparison would make it possible to analyze both the way in which the socio- technical trajectories were built and the state capacities of the local governments in both cases, which, by the way, belong to two different political parties. However, this comparative exercise will depend on the availability and access to documentary and statistical information and, above all, on contacts with relevant actors for interviews.

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The role of non- state actors in promoting equitable and sustainable education: PLANE's experience in supporting the regulation and effective management of non-state education provides in Nigeria.

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Introduction

Many school-age children around the world are not receiving an education because they are disadvantaged or difficult to reach, resulting in a serious learning crisis. While many countries have greatly expanded access to education, simply being in school is not the same as learning. Many actors, governments, and international organizations are concerned about providing education to such children, recognizing that non-formal education can and does play an important role in such efforts. This research is an analytical account of how non-state schools provide basic education and informal teaching to educationally disadvantaged children in Kano, Kaduna, and Jigawa states, all of which are located in Nigeria's northwest corridor and have a large population of out-of-school children.

Nigeria with more than 11 million Out-of-School children between the ages of 6 and 15 represents 1 in 12 OOS children globally (World Bank) and has some of the worst education indicators in the world in Teaching and Learning: Achieving quality for all (UNESCO, in Nigeria, Professor Hassana Alidou, 2013).

Fundamentally, schools are established to disseminate knowledge, build positive characters for the attainment of individual goals and national development, and so on. The success to attain these goals can only be realized if the outputs of these schools are qualitative enough to push for positive outcomes from their participants which in turn the society progresses. Though it is the primary goal of every nation to provide its citizenry with qualitative education hence, it's the proletariat's right to have access to schools and colleges. Even so, it is the government's duty to ensure that its masses have access to education. Indisputably, education in every society is pivotal to national development without which the society retrogresses.

Education is undeniably critical to national development and growth. Fundamentally, schools are established to disseminate knowledge, develop positive characters for the achievement of personal and national goals, and so on. The success of these goals can only be realized if the outputs of these schools are qualitative enough to encourage positive outcomes from their participants which in turn advances society. Though it is every nation's primary goal to provide its citizens with quality education, It is the proletariat's right to have access to school and colleges.

In Nigeria, the sad reality is particularly evident at all levels of publicly owned educational facilities. It is no news that these public schools are struggling – with positive hopes and aspirations – against many odds, to deliver high-quality human capital and other services. The painful decline in quality of inputs into, and outputs from, public educational facilities resulted mainly from multifarious but intertwined human-induced causes such as somersaults in governments' educational and allied policies and corrupt practices among those expected to make resources productive for the common good of all.

This decline has gradually become a decay, deliberately set in motion by successive governments – with consistent negative advice and encouragement – towards destroying public primary schools successfully. The state of these public facilities (primary schools) has been so pathetic that many of us that attended them now find it difficult to send our children/wards there. In bridging the gap caused by the collapse of these public educational facilities, more private entities stepped in. It is now, almost, all about private primary schools in Nigeria! However, this does not imply that the entire privately-owned educational facilities are without flaws.

The most developed nations like the United States, China, Germany, UK, France, Canada, Japan e.t.c. are able to attain substantial economic growth as a result of educational advancement through quality schools that result in the production of quality education at all levels. In these countries, education in both state and non-state institutions is well funded to meet up their innovative demands and overcome challenges. (Ismail Datti Saidu & Anas Saidu Ismail, 2018).

Today, around 20-30% of children globally are educated outside of government schools. According to 2018 data from the UNESCO Institute for Statistics, 42% of pre-primary, 18% of primary, and 26% of secondary students globally were enrolled in the non-state sector – a vibrant mix of non-profit, for-profit, and faith-based organizations providing schooling and other education services. In low- and middle-income countries, the sector caters for a sizable share of the poorest students. In India, just under half of the children are educated in privately-managed schools, with one-third coming from the poorest 40% of the population. Survey data in seven sub-Saharan African cities found that approximately 1.8 million low-income children were being educated in non-

state schools, with enrolment in this sector as high as 84% (Kampala) and 60% (Nairobi).

Although in Nigeria, state authorities recognize the complementary role of non-state schools, however, from this survey, it's discovered that they are largely unaware of the specific needs and conditions of non-state schools. State policies on registration, accreditation, and taxation of non-state schools are unclear and burdensome. Most of the non-state schools' associations say they are not profit-driven and are often not profitable. Financial sustainability is jeopardized by low and variable revenue flows. However, non-state schools are deeply rooted in their local communities, with parents, teachers, and school head teachers extensively involved in ensuring the well-being of schools. Community donations, either financial or in-kind, are critical sources of support for non-state schools. Reflecting the localized and faith-based nature of non-state schools, their student bodies are largely of the same religion or tribe. Enrollment is driven not only by religion, but also by the perceived quality that a values-based education offers.

As a result of these, the Partnership for Learning for All under Output 3 (Governance of non-state systems: improvement management and performance of the non-state sector in delivering foundational skills) funded by the Foreign, Commonwealth & Development Office is keenly interested in the non-state sector provision of education to the poor. Most of the schools that are accessible to some poor families are: non-state managed state schools, Islamiyya-integrated state schools, Independent non-state schools (Faith-based), and Independent non-state schools (Private Non-faith-based), State-funded (government-aided), non-state schools. These are Low-cost schools, affordable to the majority of poor - schools that charge N1 - N25, 000 in fees per year. Regrettably, most owners of non-state schools have deficiencies in their business management practices. These owners face several financial and non-financial constraints in running their schools. Some other challenges are Business Planning, School Structure, Cash Flow Management, Human Capital, Competition for Customers, and Financial Services, amongst others.

Despite all these encumbrances, we cannot afford to ignore the gap these schools fill in educating the poor and near-poor. The benefit of the intervention for these schools is critical. Working with Affordable Private Schools in the KKK states will create both social and economic benefits through improved quality of education for these poor and near-poor which necessitates this survey.

Purpose of the Survey

The primary aim of this research is to conduct a socio-demographic survey of Non-State Sector ecosystem of unregistered schools in Kano, Kaduna, and Jigawa states. However, the state government is unable to support the teeming pupils' population. It is interesting to note that the outcomes of the survey

would provide critical information to inform further actions and plans towards proffering effective strategies to enable the sector to get appropriate support needed largely for quality data generation and effective planning in the education sub-sector etc.

The Key Research Areas:

- The size of schools and reputation
- The challenges facing poorer private schools in improving the service they offer
- Attempts to reach out to the poor
- The curriculum and quality of service delivery
- School Governance

Objectives of the Study

The objectives of the study are to:

- assess the current registration status of non-state schools
- ascertain the different types of non-state schools that are available and operating in these states
- investigate the level of awareness on the usefulness and usage of the various school records
- examine the quality of teachers' capacity in delivering quality education and ensuring best practices
- establish the various funding sources available for smooth and effective operations of the schools
- identify human and material resources in the schools
- assess the education delivery status of non-state schools
- identify the status of the grading of non-state schools in Kaduna, Kano and Jigawa States.
- Use the result as a benchmark to measure progress over time

Research Questions

- To what extent are expected statutory and non-statutory records available in unregistered non-state schools in Nigeria?
- What is the status of unregistered schools in Kaduna, Kano and Jigawa State?
- What are the different types of non-state schools in Kaduna, Kano, and Jigawa States?
- What are the various sources of funding available for the unregistered non-state schools?
- What is the level of awareness of school proprietors on guidelines of school registration?

- To what extent do the various enumerated factors inhibit or affect school registration?
- What are the human and materials resources available in unregistered non-state schools?
- What is the status of the grading of the unregistered schools in Katakana and Jigawa States?

LITERATURE REVIEW

Non-state school provision comes in many forms (Kitaev, 1999; Lewin and Sayed, 2005). Some provision is community-based and secular, much is faith-based and linked to established or fringe groups who share common religious convictions. Some are grant-aided, and some are financially self-supporting. Some are sponsored by enterprises (e.g., commercial farms, mines, and industrial organizations), and some receive external subsidies from parent organizations. There are a myriad of different patterns of beneficial ownership and accountability which range across registered non-state organizations, legally constituted businesses, informally organized associations, and individual family-owned schools. Some pay taxes; others don't. Some are for-profit and others declare nonprofit status. The non-state sector is, thus, not a single entity, but very diverse. The contribution that different types of non-state provision may make to greater access is, therefore, very varied.

The roles non-state providers can play in extending access are thus not reducible to crude dichotomies between public and private, or states and markets. Evidently, some non-states do provide valued services. Private contributions to public schooling can support expanded access. Few doubt that schools should be in partnership with the communities they serve, that complementary partnerships can and should exist, and that individual and collective contributions to public services can be beneficial. However, depending on non-state service providers in general, or truly private schooling in particular, to achieve SDGs in Sub-Saharan Africa (SSA) is a flawed proposition for several reasons. This is especially so if wholly private and unsubsidized providers are considered.

Rights-based approaches to educational access depend on the existence of a "provider of last resort". It is States that have made commitments to EFA and the SDGs, it is States that have the responsibilities to protect minorities, promote equity, and diminish exclusion, and it is States (acting with or without external support) that have the most capacity to do so, especially in poor countries. Where they fail there is no simple "Stateless" solution to delivering human rights commitments to educational access, especially to the most marginalized.

Moreover, the relationship between typical teachers' salaries and gross domestic product (GDP) per capita is also very different. In Malawi, secondary teacher salaries are more than six times GDP per capita; in the UK they are about the same as GDP per capita. Finally, it is important to remember that domestic revenue (which supports public expenditure) often accounts for less than 15% of GDP in SSA, whilst in the Organization for Economic Co-operation and Development (OECD) it averages closer to 40%. Taken together, these demographic and cost factors limit the expansion of unsubsidized schooling supported by fees paid from household income. Third, greater dependence on non-government providers of educational services often presumes that such a strategy would lead to greater efficiency, lower cost, and higher quality and relevance, arising from greater competition and accountability. Though these potential benefits of marketization of educational services can be useful in encouraging efficient and effective service provision, this can only be the case where a wide range of conditions are satisfied. These include informed choice, transparent accountability, adequate regulation, and effective legal frameworks. In much of SSA, these conditions are not met.

Those currently excluded may have little or no choice of school to attend for reasons of location or income; public accountability is often weak, reflecting local power structures and the interests of providers rather than consumers; regulation is hampered by lack of capacity, record keeping, and procedures; and legal redress for malpractice and misrepresentation is fragile and inaccessible especially to the poor. Unplanned and uncoordinated growth in service provision is much more likely to be unequally distributed, concentrated in economically favoured areas, and wasteful of scarce resources, than planned growth which links school location to demographic needs, offers economies of scale from shared services (e.g. teacher training, curriculum development), and can promote equity and meet special needs. It may be significant that no OECD country or rapidly developing country (e.g., those in East Asia) has depended on non-government providers to universalize access to basic education.

Simply put, low rates of revenue collection constrain public finance for educational development; they are not a reason to increase dependence on private financing, especially in the delivery of services to the poorest. However, limits to the growth of private schooling reduce inequalities and enhance national capabilities, and it is widely believed that poverty is caused and perpetuated by a lack of access to education. In much of SSA, education policy seeks to promote a national identity to overcome the social divisions inherited by post-colonial States composed of disparate groups in competition and sometimes in conflict with each other. It is difficult to see how this goal can be achieved without the predominantly public provision of basic education within a common curricula framework, without a developmental national teaching service, and without the publicly supported physical provision of school

buildings, textbooks, and other facilities in areas where household incomes are less than a dollar a day.

Types of Non-State Schools

There are numerous types of non-state education institutions in Nigeria. Non-state schools are defined in this review as formal and non-formal educational institutions that are owned or operated by non-state entities such as private citizens, faith-based organizations, or NGOs, and that target lower-income or marginalized populations.

Non-state managed state schools. Islamiyya integrated state schools, which have been taken over by the state as part of the UBE programme, are jointly managed by the federal and local governments and religious individuals or organizations. These schools integrate Traditional Qur'anic Education with Basic Western Education, while learners (many of which are orphans and/or street children) are taught both by government teachers and Qur'anic scholars (Mallams)

Independent, non-state schools (Faith-based). In the northern states of Nigeria, faith-based Islamic schools play a central role in the provision of education, with the highest number (2,743) recorded in Kano State. These schools are established, managed, and funded by religious individuals or organisations and can be categorized into three types of schools. Tsangaya schools are owned by Malams and follow a more informal structure that focuses on the memorization of the Qur'an. Islamiyya schools teach the Qur'an in addition to a range of other Islamic disciplines. Integrated Islamiyya Schools, or Integrated Qur'anic Schools, combined Islamic education with mainstream secular subjects

While Islamiyya schools are tracked in official statistics and considered part of the formal education system, Almajiri children that attend Tsangaya schools (predominantly male) are viewed as "out-of-school" children in Nigeria. Faith-based Islamic schools are mainly supported through student fees and parental or charitable contributions¹.

Independent, non-state schools (Private, non-faith based)

Private schools are independent non-state schools run by private individuals, communities, and organisations that (mainly) follow the national curriculum and are predominately supported through student fees, ranging from low-fee to high-fee. Most private schools are low-fee private schools (LFPS) which provide education at a relatively lower cost to children of lower-income backgrounds. The prevalence of these schools tends to be more significant than formal data shows. For Instance, the majority of LFPS in Lagos State are unregistered and not included in government statistics. For example, only 10% of all private schools in Ajeromi-Ifelodun (Lagos) were found to be officially approved by the

Lagos State Government, while 66% of private schools in Abuja Federal Capital Territory (FCT) were recorded as unregistered².

State-funded (government-aided), non-state schools

Integrated Islamiyah schools that have been registered with their State Universal Basic Education Board (SUBEB) and follow a government-approved curriculum are eligible for different forms of government aid (varying by state), including teacher salaries and learning material. For example, Kano State provides these schools with teachers, teacher development programmes, learning materials, and technical assistance in infrastructure, and Jigawa State assists them in infrastructure development.

It is very uncommon to have private schools receive funding and aid from the government. However, in some cases, some private schools may receive government aid in several states such as Lagos State (with the government providing equipment, teacher development programmes, state-funded research, and technical or operational support) and Akwa-Ibom State (with the provision of free textbooks in core subjects). Other than this level of aid, you will not find the government to be responsible for some financial commitment to private schools such as payment of salaries or funding the operational cost of the schools.

Regulatory Framework for Non-State Sector

This responsibility to regulate private educational providers should be an integral part of national legislative frameworks. However, the National Policy of Education in Nigeria does not clearly state the role of the government in regulating private schools. The policy only states that the private sector is encouraged to participate as partners in creating equitable access to education in Nigeria

More explicit guidance appears in the MoE's Abidjan guiding principles on the human rights obligations of states to provide public education and to regulate private involvement in education in (2019). The declaration provides two overarching principles that include regulating private education:

- Overarching Principle 4: States must take all effective measures, including particularly the adoption and enforcement of effective regulatory measures, to ensure the realisation of the right to education where private actors are involved in the provision of education
- Overarching Principle 8: States must regularly monitor the compliance of public and private institutions with the right to education and ensure all public policies and practices related to this right comply with human rights principles

The PLANE focal states have developed policies on private and integrated Quranic and Islamiyah schools. The policy guidelines provide prescriptive regulations on the establishment and operation of private schools, setting minimum standards, including conditions for their recognition and operations, curriculum requirements, minimum qualifications for teachers, infrastructure standards and quality measures, and recognition of degrees or diplomas issued.

Private and community schools in Kano, Kaduna and Jigawa states are regulated by the Corporate Affairs Commission. Private schools must register the company owning the private school with the Corporate Affairs Commission, and then assign a legal representative from the company to undertake all licensing procedures for establishing and operating the school. Meanwhile, Quranic and Islamiyah schools are regulated by the Qur'anic and Islamiyah Management Board in Kaduna and Kano State. There is, however, duplication of mandates by Kano State Private and Voluntary School Boards, which have the mandate to also regulate Qur'anic and Islamiyah Schools. The Board works through the SUBEB to access the UBEC Intervention funds for capital projects and teacher professional development.

Private school regulations in the state prescribe reporting obligations, including performance measures and financial reporting. They require compliance with oversight agencies' monitoring and regulatory frameworks and may face withdrawal of operating licenses if they do not comply. While these are good policy guidelines on paper, other regulations outside the policies and laws are sometimes imposed on private schools, which has necessitated the strained relationship between government and private school associations. This is especially noticeable in Kano State.

Research evidence has shown that state policies on registration, accreditation, and taxation of non-state schools are unclear and burdensome. The lack of a suitable regulatory environment discourages non-state schools from registering. In addition, entrepreneurial incentives are missing from governmental decisions and therefore are unlikely to generate opportunities that will best serve the beneficiaries and increase social outcomes.

Despite child protection policies, child abuse and neglect – particularly sexual abuse – remain serious concerns. Ministries, Departments and Agencies in the education sector are rarely held to account for failure to incorporate conflict sensitivity approaches or for the negative impacts of their programming. Challenges are compounded by a lack of educational data.

The literature on government registration, regulation and facilitation (defined as purposeful government support) provides a few insights in this regard, though studies in this area still tend to be limited in the extent to which they investigate the tentativeness of student participation in LFPS contexts. On one

hand, LFPs frequently operate independently of the state and have expanded in an unplanned and unregulated manner.

On the other hand, Rose (2006), in her overview of government support for non-state provision of basic education in South Asia and Sub-Saharan Africa, notes that the most common examples of government-initiated engagement with LFPs are associated with registration and regulation, with fewer examples of government proactively supporting LFPs financially. She notes, however, that where governments do facilitate LFP provision it is mostly in the areas of “indirect support from the government in terms of curriculum design, training of teachers, and sometimes textbook provision.

In India, a rapidly expanding private sector and concurrent government policy trend towards market-based reforms have led to significant changes across the education landscape in recent years. Regulatory, monitoring and enforcement capacity tends to be low where the need is high. Analysis of 211 education systems for the PEER website shows that regulations tend to focus on registration, approval or licensing (98%), teacher certification (93%), infrastructure (80%) and pupil/teacher ratios (74%). Regulations are least likely to focus on quality or equity: 67% regulate fee setting, 55% prevent selective student admission procedures in non-state schools, 27% ban profit making and only 7% have quotas supporting access of disadvantaged groups. Private tutoring is unregulated in 48% of countries and regulated only in commercial legislation in 11% of countries. Governments need to see all education institutions, students and teachers as part of a single system³.

In Tooley’s (1998) estimation, for example, quasi-market measures in England distort free market competition and result in inequalities of access: ‘[in England] it is not surprising if there is inequality in current “choice” systems. This has nothing to do with markets, and everything to do with rigid state intervention which discourages innovation and enterprise’ (p. 54). Similarly, in an analysis of the regulatory environment concerning private schools in Hyderabad, Dixon argues that the circumvention of formal regulations and extra-legal practices enables schools to provide better quality education: This research has established that private schools do not comply with the official rules and regulations in Hyderabad and that bribery and corruption are the order of the day [...] It is an innovative, thriving, prosperous industry answerable not to the government but the consumer, the parent. (p. 36)⁴.

For example, Tooley championed the LFP sector as playing a key role in meeting global education targets concerning universal basic education: ‘the existence and the contribution of 75 private schools to “education for all” is a cause for celebration’ (p. 2). At the same time, concerns from those challenging this interpretation are dismissed as willfully obstructive.

The situation is similar in sub-Saharan Africa. As more stringent establishment regulations are introduced, many informal schools remain unregistered or unrecognized, with governments lacking the capacity to enforce the rules and resources to staff inspectorates (Baum et al., 2018). A survey of 1,000 schools in five cities found that 56% were unregistered, and one-third of those had been operating for at least five years. In Burkina Faso, government inspection visits in 13 regions revealed that 649 schools did not meet the minimum registration criteria. Of those, 65% were deemed 'unrecognized, but recoverable' with ministry support; the other 35% were 'unrecognized and irrecoverable' and ordered to close. Nigeria faces considerable challenges with registration. In Lagos state, the number of new private schools registered more than doubled between 2019 and 2020, from 729 to 1,660. But as of 2021, the government had approved just 1 in 4 of about 20,000 private schools in the state (Premium Times, 2021).

By contrast, Mauritania has no regulation requiring government-dependent private schools to undergo inspection. Should such schools be inspected, no sanctions based on inspection results can be administered, and they are also exempt from sanctions based on examination results⁵. In Northern Africa and Western Asia, countries including Algeria, Libya and Iraq require non-state schools' students to take state-level secondary school examinations. That is also the case in Sudan, although it generally exempts international schools from this requirement as the curriculum may require other examinations. In the United Arab Emirates, which has a sizable non-state education sector, the secondary school completion certificate in non-Arab private schools is equivalent to the national certificate 'in accordance with the conditions specified by the Ministry' (United Arab Emirates Cabinet, 2008). In Bhutan, private schools must assess and review their own performance. Most schools are subject to annual ministry assessments as well, and students sit national examinations. If the ministry receives notice that a private school has failed to comply with any guidelines, it investigates the concerns, gives the school a written warning if it is found to be non-compliant, and may recommend suspension or termination of the license and eventual school closure.

Frequently cited reasons for regulatory ineffectiveness are lack of capacity to enforce the rules (in terms of resources, information and support in enforcement) and/or lack of Low-cost private schools: Evidence, approaches and emerging issues 18 incentives to enforce them on the part of the government, front-line bureaucrats or private school owners. Often governments are without the basic information on, or knowledge of the non-state sector required to regulate them,) argue in the case of Pakistan's Private Educational Institutions Regulatory Authority and Sommers (2012) illustrates for Bangladesh. In this latter case, even basic data on private school enrolment are unavailable.

India's 2009 Right to Education Act states that schools cannot be established or recognized unless they fulfil norms and standards in an annex to the act. If non-compliance exceeds three years, the authorities must withdraw recognition, whereupon the owners are liable for substantial fines if they continue to run the school. In Karnataka state, the education minister threatened to close over 1,400 private schools not in compliance with the act. In 2016, 1,170 private schools were shut down in Punjab state. The National Independent School Alliance, which represents 55,400 private schools across India, reported that more than 15,000 schools were given closure notifications for non-compliance. In the Philippines, private accreditation has been in effect since the 1970s to address concerns about government regulation.

In the past, the government could limit the entry of private schools to protect public schools from competition. Recognized non-state schools can voluntarily apply for accreditation, a form of recognized quality certification, under the Federation of Accrediting Agencies of the Philippines. If granted, it can give the school increased autonomy, deregulated status (with schools not subject to periodic evaluations) and state financial aid. The degree of autonomy of private schools, compared with government standards, depends on the level of accreditation they receive. However, accountability issues remained between the federation and the Department of Education. All non-state schools in Fiji are subject to external evaluation by officers authorized by the permanent secretary; they may enter and inspect at any time with or without notice. The 2014 Schools Standard Monitoring and Inspection Policy requires schools also to submit self-assessment reviews to the district education officer, who must verify them at least once every three years. Schools not complying following an official warning may have their registration certificate cancelled or be ordered closed by the permanent secretary.

While a handful of studies have touched upon issues of regulation in select African countries (Härmä and Adefisayo, 2013). No study has yet provided a systematic and theoretically grounded assessment of the regulatory environment of private schools. To date, understanding of private education regulation has been driven less by empirical observation than theoretical reasoning.

Eleanor Gurney (2015) contributed new empirical evidence concerning decision-making processes amongst lower-income families in Delhi. Whilst the study focuses on a specific location and social context, the findings also generate insights that are of broader relevance to studies of school choice, private schooling and family dynamics of decision-making outside the immediate study settings and contribute to global educational debates concerning education marketisation. Building on existing research on choice in India as well as other national contexts, the analysis illuminates the nature of school choice as socially situated, and as deeply personal rather than the impersonal tool for quality improvement that education policy discourse

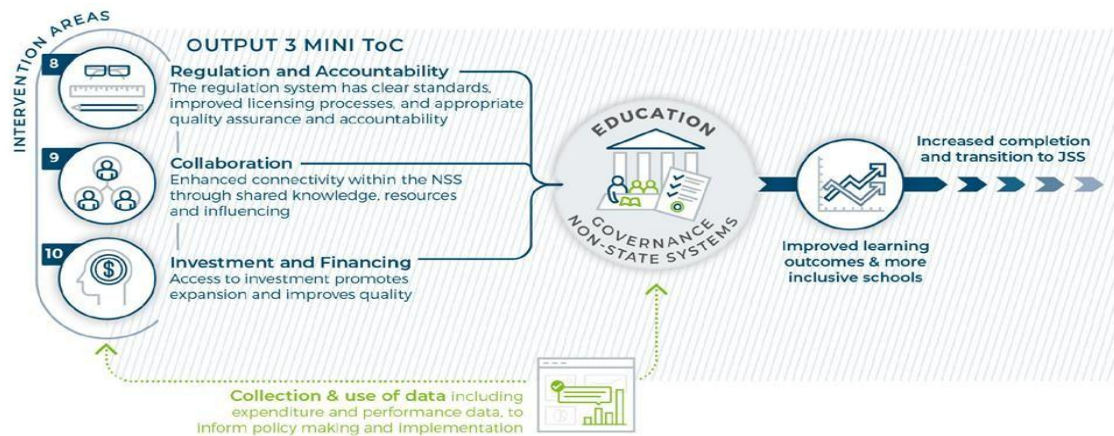
frequently implies. A scoping mission conducted in 2011, which adopted the M4P approach, attributed constraints at the core of the market (related to its size, structure, access and quality) to specific problems associated with the 'rules of the game' (the formal and informal rules on which the market was operating) and the support functions. In relation to the rules of the game, ineffective and unrealistic government regulations, often targeted at inputs rather than outputs, were failing to provide incentives for schools to improve, or to set out a clear process for them to obtain government approval. In an 'information-poor' environment, parents were making uninformed decisions on the quality and relative costs of schools. In terms of support functions, advocacy was weakened by divided and low-capacity private sector associations, strained relationships with government and a general lack of media interest in reporting on LCPSs (ibid.).

This was compounded by financial constraints, including risk-averse banks, and a political aversion to demand-side financing on the part of the government. The employment market for teachers, in particular salary differentials between state and private teachers that did not reflect knowledge or skills, was also found to be a constraint on performance.

Partnership For Learning For All

Nigerian children aren't learning foundational skills – maths, basic reading and writing in Hausa and in English. This lack of basic skills undermines their ability to transition into junior and upper secondary and, subsequently, enter the employment market with the skills and abilities that enable them to maximise their opportunities. In response to this problem – comprising both front line delivery challenges and underlying systemic bottlenecks – whilst considering the political economy context; building on evidence and lessons learned in Nigeria and internationally; and responding to the strategic priorities of both UK and Nigerian Governments, the PLANE programme has been launched. PLANE is a portfolio programme with three windows and a complimentary FCDO management component. The overarching PLANE theory of change shows that improvements in the foundational systems; specific support to children in conflict environments; and communities supporting children learning; together can contribute to more inclusive and effective education systems that deliver foundational skills, particularly for marginalised groups of children.

Output 3 strategic framework is illustrated below.



METHODOLOGY

This chapter explains in detail the methods that were used to carry out the research under the following headings: Research Design, Population, Sample and Sampling Technique, Research Instrument, Validity of Instrument, Reliability of Instrument, Method of Data Collection and Method of Data Processing and Analysis.

Research Design

The descriptive survey research design was adopted for the study. This involves gathering data that describe events and then organizes, tabulates, depicts, and describes the data collection. This type of survey design allows for a brief interview or discussion with the respondents on how to complete the research instrument and often uses visual aids such as graphs and charts to aid the reader in understanding the data distribution.

As the survey design depicts, this study ensured questions were structured both in multiple choice and open-ended forms where participants were at the liberty to choose any of the options and also express their thoughts, respectively. Also, minimal contact between the researcher and respondents and their responses were readily recorded on the instrument. Descriptive studies report summary data such as measures of central tendency including the mean, median, and mode percentage and correlation between variables.

Population

The study population consisted of all the 7,583 unregistered non-state schools in Kano, Kaduna and Jigawa state while the school proprietor/ head teachers form the focus of the study.

Sample and Sampling Technique

This survey adopted Taro Yamane Formula (Yamane, 1973) sampling equation given by equation 3.1 to sampled one thousand and seventy eighty unregistered non-state schools in three states (Kano, Kaduna and Jigawa) and twenty-four (24) (LGAs). However, the stratified random sampling technique was further used to select the unregistered non-state schools by LGAs in the sampled states. The Map of states sampled was presented in figure 3.1.

$$n = N / (1 + Ne^2)$$

Where,

n = Required sample size

N =Population Size

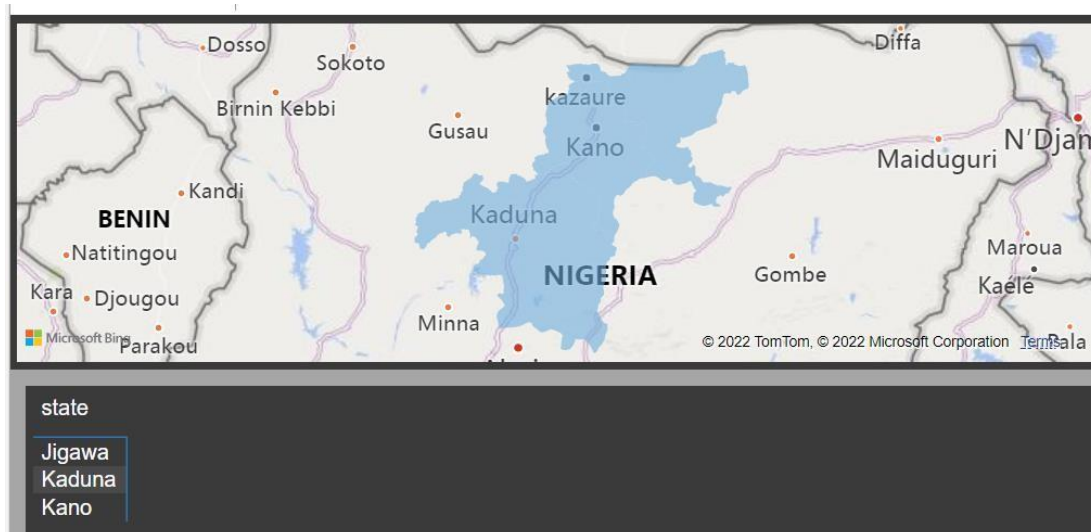
e = Error (0.05) reliability level 95%

The results of the sampling distribution are presented in Table 1

Table 1: Distribution of Study Sample by State

S/ N	State	Registere dSchool	No. of Unregistere d School (FRAME)	Unregistere d IQT	No of LGA Selected	No of School Sample d	No. of IQT Sample d	No. of Sampled Schools
1	Kano	8630	3055	313	11	354	60	414
2	Kaduna	1015	1844	201	6	329	42	371
3	Jigawa	2934	54	2116	7	17	336	353
	Total	12579	4953	2630	24	700	438	1138

Source: Field Work by Researchers



Research Instrument

Content

Two research instruments consisting of two parts were used. Part 1, titled “PLANE Instruments for Collecting Baseline Data Part 1”, was carefully designed with the items structured to suit the objectives of the study on unregistered non-state schools’ census. The design and construction of the questionnaire items were carried out by a team of research experts from the PLANE technical team that involved rigorous sessions. This was further subjected to a critique exercise by an enlarged technical group made up of educationists, planners, statisticians, academics and ICT experts. The questionnaire designed on Survey CTO was made up of seven major sections.

Section A presents the school identification under (A.1 –A.9). Section B of the instrument elicited information on school characteristics with (B.1 – B.25). Section C was designed to gather information on the use of school records in completing Annual School Census (ASC) form. Section D presents information on school enrolments under (D.1–D.7). Classrooms and Facilities were presented in section E (E.1–E.10). Section F also elicited information on Teachers' Qualifications. Finally, section G presents information on respondents' and enumerators' undertaking.

Similarly, in Part 2, titled “PLANE Graded Instruments for Collecting Baseline Data Part 2”, the instruments were divided into three sections section A presents information on School Identification, section B School Management

and Section C solicits information on respondents and enumerators undertaking. However, section B is subdivided into sixteen subsections. B1 sought information on school administration, B2 Professional leadership, B3 School governance, B4 Mechanisms between school and parents, B5 Learner participation in school governance, B6 Relationship with the community, B7 Planning for school development, B8 Learner health & hygiene, B9 Learner safety, B10 Promoting girl-child education and disability inclusion, B11 Pastoral Care, B12 Reward and Sanctions, B13 Promoting learning time, B14 Continuous assessment, B15 Co-curricular activities and B16 Quality of the school buildings and premises

Validity of Instrument

The items on the questionnaire were subjected to scrutiny using experts in educational measurement and evaluation/test items to ensure both face and content validity. Their expert advice and suggestions were carefully incorporated into the final copy of the questionnaire that was later pilot tested.

Reliability of Instrument

The reliability of the research instrument was obtained from a pilot study conducted in 20 selected unregistered non-state schools in March 2022 at the Agege Local Government Area of Lagos state. The coefficient of reliability of 0.84 was obtained which was considered high enough for reliability. This was done to check for uniformity and acceptability of the questions to the respondents. The instrument was further subjected to further critiquing at a meeting between the representatives of the state technical working group and the PLANE team held at Bolton White Hotel in Abuja in May 2022 and necessary corrections were made before the fieldwork.

Method of Data Collection

A team of twenty (51) enumerators, were trained on modalities for the data collection and deployed to the field. For ease of work, the flexibility of time and quality in the administration of the questionnaire, each researcher covered two schools per day for three weeks using Tablets provided by the PLANE technical team. Data collection lasted for an average of three weeks.

Method of Data Processing and Data Analysis

The retrieved instruments were subjected to rigorous checks and other processing procedures. Data analysis was carried out using Microsoft Excel package and Power BI. Frequency, simple percentage graphs and charts were used to present the data. The findings are presented in Tables and graphs in the next chapter.

CHARACTERISTICS OF NON-STATE UNREGISTERED SCHOOLS

The private sector, private individuals, civil society organizations, non-governmental organizations (NGOs), international development partners, as well as communities, are all referred to as non-state actors participating in the provision of education in the National Policy on Education 2014, which governs education at all levels in the nation. The features of the non-state, unregistered schools that were chosen for this study are presented in this section.

Table 2: Frequency percentage distributions of non-state unregistered school characteristics

Variable	Kano	Kaduna	Jigawa	Grand Total
Non-State Unregistered School	394(38.4)	313(30.5)	319(31.1)	1026(100.0)
Unregistered Non-State Schools by Ownership				
Non-Religion Foundation	0(0.0)	3(0.3)	0(0.0)	3(0.3)
Religious Foundation	41(4.0)	34(3.3)	98(9.6)	173(16.9)
Single Private Owner	316(30.8)	235(22.9)	133(13.0)	684(66.7)
Two or More Private Owners	30(2.9)	38(3.7)	58(5.7)	126(12.3)
Others	7(0.7)	3(0.3)	30(2.9)	40(3.9)
Types of Non-State Schools				
Independent, non-state schools (Faith-based)	221(21.5)	97(9.5)	101(9.8)	419(40.8)
Independent, non-state schools (Private, non-faith based)	50(4.9)	191(18.6)	41(4.0)	282(27.5)
Non-state managed, state schools	87(8.5)	25(2.4)	131(12.8)	243(23.7)
State-funded (government-aided), non-state schools	36(3.5)	0(0.0)	46(4.5)	82(8.0)
Membership of Associations				
AFED	0(0.0)	0(0.0)	0(0.0)	0(0.0)
AISEN	1(0.1)	1(0.1)	0(0.0)	2(0.2)
AMIS	11(1.1)	11(1.1)	16(1.6)	38(3.7)
ANSAR-UD-DEEN	3(0.3)	2(0.2)	1(0.1)	6(0.6)
ANWAR-UL-ISLAM	9(0.9)	3(0.3)	0(0.0)	12(1.2)
APEN	1(0.1)	2(0.2)	14(1.4)	17(1.7)
APSO	5(0.5)	6(0.6)	12(1.2)	23(2.2)
FOMWAN	5(0.5)	0(0.0)	0(0.0)	5(0.5)
LEAMPS	5(0.5)	3(0.3)	2(0.2)	10(1.0)
NAPPS	25(2.4)	118(11.5)	2(0.2)	145(14.1)
Others	16(1.6)	9(0.9)	63(6.1)	88(8.6)
None	332(32.4)	175(17.1)	211(20.6)	718(70.0)

Note: percentages are enclosed in parenthesis

The survey included 1026 schools in total, which were distributed by state in Table 2. According to the breakdown of these schools by state, there were 319 unregistered non-state schools in Jigawa, 313 unregistered non-state schools in Kaduna, and 394 unregistered non-state schools in Kano (38.4%, 30.5%, and 31.1%, respectively).

A closer look at the Table also revealed that 126 non-state unregistered schools had two or more private owners, 40 had other ownership (3.9%), and 3 of the

non-state unregistered schools (0.3%) were owned by non-religious foundations, 173 by religious foundations, 684 by single owners, and 3 by community ownership.

According to a state-by-state examination, the majority of the non-state's schools were privately owned, with 316 (30.8) schools in Kano, 235 (22.9%) in Kaduna, and 133 (13.1%) in Jigawa state.

Additionally, the distribution of unregistered non-state schools by state type and non-state school type was shown in the Table. In terms of independent, non-state schools (faith-based), Kano had 221 (21.5%), Kaduna had 97 (9.5%), and Jigawa had 101 (9.8%). There were 419 independent, non-state, faith-based schools overall (or 40.8%) in the state that was the sample. This meant that the majority of private schools belonged to religious organizations. These schools fall under the category of traditional Qur'anic schools since they were founded, run, and supported by religious people or groups. This outcome may be explained by the fact that Islamic schools with a strong religious component are crucial to the delivery of education in Nigeria's northern areas.

However, a total of 282 (27.5%) were independent, non-state schools (Private, non-faith based). Of these, 50 (4.9%) were in Kano, 191 (18.6%) in Kaduna, and 41 (4.0%) in Jigawa state. There were 243 (23.7% of all non-state schools) and 82 (8.0%) state-funded (government-aided) non-state schools, respectively.

The Table also shows the frequency and percentage distributions of association and state memberships for proprietors and proprietresses. The percentage of schools in Kano state without association was 332 (32.4%), Kaduna 175 (17.1%), and Jigawa state with 211 (20.6%) proprietors/proprietresses who are not members of any association. In all, 718 school owners (or 70%) do not belong to any associations.

Additionally, 88 (or 8.6%) of the non-state unregistered schools listed belong to other associations, including the Association of Quranic and Islamiyya Schools, and the Association of Alaramma for Tsangaya Schools, (the Tijaniyya Islamiyya Teachers Association, and the Kung Yar Makaranta Tsangaya, which was not included.

Registration Status of Non-State Schools

Non-state education is becoming more common in Sub-Saharan Africa. Due to a nationwide shortage of public schools, the role of non-state providers in delivering universal basic education has grown in importance in Nigeria over the past few decades. Non-state providers have entered the market to address the rising demand for educational services from parents and students as a result of the lack of public-school supply. Many pupils, especially in urban and peri-urban regions, are receiving educational chances from unregistered schools, according to Adelabu and Rose (2004). In some parts of the country, there are

many unregistered schools, according to a 2015 World Bank report. This was due to the extensive, onerous registration requirements that many small, non-state educational providers find challenging to fulfil. Therefore, the current situation of unregistered schools in KJ was examined in this section.

Table 3: Frequency Percentage Distributions of Registration Status of Non-State Schools

Variable	Kano	Kaduna	Jigawa	Grand Total
Recognition status				
Yet to be approved	333(32.5)	127(12.4)	255(24.9)	715(69.7)
In process of approval	61(5.9)	186(18.1)	64(6.2)	311(30.3)
Approved	0(0.0)	0(0.0)	0(0.0)	0(0.0)
If your school is yet to be approved, do you want it to be approved?				
Yes	314(43.9)	123(17.2)	238(33.3)	675(94.4)
No	19(2.7)	4(0.6)	17(2.4)	40(5.6)
Reasons for not ready for school approval				
I don't want to pay tax to the government	0(0.0)	0(0.0)	4(7.7)	4(7.7)
I don't want the government to monitor my school	0(0.0)	1(1.9)	5(9.6)	6(11.5)
I want to avoid government regulations	1(1.9)	0(0.0)	8(15.4)	9(17.3)
I don't want the government to take over my school	11(21.2)	1(1.9)	10(19.2)	22(42.3)
Others (pleases specify)	6(11.5)	2(3.8)	3(5.8)	11(21.2)

School's approval status

Guidelines purchased	16(2.6)	82(13.4)	4(0.7)	102(16.7)
Name search	8(1.3)	63(10.3)	1(0.2)	72(11.8)
Formal application	22(3.6)	52(8.5)	36(5.9)	110(18.0)
Site inspection	14(2.3)	57(9.3)	10(1.6)	81(13.3)
Take-off permit	6(1.0)	33(5.4)	9(1.5)	48(7.9)
Approval inspection	13(2.1)	41(6.7)	6(1.0)	60(9.8)
Provisional approval	10(1.6)	26(4.3)	4(0.7)	40(6.6)
Payment of accreditation fees/full inspection	8(1.3)	56(9.2)	6(1.0)	70(11.5)
Full approval (after 10 years)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Others	24(3.9)	3(0.5)	0(0.0)	27(4.4)

Note: percentages are enclosed in parenthesis

Table 3 showed that out of 1026 sampled non-state schools, 715 schools, representing 69.7%, were yet to be approved, while 311 schools, representing 30.3% of the schools, were in the process of approval. The number of schools yet to be approved by the state shows that Kano state had 32.5% of schools yet to be approved and 5.9% of schools in the process of approval. Kaduna had 12.4% and 18.1% while Jigawa state had 24.9% and 6.2% respectively of non-state schools yet to be approved and in the process of approval.



In the same vein, the table also showed that out of 715 non-state schools in yet-to-be-approved status, 675 schools, representing 94.4%, want their schools to be approved while 40 schools, representing 5.6% of the schools, do not want their schools to be approved. However, 22 schools, representing 42.3% of the schools not ready for approval, attributed the reason to they don't want the government to take over their school; 9 schools representing 17.3% to I want to avoid government regulations; 6 schools representing 11.5% to I don't want the government to monitor my school; and 4 schools representing 7.7% to I don't want to pay tax to the government; while 21.2% of the schools specified other reasons for not being ready for school approval, such as it is a religious school, is a religious school, I am just starting, a religious school, a religious school, I am just starting, a religious school, a religious school, a

The table further revealed that 16.7% of the non-state schools in the process of approval status had purchased guidelines, 11.8% in name search stage, 18.0% in formal application, 13.3% in site inspection stage, 7.9% in take-off permit, 9.8% in approval inspection, 6.6% in provisional approval, and 11.5% in the payment of accreditation fees/full inspection stage.

The large percentages of non-state schools that are yet to be approved indicate that the government has not kept up with the quickening rate of market expansion. If the government wants to guide unregistered non-state schools, the

government must provide solutions to the Roadblocks to school Registration identified in Table 4 –let alone expand its functions to guarantee a minimum standard of quality in all schools—it will need to establish significantly more capacity to adequately respond to these needs.

Table 4: Frequency Percentage Distributions of Roadblocks to Non-state schools Registration

Variable	Kano	Kaduna	Jigawa	Grand Total
Roadblocks				
Building structure requested by the state government for school registration.	333(32.5)	127(12.4)	255(24.9)	715(69.7)
State government protocols for registering a school are quite burdensome	165(16.1)	56(5.5)	129(12.6)	350(34.1)
Getting a consent letter from the host community is sometimes Difficult	97(9.5)	64(6.2)	75(7.3)	236(23.0)
Difficulties in registering with state internal revenue service	65(6.3)	19(1.9)	19(1.9)	103(10.0)
The uncooperative attitude of inspectorate/quality assurance staff	92(9.0)	40(3.9)	86(8.4)	218(21.2)
Reference letter from the bank	52(5.1)	45(4.4)	18(1.8)	115(11.2)
Lack of adequate school facilities	175(17.1)	65(6.3)	105(10.2)	345(33.6)
Getting a building plan/tenancy agreement is cumbersome	43(4.2)	31(3.0)	24(2.3)	98(9.6)
Other Roadblocks	35(3.4)	9(0.9)	8(0.8)	52(5.1)

The 4 revealed the road blocks to non-state school's registration. Building structure requested by the state government for school registration top the list with 69.7% of the respondents, 34.1% affirmed to state government protocols for registering a school is quite burdensome, 33.6% to lack of adequate school facilities and 26.7% to getting a certificate of registration with the CAC is quite burdensome among others. This result underlines the fact that these factors are germane in inhibiting the registration of non-state schools in Nigeria.

School Community Partnership

The goal of school-community partnerships is to improve the quality of school administration, the learning environment, curriculum delivery, and students' learning outcomes by fostering a meaningful, close-knit, strong, and goal-oriented alliance between the school authority and other pertinent stakeholders (such as the Parent-Teachers Association (PTA), the Old Students Association, non- governmental organizations, communities, ministries, and school boards).

According to Ayeni (2010), this synergy is essential because a strong and supportive school- community relationship serves as a foundation for achieving



predetermined standards and objectives as well as producing high-quality outputs that meet the needs of the institution's patrons and society.

According to the National Education Quality Assurance Handbook for Basic and Secondary Education in Nigeria 2016, all non-state primary and secondary schools in Nigeria must set up School-Based Management Committees (SBMCs), Parent-Teacher Associations, and a Learners/Students Representative Council. SBMCs are made up of elected officials from the teaching staff, student body, community, and parents, with additional state-level participants. The extent of school community partnerships in unregistered non-state schools in KJ states is therefore presented in this section.

Table 5: Frequency Percentage Distributions of School Community Partnership

Variable	Kano	Kaduna	Jigawa	Grand Total
Parents'-Teachers' Association (PTA) / Parents Forum (PF)				
Yes	144(14.0)	231(22.5) 543(52.9)	168(16.4)	
No	250(24.4)	82(8.0)	151(14.7)	483(47.1)
Evidence of PTA Availability				
Minutes Available	33(6.1)	61(11.2)	75(13.8)	169(31.1)
Minutes Not Available	111(20.4)	170(31.3)	93(17.1)	374(68.9)

School-Based Management Committee (SBMC)/(CBMC)				
Yes	72(7.0)	67(6.5)	141(13.7)	280(27.3)
No	322(31.4)	246(24.0)	178(17.3)	746(72.7)
Evidence of SBMC/CBMC Availability				
Minutes Available	24(8.6)	23(8.2)	80(28.6)	127(45.4)
Minutes Not Available	48(17.1)	44(15.7)	61(21.8)	153(54.6)
School Development Plan (SDP)				
YES	90(8.8)	145(14.1)	72(7.0)	307(29.9)
No	304(29.6)	168(16.4)	247(24.1)	719(70.1)
Evidence of (SDP) Availability				
Plan Available	61(19.9)	89(29.0)	40(13.0)	190(61.9)
Plan not Available	29(9.40)	56(18.2)	32(10.4)	117(38.1)

Note: percentages are enclosed in parenthesis

Table 5 demonstrated that out of 543 non-state schools (52.9%) with Parents'-Teachers' Associations (PTA)/Parents Forums (PF), 31.1% could only present PTA minute's books as proof. Similar to this, there were 280 schools with School Based Management Committees (SBMC)/ (CBMC) present, accounting for 27.3% of all schools, and 127 of those schools (45.5%) demonstrated evidence of SBMC functionality. This shows that in the sampled area, the non-state school gave PTA and SBMC activities less weight.

The Table also showed that 29.9% of private schools have a School Development Plan (SDP). This implied that SDP was not present in the majority of the non-state sampled schools.

Public Private Partnership-Support from State to Non-State Schools

The ability of non-state actors to deliver basic education on a worldwide scale has frequently occurred through some type of public-private partnership (PPP). Some non-state schools in Northern Nigeria don't charge students for tuition, while others rely heavily on the meagre school fees paid by parents who may have lost their jobs as a result of the country's security situation. These kinds of educational institutions lack the financial "cushion" needed to cover staff salaries and facility rent indefinitely. As a result, without assistance, portions of the non-state education industry risk shutdown or collapse. The number of non-

state schools in Kano, Kaduna, and Jigawa States that are supported by the state or non-state is shown in the table below.

Table 6: Frequency Percentage Distributions of State or Non-State School Support

Variable	Kano	Kaduna	Jigawa	Grand Total
Have you received any state or non-state support for your school since opening?				
Yes	22(2.1)	18(1.8) 103(10.0)	63(6.1)	
No	372(36.3)	295(28.8)	256(25.0)	923(90.0)
If your school received any state or non-state support. Specify the support your school received				
Financial support	4(2.9)	7(5.0)	17(12.2)	28(20.1)
Provision of school bags, exercise books, pencils, biro and sandals.	4(2.9)	2(1.4)	10(7.2)	16(11.5)
Salaries for teachers	2(1.4)	1(0.7)	0(0.0)	3(2.2)
Provision of furniture (Chair, Tables etc.)	2(1.4)	7(5.0)	2(1.4)	11(7.9)
Feeding of pupils	2(1.4)	2(1.4)	0(0.0)	4(1.4)
Salaries of Mallams	1(0.7)	0(0.0)	0(0.0)	1(0.7)
Health facilities	0(0.0)	1(0.7)	0(0.0)	1(0.7)
Toilets	3(2.2)	2(1.4)	2(1.4)	7(5.0)
Construction of blocks of classroom	4(1.4)	4(2.9)	39(28.1)	47(33.8)
Renovation of school buildings	4(1.4)	3(2.2)	0(0.0)	7(5.0)
Provision of Library equipment	0(0.0)	0(0.0)	1(0.7)	1(0.7)
Purchase of computer system	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Others	6(4.3)			13(9.4)

Note: percentages are enclosed in parenthesis

Table 6 showed that 103 (10.0%) of the owners/head teachers reported receiving state or non-state support in their institutions ever since they opened. However, the construction of classroom blocks and financial support were listed as the two largest forms of state or non-state help received across the school in the KJ States, with 33.8% and 20.1%, respectively.

Tuition Fees Charged in Non-State Schools

Education is seen as a ticket to a better life all around the world, and Nigerians are no exception in their desire to obtain the greatest education that money can buy. By imposing costly tuition and levies, owners and administrators of private and mission schools have raised the bar on the adage "if you think education is expensive, try ignorance." by capitalizing on the alleged problems of public schools.

It is disappointing that many parents are becoming unable to meet the demands of private school owners or proprietors. The reality is that many parents can no longer pay these fees given the degree of poverty and inflation in the nation.

In addition, the National Minimum Wage, which is a pitiful N30, 000 a month, has not yet been properly implemented by some state governors. Lewin (2007), quoted in the 2015 World Bank study, asserted that households in Sub-Saharan Africa spend, on average, 5–10% of their annual income on educational costs.

Accordingly, schools should be categorized as low-cost if their tuition costs are less than 10% of a family's gross income, as suggested by Tooley and Longfield (2013) in their study on non-state institutions. With this criterion in mind, low-cost non-state schools throughout the survey period would be those charging N30, 000 or less per year based on the Nigerian national minimum wage. As a result, the frequency percentage distributions of the tuition fees levied in non-state schools are shown in Table 7.

Table 7: Frequency Percentage Distributions of Tuition Fees charged in Non-State Schools

Variable	Kano	Kaduna	Jigawa	Grand Total
Pre-nursery School Fees				
N10, 000 or below	138(13.5)	234(22.8)	124(12.1)	496(48.3)
N 10,001 - N20,000	20(1.9)	34(3.3)	9(0.9)	63(6.1)
N20,001 – N30,000	7(0.7)	3(0.3)	3(0.3)	13(1.3)
Over N30,000	1(0.1)	2(0.2)	1(0.1)	4(0.4)
No School Fees	153(14.9)	40(3.9)	257(25.0)	450(43.9)
Nursery School Fees				
N10, 000 or below	120(11.7)	248(24.2)	105(10.2)	473(46.1)
N 10,001 - N20,000	10(1.0)	31(3.0)	7(0.7)	48(4.7)
N20,001 – N30,000	5(0.5)	1(0.1)	3(0.3)	9(0.9)
Over N30,000	0(0.0)	0(0.2)	0(0.0)	2(0.2)
No School Fees	184(17.9)	31(3.0)	279(27.2)	494(48.1)
Primary School Fees				
N10, 000 or below	153(14.9)	249(24.3)	131(12.8)	533(51.9)
N 10,001 - N20,000	27(2.6)	33(3.2)	11(1.1)	71(6.9)
N20,001 – N30,000	9(0.9)	2(0.2)	3(0.3)	14(1.4)
Over N30,000	0(0.0)	2(0.2)	0(0.0)	2(0.2)
No School Fees	130(12.7)	27(2.6)	249(24.3)	406(39.6)

Note: percentage are enclosed in parenthesis

According to Table 7's findings, 48.3% of non-state schools with pre-nursery classes charge less than N10,000 annually, 6.1% charge between N10,000 and N20,000, 1.3% charge between N20,000 and N30,000, and 0.4% charge more than N30,000. Of these schools, 43.9% charge no fees. In the nursery class, similarly, 46.1% of the schools charge less than N10,000 per year, 4.7% charge between N10,000 and N20,000, 0.9% charge between N20,000 and N30,000, and 0.2% charge more than N30,000. Meanwhile, 48.1% of the schools have no fees at all. The table also showed that 51.9% of non-state schools in the primary grades charge less than N10,000 annually, 6.9% charge between N10,000 and N20,000, 1.4% charge between N20,000 and N30,000, and 0.2% charge more than N30,000, while 39.6% of non-state schools operate tuition-free schools in KJ states. The data mentioned above usually imply that the majority of private schools provide their students with free education.

Teachers' Salaries

Despite their commitment to the growth of the country, teaching positions in Nigeria are among the least respected and among the lowest paid. Non-state school teachers in Nigeria struggle to make a living because their pay is significantly less than the minimum salary for the nation amid rising inflation. The teachers in KJ state non-state schools are paid monthly according to this section.

Table 8: Frequency Percentage Distributions of Non-State Schools' Teachers' Salary

Variable	Kano	Kaduna	Jigawa	Grand Total
Teachers Monthly Salary				
N10, 000 or below	69(6.7)	214(20.9)	113(11.0)	396(38.6)
N 10,001 - N20,000	16(1.6)	61(5.9)	19(1.9)	96(9.4)
N20,001 - N30,000	0(0.0)	8(0.8)	3(0.3)	11(1.1)
N30,001 - N40,000	1(0.1)	2(0.2)	1(0.1)	4(0.4)
N40,001 - N50,000	0(0.0)	0(0.0)	1(0.1)	1(0.1)
Over N50,000	1(0.1)	0(0.0)	0(0.0)	1(0.1)
No Salary for Teachers	232(22.6)	28(2.7)	257(25.0)	517(50.4)

Note: percentages are enclosed in parenthesis

According to Table 8, 396 non-state school owners (38.1%) pay their teachers less than N10,000 per month, 96 proprietors (9.4%) pay between N10,000 and N20,000, 11 proprietors (1.1%) pay between N20,000 and N30,000, 4 proprietors (0.4%) pay between N30, 000 and N40, 000, and 1 proprietor (0.1%) pays between N40, 000 and N50, 000 as well as above N50,000 per month. While the non- state school proprietors/proprietresses reported that teachers in 517 non-state schools (50.4%) did not receive a wage at the end of the month.

Special Needs/ Disabilities Education

The basic goal of inclusive education is to provide people with special needs with access to suitable education. One surefire approach to achieving access and equity, as required by UNESCO for inclusive education programs, is to make suitable education available to children with Special Needs. Nigeria participates in special education, however current methods are not entirely in line with accepted international best practices (FME, 2015). Furthermore, there are currently no technology- driven special needs classrooms or laboratories in the nation. In Nigeria, it appears that anyone can perform special education. In Nigeria, practitioners lack a formal operating license. Some people mistakenly associate mainstreaming or integration with inclusive education. Due to the other competing disciplines, there is a limited amount of place for Special Needs Education service instructors in the school curriculum (FME, 2015). The provision for disabilities in non-state schools is discussed in this section.

Table 9: Frequency Percentage Distributions of Non-State Schools with Provisions for Disabilities

Variable	Kano	Kaduna	Jigawa	Grand Total
Does your school have any provision for students with disabilities?				
Yes	62(6.0)	34(3.3)	69(6.7)	65(16.1)
No	332(32.4)	279(27.2)	250(24.4)	861(83.9)
If your school has a provision for students with disabilities. Specify the provisions.				
Ramps	15(9.1)	10(6.1)	28(17)	53(32.1)
Hearing aid	14(8.5)	8(4.8)	16(9.7)	38(23.0)
Braille	6(3.6)	0(0.0)	12(7.3)	18(10.9)
Wheelchair	32(19.4)	10(6.1)	24(14.5)	66(40.0)
Magnifier for Albinos	5(3.0)	0(0.0)	9(5.5)	14(8.5)
Paved paths and rails	4(2.4)	3(1.8)	1(0.6)	8(4.8)
Others (please specify)	9(5.5)	14(8.5)	19(11.5)	42(25.5)

Note: percentages are enclosed in parenthesis

According to the information in Table 9, 165 (16.1%) of the non-state schools had provisions for students with disabilities. Out of the 165 non-state schools, however, 53 (32.1%) had ramps, 38 (23.1%) had hearing aids, 18 (10.9%) had braille, 66 (40.0%) had wheelchairs, and 14 (8.5%) and 8 (4.8%) had magnifiers for albinos, as well as paved walks and rails, in their respective buildings

Graded Assessment of Non-State Schools

To increase learner attainment, school leaders play a significant role in establishing strong connections between various educational and training levels, families, the workplace, and the local community. Due to an increase in student enrolment, knowledge, and expectations for the transfer of knowledge, the importance of school management has grown even more. This section analyses the different indicators under School Management effectiveness. For each State, performance under each indicator was ranked in order to highlight strengths and weaknesses in the work of the school manager towards supporting better school management practices overall

Pass Ratings Scale

Dimension 1: Mark Obtainable 5

0-1 = Emerging

2-3 = Establishing

4-5 = Enhancing

Dimension 2: Mark Obtainable 8

0-2 = Emerging

3-5 = Establishing

6-8 = Enhancing

Dimension 3: Mark Obtainable 11

0-2 = Emerging

4-7 = Establishing

8-11 = Enhancing

In the same vein, a total of 171 questions were raised for all the indicators, with 1 mark for each question; the overall pass rating scale was set as follows:

Less than or equal to 50 points = Emerging,

51-100 = Establishing Above 100 = Enhancing.

The KKJ Non-State overall school graded assessment were presented in Table 18

Table 18: Whole School Graded Assessment of Non-State Schools in KKJ States

Items	Dimension Scale 1		
	0-1	2-3	4-5
School administration	171(15.7)	266(24.3)	655(60.0)
School governance	746(68.3)	265(24.3)	81((7.4)
Mechanisms between school and parents	337(30.9)	264(24.2)	491(45.0)
Supervision at Playtime	317(29.0)	560(51.3)	215(19.7)
Learners Attendance	348(31.9)	281(25.7)	463(42.4)
Teachers Attendance	368(33.7)	287(26.3)	437(40.0)
Promoting learning time	341(31.2)	564(51.6)	187(17.1)
Co-curricular activities	582(53.3)	153(14.0)	357(32.7)
Dimension 2 Scale			
	0-2	3-5	6-8

Learners' health	709(64.9)	229(21.0)	154(14.1)
Mealtime for Learners	502(46.0)	378(34.6)	212(19.4)
Reward and Sanctions	423(38.7)	481(44.0)	188(17.2)
Continuous assessment	334(30.6)	274(25.1)	484(44.3)
Dimension 3 Scale			
	0-3	4-7	8-11
Professional leadership	340(31.1)	277(25.4)	752(68.9)
Learners participation in school governance	543(49.7)	418(38.3)	131(12.0)
Relationship with the community	176(16.1)	323(29.6)	593(54.3)
Planning for school development	232(21.2)	218(20.0)	642(58.8)
Learners Hygiene	637(58.3)	356(32.6)	99(9.1)
Safeguarding & Child Protection	418(38.3)	237(21.7)	437(40.0)
Promoting girl-child education and disability inclusion	530(48.5)	331(30.3)	231(21.2)
Pastoral Care	210(19.2)	605(55.4)	277(25.4)
Quality of the school buildings and premises	615(56.3)	417(38.2)	60(5.5)

Note: percentages are enclosed in parenthesis

Table 18 shows the level of school administration in KKJ states. A closer look at the Table indicated that more than 50% of the sampled schools could be classified as emerging schools in the areas of school governance, Co-curricular activities, learner health, learner hygiene and quality of the school buildings and premises. In the same vein, more than half of the schools were regarded as establishing schools in the area of supervision at play time, promoting learning time and pastoral care. While on school administration, professional leadership, Relationship with the community and Planning for school development met enhancing school criteria.

Table 18: KKJ Non-State Schools Graded Assessment

	School Grading Categories			Total
	Emerging	Establishing	Enhancing	
Kano	129 (11.8)			113(10.3)
Kaduna	10(0.9)			202(18.5)
Jigawa	104(9.5)			120(11.0)
Total	243(22.3)			435(39.8)

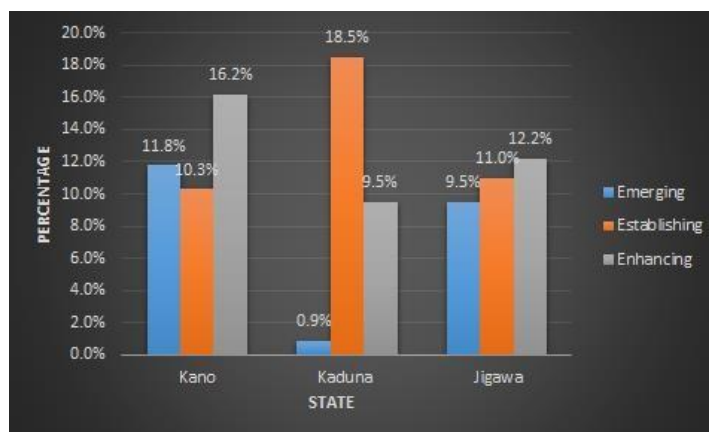
Note: percentages are enclosed in parenthesis

Figure 1 Graphical Illustration of KJ States Non-State Schools Graded



According to Table 4.14's findings, 22.3% of non-state schools were regarded as emerging, 39.8% as establishing schools, and 37.9% as enhancing schools. A closer look at the table also indicated that Kano states had the highest number of emerging and enhancing schools with 11.8% and 16.2%, respectively, while many schools in Kaduna (18.5%) were in the establishing category.

Figure 2 Graphical Illustration of KJ States Non-State Schools Graded Assessment in Percentages



Conclusion

The government unquestionably plays a major and significant role in providing education at all level with emphasis to free, compulsory and Universal Basic Education in Nigeria, as it does in a number of other low-income nations. However, the contributions of non-state school providers, in accord with other participants like corporate entities and international organizations provide

complementary support or services in this regard. Results unequivocally demonstrate that where non-state provision is developing, there have been unwelcome government impulses to promote provision to individuals who are underserved by the state system.

The degree to which governments and non-state school service providers have a strong rapport is largely affected by a number of consistent factors. The state's features will undoubtedly have an impact on how well NSS are supported. These qualities include the country's capabilities and governmental will, the degree of democracy that affects electoral responsibility, and its political and economic thoughts. The ability and incentive of NSSs to develop as providers of services to disadvantaged populations will depend largely on stakeholder'. This may depend on how much the top and middle class are driven to raise the standard of living for those who are less fortunate. The extent to which government provision falls short of achieving Sustainable Development Goals will also have an impact on relationships, regardless of whether this is a general problem, a problem that only affects certain demographics, or primarily a problem with filling in quality gaps in government provision.

Recommendations

- For accountability, the government should work to ensure that all unregistered non-state schools are members of a recognized professional association of their choice. In addition, the association should actively engage the government on contextual basic education issues that relate to the needs of the schools' owners.
- The government should conduct a downward review of the current guidelines for non – state schools' registration in place to allow for more reasonably priced schools in the states.
- The contributions of non-state schools are invaluable, however, complimentary to the growth of education in the nation, the government must lower taxes on them. As a result, people from lower and intermediate income groups will have access to the schools.
- Non-state schools should be encouraged to establish effective School-Based Management Committees (SMBCs), Parent-Teacher Associations, and a Learners/Students Representative Council in accordance with regulations outlined in the National Education Quality Assurance Handbook for Basic and Secondary Education in Nigeria (2016). The associations of the non- state schools must also be autonomous and independent. All parents, students, and communities are empowered. When parents and children have knowledge about the relative quality of their schools, they can hold them accountable and use their voices to advocate to the government for higher-quality services.
- All key stakeholders such as community, religious heads, parents, government, and educational institutions must all play a significant role in

the pursuit for high-quality service provision that can improve the quality of educational development. Legislation imposing punitive measures must be in place, such as revocation of a school's operating license for non-state schools caught in violating laws.

- Depending on the classification, the government should provide non-state schools with subvention-grants and some subsidies. Additionally, the government should support a dynamic policy framework for non-state school providers so they can leverage resources and increase access and quality of education for the underprivileged.
- In particular, the government ought to provide visual aids, hearing aids, etc. to non-state schools to encourage the launch of fully inclusive basic education; all these facilities and infrastructure should be in place. They should also establish benchmarks that will determine the standard of education that should be offered to the public.
- To ensure proper delivery and long-lasting positive effects of inclusive basic education for children with disabilities in non-state schools, governments should establish a support fund for the implementation of inclusive education methods.
- State Ministries of Education should put in place an enabling policy environment to achieve a gender responsive and inclusive education system that improves participation and quality outcomes for all and aiming to improve planning and management using a gender equality and social inclusion lens as well as creating an enabling environment for improved access to rights, assets and services.
- State Ministries and agencies in charge of regulating non-state schools should support market entry of new private schools by easing criteria for school registration. Ease registration criteria for private schools. By facilitating the market entry of a more diverse set of providers, governments can increase their responsibility for results, as providers subsequently become directly accountable to citizens and the state. To do so, a conducive regulatory environment is needed to promote a diversity of supply.
- Provision of information availability for parents and provide financial support to families whose children attend private schools Increase information provided to parents. Based on its current policies, KKJ States could increase the information provided to parents on school quality. State governments ought not be the only monitors of school performance. Access to comparative information could enable parents and students to influence school quality through increased choice and direct voice to providers. School report cards, for example, can provide information in one place and allow parents to easily compare schools in their area. State Accountability mechanisms in the three states should be strengthened to provide independent assessment of these schools and also act as their voice to governments.

- State Ministries of Education should ensure that private and IQTE schools establish and maintain an environment where pupils feel safe and secure and are encouraged to talk and are listened to.
- Free in-service training should be available to instructors in private schools. Due to their schools' inability to pay for it, most teachers at unregistered or affordable schools lack access to in-service training. This needs to be viewed as a component of the government's effort to invest in the future of Nigerian children.
- The government should be dedicated to integrating Tsangaya non-state schools with Islamic Quranic institutions. For stakeholders to conclude that IQT non-state schools are expressing a wish to be included in the basic education curriculum, they must consider the evidence provided by the baseline.
- Lastly, to realize inclusive education in Nigeria, it is expedient to identify potential approaches to improve the roles and duties of stakeholders. These stakeholders' engagement and collaboration are inevitable.

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Does Income Inequality endanger Green growth? Evidence from selected countries in the Global South countries.

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Abstract

Income inequality poses a constraint to inclusive growth and development, but whether and how economic inequality affects green growth is relatively understudied in the existing literature. Greater commitment to green growth by governments, academia, and relevant stakeholders necessitates addressing people's relative income distribution. However, the pathways in which economic inequality exacerbates environmental damage remain unclear. The analysis of the paper begins with theoretical perspectives on the diffusion of green growth technologies and how it relates to income inequality. This paper addresses these research gaps by employing the pooled mean group-autoregressive distribution lag (PMG-ARDL) and cross-sectional autoregressive distribution lag (CS-ARDL) for robustness tests on panel data from the Global South from 1991 to 2019. The results show that higher income inequality is associated with reduced green growth in the long run, whereas the short-run results are mixed. The findings suggest that governments in the Global South should implement effective reforms aimed at lowering inequality while reducing carbon emissions and promoting a green economy.

Keywords: Income inequality, green Growth, CO₂ emissions, Climate change, Global South

JEL: P46, Q43, Q55

1. Introduction

The interaction between the environment and the economy has recently garnered much attention (Stern, 2008), which has important implications for inclusive development and poverty reduction in the Global South. These are critical to attaining the Sustainable Development Goals (SDGs) 2030. In the quest to green the economy, inequality is at the centre stage of economic policy debate across the globe. A 'fair share' in income distribution is fundamental to 'going green'. Efficient production practices (output-input ratio) across countries and businesses can influence productivity levels and Growth (Syverson, 2011). However, developing economies in the global South rely more on exploiting the environment's natural resources. At the same time, these countries are inaccessible to green technologies. This has proven difficult to account for both environment-related inputs (e.g., use of natural resources) and environment-related outputs (e.g., air pollution). Recent studies have linked economic inequalities with environmental problems (Khan et al., 2022; Langnel et al., 2021; Uzar & Eyuboglu, 2019). The Organization for Economic Co-operation and Development (OECD) has estimated a measure of productivity growth that accounts for the generation of a small set of greenhouse gases (GHGs) and criteria air contaminants (CACs) that cause environmental damages from economic activity. The works of Brandt et al. (2014), Dang and Mourougane (2014), and Cárdenas Rodríguez et al. (2018) have provided a roadmap that allows environmentally adjusted multifactor productivity (EAMFP) growth to be calculated in a growth accounting framework.

Several theoretical approaches have been presented to question whether green growth, as a policy solution to climate change and environmental concerns, may help to reduce income disparities. For example, government intervention, such as progressive taxes and income transfers, may ameliorate income inequality, and green development can only be realised through public investment in renewable energy and energy efficiency (Duraiappah, 1998). Similarly, O'Neill (2020) contends that the dominance of corporations and the rich, who frequently have a strong interest in sustaining the status quo, can limit government action. Income inequality is caused by unequal distribution of natural resources, according to ecological economists, and green growth can only be attained through a massive overhaul of the market structure, including the adaptation of a green new deal and the progress of alternative forms of ownership, such as microcredit and commons-based peer production (Kallis, 2011). Furthermore, Hickel and Kallis (2020) believe that even under favourable policy conditions, the rate of CO₂ emission reductions required to prevent global warming of more than 1.5 °C or 2 °C is highly unlikely. On the other hand, transitioning to green growth has the potential to create 24 million new jobs globally by 2030 if appropriate policies are adopted (ILO, 2018), as well as reduce poverty among low-income households.

Previous empirical research has concentrated on environmental technologies and green Growth (Danish & Ulucak, 2020), technological diffusion and green growth (Wang et al., 2021), environmental entrepreneurship and green development (Wei et al., 2023), innovation technology efficiency and green Growth (Mensah et al., 2019; Zhang & Vigne, 2021; Zhang et al., 2018), and financial development and green Growth (Chen et al., 2023). However, only a few studies focused on economic inequality (Fiorino, 2018; Napolitano et al., 2022; UNEP, 2016). According to a study conducted by the United Nations Environment Programme (UNEP, 2016), green growth can help to reduce economic disparities by creating new green jobs and boosting low-income households' access to clean energy and energy efficiency. Considering all of the preceding points, the extant literature produces mixed results due to their complexity.

Does income inequality endanger green growth? In this paper, data on the EAMFP and environmental innovation were sourced from the OECD database, income inequality from the Standardized World Income Inequality Database (SWIID), financial development from the KOF Swiss database, general government final consumption expenditure from the World Bank's World Development Indicators, and educational attainment from the Barro & Lee database. This paper employs the PMG-ARDL model for the baseline estimation and the CS-ARDL model for robustness checks. A novel battery of tests to examine the cross-dependence, panel unit roots, and cointegration among variables in the sampled group of countries.

We find that rising income inequality is negatively associated with green growth. The results of the PMG-ARDL model suggest that addressing income inequality is crucial for cutting down carbon emissions and fostering a green economy. Further, the coefficients for environmental innovation are positively and statistically significantly linked to green growth, suggesting that countries in the Global South can develop new solutions and technologies that help mitigate environmental damage by investing in and promoting environmental innovation. In terms of the country-specific models, coefficient estimates show that a 0.1%-point increase in income inequality reduces green growth by 0.002% in Brazil and Costa Rica, 0.001% in Colombia, 0.003% in China, 0.004% in India and South Africa, and 0.005% in Indonesia in the long run. These results are similar to those reported in the robustness checks (CS-ARDL model), and the computed coefficients for the ECT are negative and statistically significant at the 1% level for both model results. Similarly, this paper reveals three possible ways of Granger causation (unidirectional, bidirectional, and no-causality) for the effects of income inequality on green growth.

This paper contributes to the literature on the relationship between income inequality and green growth in the Global South. Several studies have been conducted to investigate whether and how income inequality affects the green economy (Boyce, 1994; Danish & Ulucak, 2020; Fiorino, 2018; Heerink et al.,

2001; Mensah et al., 2019; Napolitano et al., 2022; UNEP, 2016; Wang et al., 2021; Zhang et al., 2018), all either concentrated on green technology innovation or the diffusion of technologies in one or a few countries. Others were concerned with environmental entrepreneurship and financial development (Cao et al., 2022; Chen et al., 2023; Wei et al., 2023). Compared to these previous measures, green growth captures other significant indicators, such as the efficient use of natural resources. Further green growth measures the balance between economic development and environmental sustainability (Tawiah et al. 2021). Our measure of green growth is not one-sided, as used in prior studies. This paper distinguishes itself from the others by investigating how income inequality affects green Growth in Global South economies using the OECD's green growth measurement. Although similar in spirit to the studies of Fiorino (2018) and UNEP (2016), this paper differs in using novel methodological investigation.

Given the lack of consensus among theoretical and empirical studies on the relationship between income inequality and green growth, this paper contributes to a better understanding of these complex issues. The transition to a green economy is about more than just lowering carbon emissions and safeguarding the environment; it is about providing inclusive economic opportunities and encouraging energy independence. Green energy accessibility and consumption are very unequally distributed across the Global South, with low-income households meeting their energy demands using firewood and charcoal and facing an increasing price of some of these green energies. This condition has hindered some consumers from transitioning to cleaner energy and increases the risk of increasing inequality. Green growth policies can have either negative or positive societal consequences depending on how they are designed and implemented. For example, when a policy gives economic support to lower-income households, lowering poverty benefits higher-income households even more by allowing them to take advantage of the direct benefits of green growth policy incentives more easily, widening the wealth gap. Finally, this paper discusses policy implications for Global South policymakers and private-sector enterprises. The findings could help them focus more on appropriate climate financing measures, equal access to resources and opportunities, green incentives for the private sector, enabling access to education, and considering progressive tax policies, all of which are important factors in the race to a green economy.

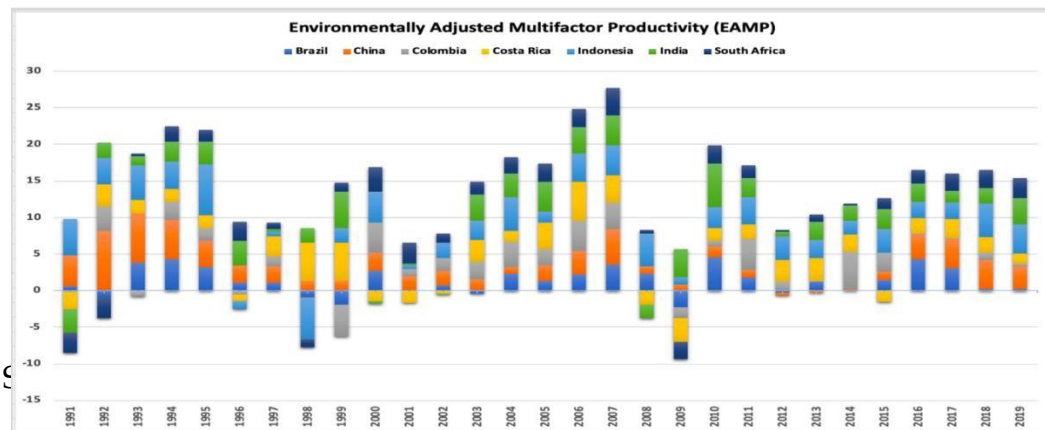
The following is a reminder of this paper. Section 2 presents the background to income inequality and green growth. Section 3 discusses theoretical perspectives and related empirical literature. Section 4 describes the data sources, summary descriptions, and econometric specifications. Section 5 presents the results and discussions. Section 6 concludes with policy implications.

2. Background to inequality and green growth

The EAMFP measures a country's ability to produce more income using a given set of inputs, such as domestic natural resources while accounting for the undesirable by-products of pollution (Cárdenas Rodríguez et al., 2018). According to the OECD (2023), EAMFP compares multifactor productivity (MFP) more accurately in measuring and evaluating an economy's growth quality, as natural resources and the environment become a harder constraint on economic growth. Several factors, such as technological improvements-oriented production of good outputs and transitioning towards cleaner technologies, human capital enhancement, strong and efficient institutions, and comparative advantage of economies of scale, can play a huge role in productivity. However, the undesirable outputs consist of emissions of greenhouse gases (GHGs), which induce climate change and constitute environmental problems.

Figure 1 presents EAMFP growth in seven Global South economies (Brazil, China, Colombia, Costa Rica, Indonesia, India, and South Africa) from 1991 to 2019 using the OECD database. Compared to the rest of the countries, China has consistently assessed an economy's productivity performance while considering the effects of environmental degradation. However, China was responsible for 32.9% of global CO₂ emissions (EU, 2021).

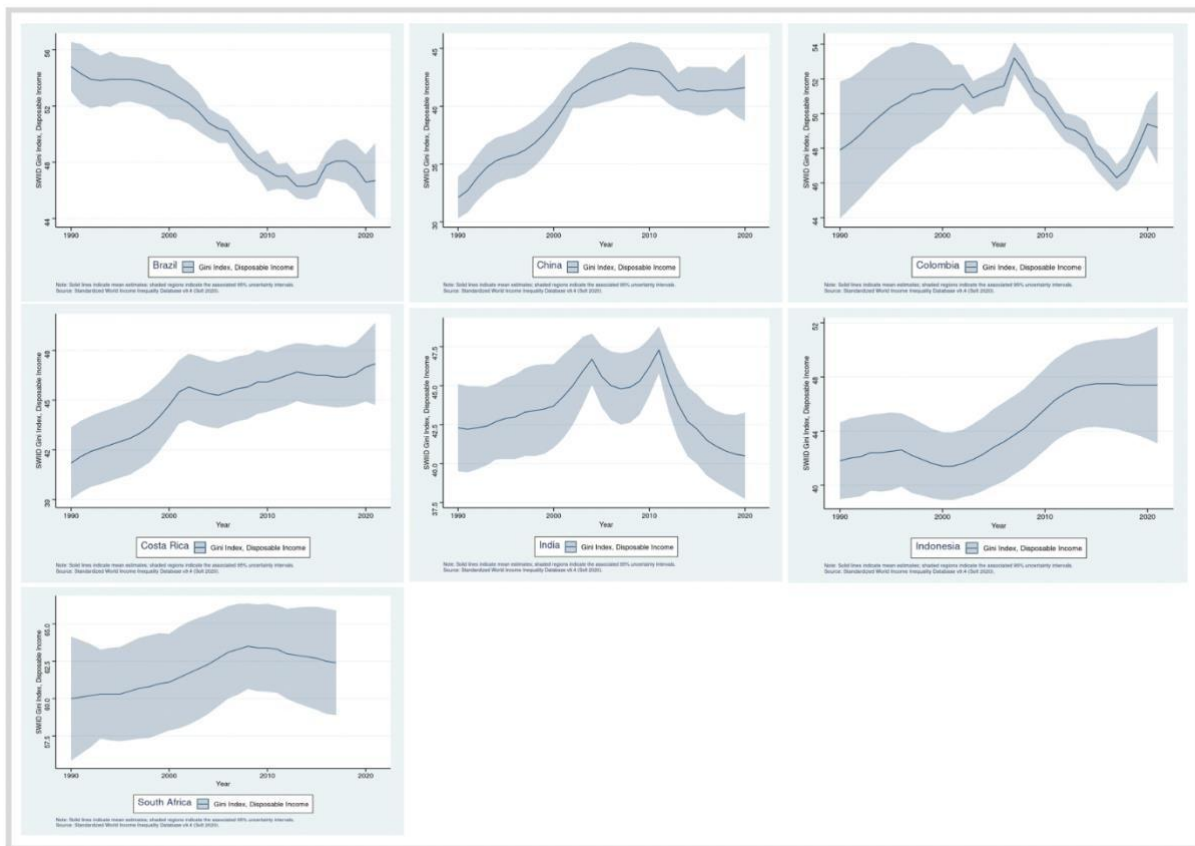
Figure 1: Trend of Environmentally Adjusted Multifactor Productivity Growth (EAMFP) in selected Global South countries (1991-2019)



Despite global attempts to lift millions out of poverty, the gap between the "haves" and "have-nots" is growing. Inequalities in the Global South have many faces when compared to the Global North, such as lack of access to opportunities, healthcare, Education, water, food, and basic infrastructure—all of which render poorer households more vulnerable to natural disasters and climate change. For example, 40% of the poorest South Africans' annual salary is less than US\$1,000 per person, compared to US\$39,000 per person income for the Global North's top 10% in 2017 (Gradin et al., 2021). Regarding income

inequality, as shown in Figure 2, the percentage of poor individuals has decreased in Brazil and India during the last decade. China, Indonesia, and South Africa, on the other hand, are steadily declining. Income inequality can have a negative impact on green growth by limiting poorer households' access to resources and opportunities. Low-income households, for example, may lack the financial ability to invest in environmentally beneficial technologies such as renewable energy systems or energy-efficient appliances. As a result, these households' ability to engage in a low-carbon and green economy is limited

Figure 2: Trends in income inequality in selected Global South countries



Green Growth, or the green economy, has dominated development and environmental economics in recent years. This was the biggest concern of the 2012 Rio+20 Conference on Sustainable Development. Many governments worldwide consider green growth as an overwhelmingly dominant policy response to increasingly urgent warnings about climate change and ecological concerns (Dale et al., 2016). However, few studies link income inequality to green growth. This linkage is also understudied in other parts of the world, with most studies focusing on environmental sustainability. This section

provides a brief theoretical basis and related empirical literature and tests two hypotheses.

3.1 Theoretical explanation

Green Growth is synonymous with a low-carbon or green economy that is both environmentally sustainable and socially inclusive. The OECD (2001) defines green growth as "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (p.18). There have been several theories put forward to explain these two concepts. Academia has shaped theoretical views on the link between income inequality and green growth, including neoclassical, Keynesian, and ecological economics. Income inequality is caused by market forces, according to neoclassical economists, and green growth can only be achieved by market-based solutions such as carbon tax and carbon trading (Stiglitz, 2012). According to this theory, markets can absorb environmental costs and drive businesses to implement more sustainability measures, reducing economic disparities. Other schools of thought, however, stated that market-based remedies primarily benefit the wealthy while neglecting the poor and are insufficient to address the core causes of environmental degradation and social exclusion (O'Neill, 2020). On the other hand, they include the OECD, the United Nations Environment Programme (UNEP), and the World Bank.

Conversely, Keynesians believe that government intervention, such as progressive taxation and income transfers, may alleviate income inequality and that green development can only be realised by public spending on renewable energy and energy efficiency (Duraiappah, 1998). This school of view claims that government intervention can help produce a more equitable income distribution and that public investment can help overcome market failures and provide the infrastructure needed for green growth. Some critics, however, argue that the influence of corporations and the wealthy, frequently vested in maintaining the status quo, can constrain government action (O'Neill, 2020). Income inequality, according to ecological economists, is caused by the unequal distribution of natural resources, and green growth can only be achieved through a significant overhaul of the market structure, including the adoption of a green new deal and the advancement of alternative forms of ownership, such as microfinance institutions and commons-based peer production (Kallis, 2011). They believe that the current economic system, based on the extraction of natural resources and the accumulation of private wealth, is the fundamental cause of income inequality and environmental degradation. The economic system must be significantly restructured to achieve green development and eradicate wealth disparities.

From institutional viewpoints (the OECD, the United Nations Environment Programme (UNEP), and the World Bank), technological change and substitution advances will increase the economy's ecological efficiency, and government should accelerate the formulation of appropriate regulations and incentives. Transitioning to green growth could generate 24 million new employment globally by 2030 if the appropriate policies are implemented (ILO, 2018) and reduce poverty among low-income households. Although China and India have experienced relative decoupling (Wiedmann et al., 2015), there is little indication of persistent absolute decoupling of GDP in South Africa (Hickel & Kallis, 2020). One persistent debate is that green growth necessitates a shift toward cleaner, more sustainable energy systems – a type of decoupling of economic growth from resource use and its negative environmental consequences. Because economic progress in the form of GDP is compatible with the planet's ecology, green growth theorists assume absolute decoupling of GDP growth from resource utilisation and carbon emissions at a rate sufficient to prevent climate change and other ecological concerns (see Solow, 1973). To that end, Stern's (2008) seminar work has consistently made a case for incorporating environmental problems into economic activity, arguing that firm and timely actions can avoid the economic costs of delaying decisions on climate change and environmental challenges.

3.2 Empirical literature

Following the theoretical views, many previous studies have used empirical data to focus on environmental technologies and green Growth (Danish & Ulucak, 2020), technological diffusion and green Growth (Wang et al., 2021), environmental entrepreneurship and green development (Wei et al., 2023), innovation technology efficiency and green growth (Mensah et al., 2019; Zhang & Vigne, 2021; Zhang et al., 2018) and financial development and green Growth (Cao et al., 2022; Chen et al., 2023), but few have looked at inequality and environment (Boyce, 1994; Heerink et al., 2001), green innovation and inequality (Napolitano et al., 2022), and green economy and inequality (Fiorino, 2018; UNEP, 2016). Green Growth, for example, might assist in reducing economic disparities by creating new green jobs and boosting low-income households' access to clean energy and energy efficiency, according to a study conducted by the United Nations Environment Programme (UNEP, 2016). Greener societies are more economically equitable, but excessive economic inequality fosters social mistrust and isolation, undermining the ability to collectively value public assets (Fiorino, 2018).

In contrast, Napolitano et al. (2022) show that inequality harms countries' ability to create complex green technology. Excessive economic inequality can impede green growth by reducing the market for environmentally sustainable goods and limiting authorities' opportunity to invest in renewable energy and energy efficiency. Similarly, large income disparities may reduce the purchasing power of low-income households, restricting them from spending

on renewable energy and energy-efficient technologies. Aghion et al. (2019) confirm a similar finding by looking at the distribution of labour and firm owners and the rate of technology innovation. They observe that technological innovation promotes entrepreneurship while increasing income inequality.

Additionally, high levels of economic inequality may impede political will to invest in sustainable innovation because the wealthy and businesses hold more power over government policy and are more inclined to resist government intervention. As a result, there is a trade-off between increased social expenses of green growth and poverty-reduction growth (Dercon, 2012), and government should evaluate environmental policies and huge promises of obvious benefits at little or no cost (Schmalensee, 2012). Understanding the potential trade-off between sustainability and social fairness in fostering green growth in the Global South is important. The relationship between income inequality and green growth is complex. While different theoretical perspectives provide different approaches, it is widely accepted that reducing economic inequality and boosting green growth are complementary and interrelated goals that must be addressed simultaneously to ensure sustainable development.

Based on the preceding literature review, we put forward the following hypotheses.

H1. An increase in income inequality reduces green growth

4. Data and methodology

4.1 Data sources and descriptive statistics

This study uses panel data from seven Global South countries (China, Colombia, Costa Rica, India, Indonesia, and South Africa). Based on data availability, these countries were carefully selected. Data on the EAMFP (measured as green growth) were obtained from the OECD (2023) database, Income Inequality (as measured by the Gini index) from the Standardized World Income Inequality Database (SWIID), Environmental Innovation (as measured by the development of environment-related technologies) from the OECD database, Financial Development from the KOF Swiss database, General Government Final Consumption Expenditure from the World Bank's World Development Indicators, and Educational Attainment from the Barro & Lee database.

Table 1 shows the descriptive statistics for the model's dependent and explanatory variables, which were used to investigate whether income inequality harms green growth in the Global South's economies. These variables came from various sources. Green Growth in this study has an average value of 7.8%, with the maximum value being 14.2% and the minimum value being 0.3%, with a standard deviation of 2%. The Gini index, on the other hand, has a mean value of 13%, with maximum and minimum values of 47.5% and 0.30%,

respectively. The average value of environmental innovation is 10.4%, with a maximum of 42.9%, a minimum of 2.3%, and a standard deviation of 10.4%. Furthermore, the pairwise correlation matrix is shown in Table A6 (appendix), and this study ensures that it does not exceed generally utilised standards (0.7). The variable definitions and descriptive statistics are listed below.

Table 1: Variable definitions and descriptive statistics

Variable	Definitions	Mean	Std. Dev.	Min	Max	Sources
GG	Environmentally adjusted multifactor productivity	7.86	2.09	0.38	14.20	OECD
GN	Income inequality	13.44	19.55	0.30	47.50	SWIID
EI	Development of environment-related technologies (% of all technologies)	10.42	5.20	2.32	42.92	OECD
FD	Financial globalisation index	45.28	11.60	16.84	76.42	KOF Swi
GovSpend	General government final consumption expenditure (% of GDP)	14.45	3.72	5.69	22.16	WDI
EDU	Educational attainment	24.30	11.28	1.88	63.76	Barro & L

Note: OECD computed EAMFP as a percentage change over time by comparing the performance of different nations.

4.2 Econometric model

From a theoretical standpoint, income inequality could have a negative or positive effect on green growth, depending on the trade-off between sustainable environmental policies and addressing the issues of social inequities (Hickel & Kallis, 2020; O'Neill, 2020). Following Sun (2022) and Kousar et al. (2022), the model is expressed as follows:

$$GGit = \beta_0 + \beta_1 GINIit + \beta_2 EIit + \beta_3 FDIit + \beta_4 GovSpendit + \beta_5 Eduit + \varepsilon it \quad (1)$$

where $GGit$ is the dependent variable; $GINIit$ represents income inequality; $EIit$ denotes environmental innovation; $FDit$ is the financial development; $GovSpendit$ and $Eduit$ represent government spending and educational attainment, respectively; and εit is the error term. Equation (1) presents only the long-run estimates.

To capture both the long-run and short-run estimates, the PMG-ARDL model introduced by Pesaran et al. (1999) is specified as follows in error correction form:

$$\begin{aligned}
\Delta GG_{it} = & \beta_0 + \sum_{i=1}^p \pi_{1k} \Delta GG_{it-i} + \sum_{i=1}^p \pi_{1k} \Delta GINI_{it-i} + \sum_{i=1}^p \pi_{1k} \Delta EI_{it-i} + \sum_{i=1}^p \pi_{1k} \Delta FD_{it-i} \\
& + \sum_{i=1}^p \pi_{1k} \Delta GovSpend_{it-i} + \sum_{i=1}^p \pi_{1k} \Delta Edu_{it-i} + \beta_1 GINI_{it-1} + \beta_2 EI_{it-1} + \beta_3 FD_{it-1} \\
& + \beta_4 GovSpend_{it-1} + \beta_5 Edu_{it-1} + \eta_t ECM_{t-1} + \varepsilon_{it}
\end{aligned} \tag{2}$$

In addition to the panel PMG-ARDL model, the CS-ARDL model proposed by Chudik and Pesaran (2015) is used as a robustness check. This augmented ARDL model captures cross-sectional correlation in the error term by using a linear combination of cross-sectional averages and all regressors. As in Chudik and Pesaran (2015), the CS-ARDL is estimated using both mean group (MG) and PMG-ARDL estimators. The following is the model's specification:

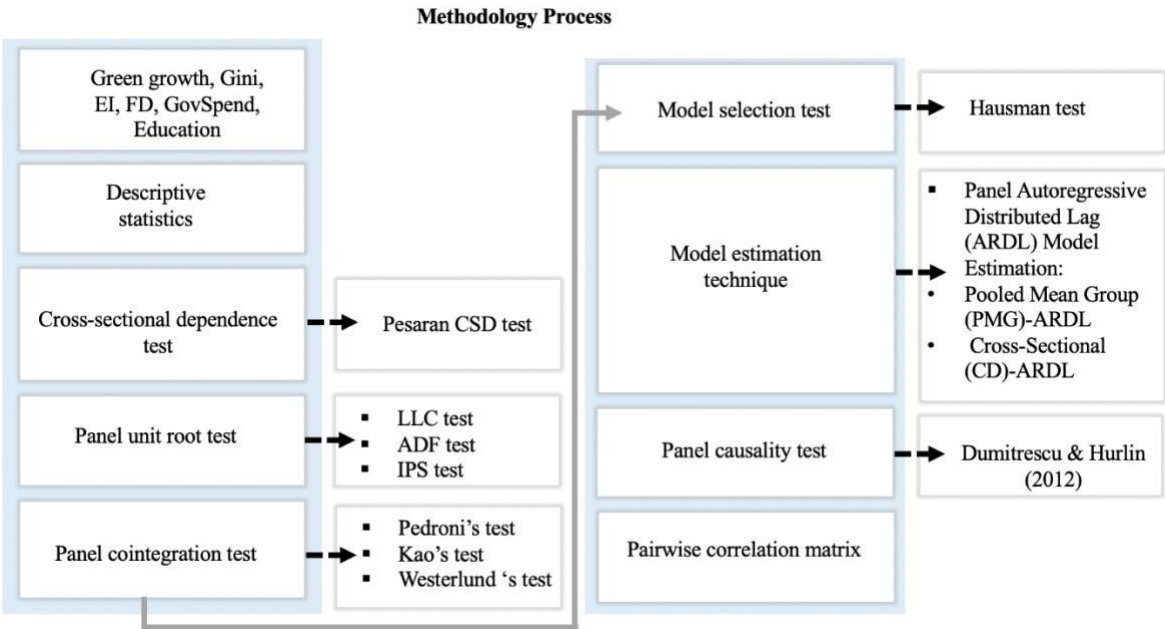
$$\begin{aligned}
\Delta GG_{it} = & \varphi_0 + \gamma_{it}(GG_{it-1} - \beta_i X_{it-1} - Y_i C_{it-1} - \phi_{1i} GG_{it-1} - \theta_2 \bar{X}_{t-1} - \rho_2 \bar{\epsilon}_{t-1}) + \sum_{j=1}^{p-1} \phi_{ij} \Delta GG_{it-j} \\
& + \sum_{i=1}^{q-0} \zeta_{ij} \Delta X_{it-j} + \sum_{i=1}^{q-1} \pi_{1k} \Delta C_{it-j} + \omega_{1it} \Delta GG_{it} + \omega_{2it} \bar{\Delta X} + \omega_{3it} \bar{\Delta \epsilon} + \varepsilon_{it}
\end{aligned} \tag{3}$$

where $\bar{X}$ and $\bar{C}$ are the cross-section average of GG_{it} and X_{it} . The CS-ARDL assists in jointly handling the dynamics, heterogeneity, and cross-sectional dependency in data that requires the estimation of heterogeneous coefficients (see Eberhardt & Presbitero, 2015; McNabb, 2018). It is critical to emphasise that the time dimension (T) must be large enough to allow the model to be assessed across every cross-country unit, and a considerable number of lagged cross-section averages may be added to validate the estimators. These estimators have been used in various empirical growth studies due to their consistency and effectiveness (De V. Cavalcanti et al., 2015; Samargandi et al., 2015).

The first step in the panel ARDL approach is determining whether the variables have a long-run correlation. Specifically, the null hypothesis of no cointegration ($H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$) is assessed using an F-test against the alternative hypothesis ($H_0 : \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq 0$) using an F-test. After that, the computed F-statistics are compared to two sets of critical values: upper and lower (Pesaran et al., 2001). The null hypothesis can be rejected if the computed F-statistics are more than (less than) the upper (lower) critical value, confirming the existence (absence) of the long-run relationship. For this reason, this study investigates the time series properties of the order of integration. This is required to determine whether the variables are stationary at order I(0), I(1), or both. Following that, the Hausmann test was used to choose an ARDL model based on the model selection criteria used to estimate the short- and long-run models. The panel ARDL evaluates both short- and long-run impacts at the same time. The long-run effects are derived from $\beta_2 - \beta_5$, by normalising β_1 ,

but the short-run effects in Equation (2) are established by first-differenced signs, as this technique considers endogeneity and serial correlation. The methodological approaches used in this investigation are shown in Chart 1.

Chart 1: Methodological framework in this study.



Source: Author’s construction

5. Results and discussion

5.1 Preliminary tests

Some preliminary tests, such as cross-sectional dependence, unit root, and cointegration, must be conducted before proceeding with the model estimate (Choi, 2022). The results of the proposed cross-sectional dependence test are presented in Table 1(Pesaran, 2015). The estimates show that the variables are interdependent and statistically significant at the 1% level. Consequently, the null hypothesis of no cointegration is rejected. Any shocks in one economy will almost surely affect the others in the sampled group. The unit root tests are then run, and the results are displayed in Table 2. This study employs the Levin, Lin, and Chu (LLC), Augmented Dickey-Fuller (ADF), and Im, Pesaran, and Shin (IPS) tests. For example, the LLC unit root test results demonstrate that Green Growth, ENVINNO, FINDEV, GOVSpend, and Education are stationary at order $I(0)$, whereas Gini is stationary at order $I(1)$. However, ADF and IPS follow the same pattern of Green Growth and GOVSpend stationarity at the order $I(0)$, whereas Gini, ENVINNO, and FINDEV are stationary at $I(1)$.

Furthermore, after assessing the data series' stationarity properties, the LLC, ADF, and IPS are utilised to test the long-run cointegration relationship between green growth and its drivers. Table 3 (Panel1-3) shows the results of the panel cointegration tests, demonstrating that the null hypothesis is rejected and that long-run cointegration exists among some of the variables in the model. The findings of the Westerlund panel cointegration test with constant and trend, for example, show evidence of rejecting the null hypothesis for Gt , Pt , and Pa tests statistics, indicating a cointegration relationship in at least a few cross-sectional units (i.e., in at least one group) (Westerlund, 2007). Because there are indications of mixed order of integration, the findings highlight an important conclusion for adopting the approach to assess cointegrating relationships. This investigation considers a second-generation cointegration test with mixed and strict integration orders. Given the cross-sectional dependency and unit root results, the next step is to focus on and analyse the long-run model using a robust estimator that can accommodate cross-sectional dependency, given the variables' stationarity.

Table 1: Cross-sectional dependence.

VARIABLES	GG	GN	EI	FD	GS	ED
Pesaran (2004) test	3.99***	4.160***	6.912***	4.736***	3.36***	5.173***
Prob.	0.000	0.000	0.000	0.000	0.001	0.000
Off-diagonal elements	0.202	0.357	0.478	0.306	0.353	0.416

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 2: Panel unit root test.

VARIABLES	ADF			IPS		
	I(0)	I(1)	Decision	I(0)	I(1)	Decision
Green Growth	-		I(0)	-		I(0)
Gini	6.670***		I(1)	8.532***		I(1)
	4.020	-		3.583	-	
				4.850***		
ENVINNO		3.522***				
	-1.567*		I(0)	-0.514	-	I(1)
FINDEV				6.224***		
	-		I(0)	-1.106	-	I(1)
	2.878***			6.362***		
GOVSpnd	-1.972**		I(0)	-1.501*		I(0)
Education	-2.124**		I(0)	3.601	-3.524**	I(1)
						2.574***

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3: Panel cointegration tests

Panel A:		
Pedroni (2004)'s Estimates		
CG = f(GG, GN, EI, FD, GS, EDU)	Statistics	Prob.
Modified Phillips-Perron t	1.848**	0.032 ^b
Phillips-Perron t	-5.415***	0.000 ^a
Augmented Dickey-Fuller t	-5.391***	0.000 ^a
Panel B:		
Kao's Estimates		
CG = f(GG, GN, EI, FD, GS, EDU)	Statistics	Prob.
Modified Dickey-Fuller t	-6.524***	0.000 ^a
Dickey-Fuller t	-7.504***	0.000 ^a
Augmented Dickey-Fuller t	-6.665***	0.000 ^a
Unadjusted modified Dickey-Fuller t	-15.947***	0.000 ^a
Unadjusted Dickey-Fuller t	-9.761***	0.000 ^a

Note: In both panels, Pedroni and Kao procedures are estimated, *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Note: (a, and b) show a significance level of 1% and 5%, respectively.

Panel C: Westerluud panel cointegration test

Statistics	Gt	Ga	Pt	Pa
Value	-4.383***	-15.765-12.554***	-18.021**	
z-value	-4.822	-0.254-5.806	-2.129	
P-value	0.000	0.4000.000	0.017	

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

5.2 Empirical results

Table 4 presents the estimation results for the PMG-ARDL and CS-ARDL models. The long- run estimates based on the PMG-ARDL model in column 1

indicate that the coefficient on the error correction term (ECT) is statistically significant at the 1% level. This conclusion suggests that following a shock, the system regresses to its long-run values, showing that some variables are cointegrated. The main focus of this analysis is income inequality. According to the findings, rising income inequality reduces green growth. The coefficient is statistically significant at the 1% level, implying that every 0.1-point increase in income inequality reduces green growth by 0.038%. These findings are consistent with Hallegatte et al. (2012) and Kim et al. (2014).

Furthermore, environmental innovation is positively and statistically significantly associated with green growth at the 1% level, implying that a 0.1% increase in environmental innovation boosts green growth by 0.143%. These findings corroborate prior empirical work by Mensah et al. (2019), Zhang et al. (2018), and Danish and Ulucak (2020). In the long run, government spending and educational attainment have a positive and statistically significant impact on green growth at the 1% level, respectively. This means that long-term investment in research and development can lead to increased green growth. However, the short-run estimate gives mixed findings. However, utilising the third lag, income inequality continues to have a negative impact on green growth. High levels of income inequality can limit low-income households' purchasing power, as they may lack the funds for investment in renewable energy and energy-efficient technologies.

Moving on to the robustness checks in column 2, the estimates of the CS-ARDL model confirm the results reported from the baseline model in column 1. The computed coefficients for the ECT are negative and statistically significant at the 1% level. According to this specification, income inequality has a negative and significant impact on green growth at the 10% level, demonstrating the CS-ARDL consistency in detecting the cross-sectional correlation in the error term Chudik and Pesaran (2015). The findings show that a 0.1-point increase in income inequality leads to a decline in green growth in the sampled Global South countries in the long run.

Table 4: Panel estimation of green growth

Variables	(1)		(2)	
	Basic model PMG-ARDL Coefficient	t-Stat	Robustness model CS-ARDL Coefficient	z-Stat
Long-Run Equation				
GINI	-0.038***	-6.139	-0.002*	-1.97
ENVINNO	0.143***	3.662	0.017	1.50
FINDEV	0.963	0.912	-5.509	-1.01
GOVSpand	0.969***	5.364	-0.134	-0.60
Education	0.077***	2.798	0.145	0.56
Short-Run Equation				
$\Delta(\text{GINI})$	0.012	1.245	-0.001	-0.60
$\Delta(\text{GINI}(-1))$	0.002*	1.672	-0.004***	-3.74
$\Delta(\text{GINI}(-2))$	-0.003**	-2.143		
$\Delta(\text{ENVINNO})$	-0.019	-1.219	0.002	0.36
$\Delta(\text{ENVINNO}(-1))$	-0.018	-0.928	0.018	1.52
$\Delta(\text{ENVINNO}(-2))$	-0.012*	-1.804		
$\Delta(\text{FINDEV})$	0.967	0.146	-5.935	-0.99
$\Delta(\text{FINDEV}(-1))$	5.854*	1.775		
$\Delta(\text{FINDEV}(-2))$	-1.486	-0.400		
$\Delta(\text{GOVSpand})$	-0.710*	-1.831	-0.158	-0.56
$\Delta(\text{GOVSpand}(-1))$	-0.171	-0.238		
$\Delta(\text{GOVSpand}(-2))$	-1.348*	-1.772		
$\Delta(\text{Education})$	-0.153	-0.302	0.176	0.49
$\Delta(\text{Education}(-1))$	-0.080	-0.147		
$\Delta(\text{Education}(-2))$	0.715 □	0.796		
C	3.677***	2.706	2.362***	-12.59
ECM(-1)	-0.868***	-4.66	-0.381***	-5.12

Note: Column (1) indicates the estimation of PMG-ARDL, while column (2) provides the estimation of CS-ARDL. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 5 then presents the country-specific models. The PMG-ARDL model is the main model employed in this estimation. The negative sign linked with the ECT coefficient estimations indicates the convergence towards stability at the 1% level. The findings show that income inequality has a negative and statistically significant long-run impact on green growth in all of the selected countries of the Global South (at the 1%, 5%, and 10% levels). The coefficient estimates prove that a 0.1% increase in income inequality reduces green growth by 0.002% in Brazil and Costa Rica, 0.001% in Colombia, 0.003% in China, 0.004% in India and South Africa, and 0.005% in Indonesia in the long run. Similarly, the coefficient estimates in environmental innovation are positive and statistically significant (at the 1%, 5%, and 10% levels), implying that a 0.1%-point rise in environmental innovation enhances green growth by 0.003% in Brazil, 0.001% in China, 0.013 % in Colombia, 0.296% in Costa Rica, 0.012 % in India, 0.010% in Indonesia, and 0.010% in South Africa. As previously stated, these findings appear to give strong evidence of investment in environmental-related technologies that promote the green economy. This finding is consistent with Cao et al. (2022). The coefficients for control variables, notably financial development, government spending, and education, are somewhat comparable to those obtained in Table 4.

The short-run findings show a mixed result among the sampled countries. For example, even at different lagged levels, both the coefficients for environmental

innovation, financial development, government spending, and Education are positive and statistically significant (at the 1%, 5%, and 10% levels) on green growth. The estimated results, particularly for Indonesia, have been consistent. One likely reason is that the Indonesian government significantly reduced poverty by 10% in 2019 (World Bank, 2022) and moved toward net-zero emissions at a reduced cost (IRENA, 2018). Finally, the F-statistics coefficient estimates and the ECT corroborate the long-run cointegration relationship among the variables in all models of the selected group of Global South countries. Furthermore, in this investigation, the Ramsey and CUSUM tests confirm the model's exact specification and stability.

Table 6 estimated the statistical significance of the W-statistics and Z-bar-statistics using the pairwise Dumitrescu and Hurlin (2012) panel causality test. The W-statistic is primarily based on linear hypotheses integrating the average Wald statistics for independent variable coefficients for Granger causality. On the other hand, the Wald test's Z-bar depicts the standardised statistics under the Wald test's premise that they are separately and identically distributed among individuals. The findings reveal three different directions of Granger causation (unidirectional, bidirectional, and no-causality) for the effects of income disparity on green growth. The model estimation demonstrates that Gini and environmental innovation have a unidirectional causal effect on green growth; the financial development granger caused Gini unidirectionally; the government spending granger caused Gini bi-directionally; and Gini, financial development, and Education granger caused environmental innovation unidirectionally. Therefore, the mixed findings are especially useful for policymakers in the Global South who are trying approaches to boost the green economy.

Table 5: Country-specific estimates of green growth

Variables	Brazil		China		Colombia		Costa Rica		India		Indonesia		South Africa	
	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Long-Run Equation														
GINI	-0.002*	-2.043	-0.003**	-3.530	-0.001**	-2.631	-0.002*	-1.607	-0.004*	-1.516	-0.005***	-4.621	-0.004*	-3.509
ENVINNO	0.003**	2.762	0.001***	4.681	0.013**	3.710	0.296*	2.330	0.012*	0.420	0.010**	2.939	0.022**	1.682
FINDEV	3.093*	2.017	2.092	3.882	-0.847	1.513	0.099	0.015	0.666	0.032	1.739***	5.257	0.016*	2.115
GOV.Spend	0.417*	1.093	0.578*	2.194	0.446**	2.238	1.288*	2.283	0.880*	2.107	0.682**	3.008	1.096*	3.750
Education	0.354***	5.152	0.435**	3.430	0.025	1.228	2.403**	3.752	1.639**	2.203	2.094***	4.941	0.018	0.408
Short-Run Equation														
$\Delta(\text{GINI})$	-0.005***	-6.223	0.013**	3.324	0.079*	4.024	0.003	1.261	-0.028**	1.783	0.015**	3.799	0.009**	3.529
$\Delta(\text{GINI}(-1))$	0.001	1.392	0.024*	2.411	1.049	3.236	-0.003	-1.583	0.020*	-1.203	0.007*	2.340	0.002	2.675
$\Delta(\text{ENVINNO})$	0.004***	3.614	0.243***	4.960	0.106**	3.984	0.019	0.136	0.007**	0.402	0.015*	1.282	0.020**	1.466
$\Delta(\text{ENVINNO}(-1))$	-0.002	-1.176	0.180**	3.520	0.110*	2.452	-0.041	-0.412	-0.041	-0.412	-0.056	-1.573	0.017**	2.745
$\Delta(\text{FINDEV})$	0.367*	1.146	2.378**	3.990	1.264**	3.590	1.782	3.757	1.430	2.757	0.291**	2.334	0.979**	1.787
$\Delta(\text{FINDEV}(-1))$	0.654*	1.775	1.193*	2.922	0.302*	1.712	0.429	2.305			1.529*	2.501		
$\Delta(\text{GOV.Spend})$	1.824***	3.952	0.091	0.341	0.231	1.631	1.076**	3.149	0.328***	3.583	2.540**	1.639	0.848*	1.931
$\Delta(\text{GOV.Spend}(-1))$	0.613**	4.103	0.719*	2.552	0.023*	3.110	1.033	3.642	0.518**	3.902			0.460	1.527
$\Delta(\text{Education})$	0.354***	1.785	0.475*	2.193	0.136*	2.710	0.478*	2.571	0.950***	1.692	0.896**	3.955	0.187	1.890
$\Delta(\text{Education}(-1))$			0.300	0.434										
C	4.151*	1.588	2.362***	7.049*	3.924***	2.049*	1.478***	3.049*	3.682***	2.418*	1.478***	3.049*	3.682***	2.418*
Diagnostics														
F-test	6.129***		7.075***		5.751***		11.943***		8.848***		9.316***		5.271***	
ECM(-1)	-1.470***	6.31	-0.771***	5.12	-1.666***	6.23	-1.106***	5.33	-0.780***	4.82	-1.966***	6.04	-0.674***	7.24
LM	0.357		0.408		0.376		0.363		0.446		0.598		0.682	
RESET	0.414		0.229		0.125		0.407		0.294		0.281		0.378	
S			S		S		S		S		S		S	
CUSUM														
CUSUM-sq														

Table 6: Pairwise Dumitrescu and Hurlin (2012) Panel Causality Test Results

Null hypothesis	W-Stat.	Zbar-Stat.	p-value	Direction of causality
GINI $\approx$ Green Growth	6.288	11.321	0.016	GINI $\square$ Green Growth
Green growth $\approx$ GINI	4.891	7.279	0.263	
ENVINNO $\approx$ Green growth	3.328	4.035	0.042	ENVINNO $\square$ Green Growth
Green growth $\approx$ ENVINNO	4.524	5.735	0.462	
FINDEV $\approx$ Green growth	3.128	5.165	0.243	Green growth $\neq$ FINDEV
Green growth $\approx$ FINDEV	3.646	4.573	0.115	
GOVSpend $\approx$ Green growth	5.163	3.039	0.168	Green growth $\neq$ GOVSpend
Green growth $\approx$ GOVSpend	3.044	4.169	0.265	
Education $\approx$ Green growth	4.456	5.808	0.218	Education $\neq$ Green growth
Green growth $\approx$ Education	5.605	4.646	0.117	
ENVINNO $\approx$ GINI	3.476	3.388	0.165	GINI $\square$ ENVINNO
GINI $\approx$ ENVINNO	5.162	3.222	0.001	
FINDEV $\approx$ GINI	3.908	3.858	0.053	FINDEV $\square$ GINI
GINI $\approx$ FINDEV	3.376	4.279	0.200	
GOVSpend $\approx$ GINI	3.912	3.862	0.052	GINI $\sqsubset$ GOVSpend
GINI $\approx$ GOVSpend	4.511	3.515	0.011	
Education $\approx$ GINI	7.071	5.299	0.351	GINI $\neq$ Education
GINI $\approx$ Education	4.081	3.128	0.297	
FINDEV $\approx$ ENVINNO	5.403	4.221	0.054	ENVINNO $\square$ FINDEV
ENVINNO $\approx$ FINDEV	4.652	3.683	0.092	
GOVSpend $\approx$ ENVINNO	6.908	11.317	0.012	ENVINNO $\square$ GOVSpend
ENVINNO $\approx$ GOVSpend	4.867	3.813	0.069	
Education $\approx$ ENVINNO	5.893	4.842	0.055	Education $\square$ ENVINNO
ENVINNO $\approx$ Education	4.621	3.629	0.129	
GOVSpend $\approx$ FINDEV	4.340	4.153	0.218	FINDEV $\square$ GOVSpend

FINDEV $\approx$ GOVSpend	7.983	3.940	0.052	
Education $\approx$ FINDEV	4.633	3.647	0.008	Education $\square$
FINDEV $\approx$ Education	3.514	4.430	0.152	
Education $\approx$ GOVSpend	6.58465	4.769	0.206	GOVSpend $\square$
GOVSpend $\approx$ Education	5.87211	3.818	0.058	

Notes: ($\approx$, $\rightleftharpoons$, $\square$ and $\neq$) denotes null hypothesis, bidirectional, unidirectional causality and no causality. ***p<0.01; **p<0.05; *p<0.1

6. Conclusion and policy implications

This paper infuses various theories and related empirical studies into a cohesive analysis framework that helps better understand the role of income disparity in reducing greenhouse gas emissions. This paper, which focused on a sample of seven countries from the Global South (Brazil, China, Colombia, Costa Rica, India, Indonesia, and South Africa) from the period 1991-2019, moved away from overly concentrated studies on the contributors to environmental sustainability to fill a gap in the extant literature on green growth. Therefore, our primary contribution to this investigation is to account for the short- and long-run implications of income inequality on green growth. This paper employs a novel battery of tests to examine the cross-dependence, panel unit roots, and cointegration among variables in the sampled countries.

Two estimation techniques were used to overcome the cross-dependence and slope heterogeneity concerns: PMG-ARDL for the baseline model and CS-ARDL model estimations as robustness checks.

The empirical results show that the parameters tested exhibit long-run cointegration relationships. The PMG-ARDL model shows that rising income inequality negatively and significantly affects green growth. For this reason, addressing income inequality is crucial for reducing carbon emissions and fostering a green economy. Further, the coefficients for environmental innovation are positively and statistically significantly linked to green growth, suggesting that countries in the Global South can develop new solutions and technologies that help mitigate environmental damage by investing in and promoting environmental innovation. This, in turn, can potentially increase economic prosperity and alleviate poverty among low-income households. Government spending and educational attainment, on the other hand, have a positive and statistically significant impact on green growth. This also suggests that long-term government investment in R&D, particularly in human capital development, might increase green growth.

We conducted a robustness check for the CS-ARDL model; the findings show that income inequality significantly negatively affects green growth at the 10% level, demonstrating the CS-ARDL consistency in capturing the cross-sectional correlation in the error term Chudik and Pesaran (2015). These results are similar to those reported in the baseline model, and the computed coefficients for the ECT are negative and statistically significant at the 1% level for both model results. Similarly, this paper reveals three possible ways of Granger causation (unidirectional, bidirectional, and no-causality) for the effects of income inequality on green growth. In terms of the country-specific models, coefficient estimates show that a 0.1%- point rise in income inequality lowers green growth by 0.002 % in Brazil and Costa Rica, 0.001 percent in Colombia, 0.003 % in China, 0.004 % in India and South Africa, and 0.005 % in Indonesia in the long run.

This paper offers different practical ways of minimising the effects of income inequality on green growth based on empirical findings. First, the government may consider implementing progressive tax policies and enabling access to Education and equality of opportunity to help reduce income disparity and ensure increased access to resources and opportunities that ensure more equitable wealth distribution. Second, the governments of the Global South need to promote more development in environmental-related technologies. The efficacy of environmental innovation in supporting green growth, however, is dependent on government investment in R&D as well as providing incentives to private sector stakeholders to contribute to inclusive green growth. With more private sector participation, the cost of buying renewable energy-saving appliances for low-income households might be reduced, lowering carbon emissions. Finally, this paper suggests that the government focus resources on sectors crucial to encouraging green growth. These include renewable energy, energy efficiency, environmental protection, sustainable transportation, and agriculture. Investing in such areas may create the conditions for a thriving green economy.

Future research might look at how green growth policies affect income inequality at the household level, bearing in mind individual purchasing power to transition to renewable energy usage. This entails investigating the micro-level effects of green growth policies on various socioeconomic cohorts. This could assist in offering more insight into the distributional implications of green growth policies, which could be used to design more effective and inclusive policy measures. Second, the private sector's involvement as a driver of green finance is critical to greening the economy, particularly the incentives and constraints that impact the behaviour of private sector stakeholders and how they might contribute to inclusive green growth. Finally, the relevance of government policies and institutions in enabling inclusive green growth should be considered. This could contribute to a better understanding of the increasingly interconnected nature of these issues and the development of

appropriate policy measures that promote both environmental sustainability and social fairness.

Appendices

A1: Pairwise correlation matrix

Variables	Green Growth	GINI	ENVINNO	FINDEV	GOVSpend	Education
Green Growth	1.000					
GINI	-0.175	1.000				
ENVINNO	0.046	0.107	1.000			
FINDEV	-0.073	0.622	0.060	1.000		
GOVSpend	-0.237	0.655	0.119	0.188	1.000	
Education	0.052	0.313	0.032	0.442	0.398	1.000

Note: ***p<0.01; **p<0.05; *p<0.1

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Urban Households' Investment Behaviour towards Home Appliances in India: Do Gender and Neighbourhood Effect Matter?

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Abstract

This study assesses the influence of women's bargaining power and the peer or neighbourhood effect on urban households' investment behaviour towards home appliances, i.e., refrigerator and air conditioner. Studies in different domains have demonstrated the impact of the former on household expenditure/ investment decisions, technology and clean fuel adoption, children's education, and so on. Since women primarily operate household appliances, for example, refrigerators, we argue that the former could impact investment decisions related to appliances. Additionally, we study the neighbourhood effect as the acquisition and choice of appliances, vehicles, and new technologies and reduction of household energy consumption heavily rely on information acquired from the neighbours. This communication dynamic reduces perceived social and technological uncertainties related to the product. Therefore, we hypothesise that household appliance ownership accelerates when there is increased use in the neighbourhood. Analysis based on data from the Indian Human Development Survey (IHDS, 2005 and 2012) shows that women's education and property ownership are positively associated with possessing refrigerators and air conditioners. The neighbourhood effects on the same have also been found to be positive and significant. This study, in sum, provides new insights into the factors that influence urban households' investment behaviour towards appliances, and in terms of policy implications, these findings could be useful in the promotion of energy-efficient home appliances as we are aiming for net zero emission in the decades to come.

Keywords: Investment Decision; Home Appliance; Gender; Peer Effects; Urban Households; India

JEL Classification D13 R23

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1. Introduction

The rapid growth in appliance ownership around the world has caught the interest of policymakers and researchers, who are attempting to analyse the key factors contributing to the increase. A large number of studies consider household and residence-related characteristics such as family income, the number of persons in a household, the educational accomplishments of the household head, the household head's age, type of dwelling, access to electricity, etc. (O'Doherty et al., 2008; Leahy & Lyons, 2009; Matsumoto, 2016; Rao & Ummel, 2017; Dhanraj et al., 2018; Sakah et al., 2019; Ramakrishnan et al., 2020). While these studies emphasise household heterogeneity, appliance ownership also depends on gender preferences and power relations within the household (Mohapatra & Simon, 2017; Dhanraj et al., 2018; Debnath et al., 2019; Richmond & Urpelainen, 2019) (Table A1)¹. According to intra-household bargaining theory, men and women have different natures, preferences, responsibilities, and power relationships, which affect key household outcomes (Pachuri & Rao, 2013; Li et al., 2019). The bargaining model mainly focuses on the impact of women's preferences and their control of resources on household outcomes (Doss, 2013). Studies in developing countries have examined the effects of women's preferences and their bargaining power on variables such as household expenditures, technology purchases, choice of clean fuel, children's education, fertility, health outcomes, and other economic decisions (Duflo, 2003; Schmidt, 2012; Mahapatra & Simon, 2017). The findings of these studies imply that greater bargaining power allows women to steer the allocation of resources in their preferred direction, leading to improve household welfare (see Duflo, 2003; Schmidt, 2012; Mahapatra & Simon, 2017). In the case of household appliances, women benefit more from it as it increases their productivity, gives them more time to engage in productive activities outside the home, and provides relief from the heat-related effects of indoor chores that are expected to be borne primarily by them. This indicates the possibility that the higher their bargaining power, the more likely they are to be involved in appliance purchasing decisions. Thus, in this paper, we study a less-explored explanation of appliance ownership, i.e., the contribution of women's bargaining power to the ownership of home appliances. We hypothesise that when women have

high bargaining power, they account for the full benefits of appliances and influence investment decisions.

In addition to the role played by women's bargaining power, the neighbourhood's possession influence on appliance ownership is also examined in this study as households living in similar areas tend to adopt similar perspectives, attitudes, and behaviours of their neighbours (Brown, 2014). This is called imitation behaviour in social learning theory, i.e., households choose the most popular product in their social network (Du et al., 2022). Imitation behaviour leads to the neighbour or peer effect and has been observed in technology adoption studies that examine the purchase of hybrid or electric vehicles, flexi fuel vehicles, cookstoves, solar photovoltaics, energy-efficient products, etc. (Mau et al., 2008; Palm, 2017; Wolske et al., 2020). These studies highlight the influence of the neighbourhood, quantified in terms of the increased likelihood of adoption within a geographical area (Mau et al., 2008; Palm, 2017; Wolske et al., 2020). Following previous research, we hypothesise that ownership of appliances increases as the number of households that own home appliances in the neighbourhood increases. Understanding the influence of the neighbourhood effect is required for more insightful research and policy formulations to promote sustainable energy solutions. For instance, the role of peer effect has been studied in developed countries such as the USA and European Union for household energy conservation; however, lack of studies in the context of developing countries like India (Bahinipati et al., 2022). Therefore, this study aims to understand the influence of women's bargaining power and the neighbourhood effect on household appliance ownership, i.e., refrigerator and air conditioner.

The paper uses household-level data from the India Human Development Survey (IHDS, 2005 and 2012). We employed a logit (logistic) model to estimate the impact of women's bargaining power, the neighbourhood effect, household characteristics, and building characteristics on the ownership of appliances. The rest of the paper is organised as follows: Section 2 discusses the literature, highlighting the relevance of gender and neighbourhood effects as determinants of appliance ownership; Section 3 describes the data and methods; Section 4 explains the findings and policy implications; Section 5 concludes the paper by examining the limitations of the study and the way forward for future research.

2. Background

Traditionally economists and policymakers assumed the household as a single decision-making unit where all the family members have the same utility function, and the household decisions are taken considering the preferences of one household member and are not influenced/affected by who in the house earns the income or owns any assets (Haddad et al., 1997; Doss, 2013; Schmidt, 2012; Arthur-Holmes & Busia, 2020). This is called the unitary household

model. Recent studies, however, have rejected the unitary model of intra-household resource allocation, which assumed that the bargaining power of an individual member does not affect the household production and consumption decisions (Haddad et al., 1997; Doss, 2013; Dhanaraj et al., 2018). Empirical evidence finds men and women have different preferences; they do not pool their resources within the household nor follow similar expenditure patterns. As a result, their bargaining power impacts key household outcomes differently (Dufflo et al., 2003; Schmidt, 2012). The collective model accommodates such intra-household preferences and allows bargaining power to play a major role in spending decisions (Schmidt, 2012). This paper builds on the collective model's framework by not addressing the household as a single economic actor and considering the individual preferences and their relative economic resources.

The bargaining models, in particular, focus on how women's bargaining power gives them greater power to influence intra-household resource allocation and leads to increased participation in household decision-making (Dufflo, 2003; Doss, 2013). A substantial body of literature has already examined the role of women's bargaining power on household outcomes such as children's education, the well-being of women and girls, health, savings, expenditure, choice of technology, and purchases (Wang, 2014; Doss, 2013; Magnan et al., 2014; Mahapatra & Simon, 2017; Afoakwa, 2020). However, the impact of women's bargaining power on appliance ownership has not received as much attention. Women prioritise home appliances more than men because it gives them more leisure time and comfort and allows them to enter the job market (Bose et al., 2022). This *prima facie* justifies the assumption that women having more bargaining power at home will affect appliance ownership. But the empirical analysis of the impact of women's bargaining power on appliance ownership requires reliable measures such as women's earned and unearned income from pension benefits, remittances, and interest from the capital. But they involve endogeneity issues because wage income influences and is influenced by the decision of how many hours to work, which is frequently determined jointly with household consumption decisions (Doss, 1996; Kibe, 2017). Thus, using income as a proxy for bargaining power is problematic in explaining the bargaining effect. To avoid the endogeneity issue, studies have instead focused on gender-linked indicators, where any improvement in them will signal an increase in bargaining power. For example, studies in other domains use gender-linked indicators such as land rights or asset ownership, education, involvement in family decision-making, and autonomy to analyse their impact on household outcomes (Acharya et al., 2010; Schmidt, 2012; Wang, 2014; Frempong & Stadelmann, 2017; Mohapatra & Simon, 2017)². The education level of women has been widely used in the literature as a proxy for bargaining power as it endows them with the knowledge, skills, and resources to make life choices and can be used as a proxy for their employability (Frempong & Stadelmann, 2017; Samarakoon & Parinduri, 2015). Further,

evidence suggests more years of schooling among women lead to decreased child labour, better health outcomes for children, more job opportunities, and increased appliance ownership (Breierova & Duflo, 2004; Glick & Sahn, 2000). Similarly, Dhanraj et al. (2018) used education as a proxy for women's bargaining power and found that the likelihood of appliance ownership is higher for women who have completed their tertiary level of education.

Apart from education, evidence from various studies also reinforces that access to credit or property rights, information, and transport are the other measures that can be used as proxies for women's bargaining power. Doss (2018) found that the distribution of property rights between men and women affects household expenditure decisions. When a woman holds property rights, it decreases their share of work, strengthens their decision-making power over durable goods, and reduces the consumption of male-centric goods such as tea and alcohol (Wang, 2014). According to Seebens (2010), ownership of land assets is an important indicator of bargaining power as it serves as a 'credible threat' that women will keep/use after leaving the household. Another measure of the intrahousehold bargaining power of women is their involvement in household decision-making and freedom to move short distances without asking for permission. For example, Agarwal (1997) states that the distribution of bargaining power within the household is revealed through 'who participates in the decision-making and about what'. Hence the participation of women in decision-making could reflect their greater bargaining strength.

Restricting women's mobility will impact their access to goods and services and economic empowerment (Choudhuri & Desai, 2020); thus, it can be used as a proxy for women's bargaining power.

In addition, this study aims to inquire about the neighbourhood effects because, according to social learning theory, adopting a particular technology affects other groups of people through a learning process or peer effects (Wolske, 2020). Research in domains like agriculture, solar energy, and the automobile sector provides evidence of the impact of neighbours/peers on technology purchases (Zhu & Liu, 2013; Tessema et al., 2016; Defrancesco et al., 2018). The impact of neighbours is called the spatial neighbourhood effect, where individuals/households learn from their neighbours whether to adopt a new technology or not. It operates through interaction among individuals/households in the same geographical regions. Studies on alternative fuel vehicle purchases show spatial clustering where adopters are more likely to adopt alternative fuel vehicles when their exposure is high in the surrounding areas (Mau et al., 2008; Zhu & Liu, 2013). Moreover, the information gained from observing the purchases of neighbours reduces the perceived social and technological uncertainties related to the product (Adjemian et al., 2010). The theoretical model for such neighbourhood effect explicitly models the contagion or spatial effects and captures the spatial interdependence across the neighbours (Noonan et al., 2013; Zhu & Liu, 2013;

Heutel, 2014). While the literature on the neighbourhood effect shows its positive effect on the ownership of cars, new vehicles, and solar photovoltaic technologies, discussions on the impact of the neighbourhood effect on appliance ownership have been sparse. Research on behavioural theories concerning households' energy consumption behaviours and energy efficiency investments show the involvement of a strong social component, i.e., being influenced by others in household behaviour which is more powerful than cost considerations (Wolske et al., 2020; see Bahinipati et al., 2022). Therefore, we argue that household appliance ownership accelerates when appliance use is increasingly visible in the neighbourhood areas.

3. Methods

3.1 Data Set

Our goal is to explore and analyse women's bargaining power and the neighbourhood effect as determinants of ownership of refrigerators and air conditioners in urban India. We have used Indian Human Development Survey data, a nationally representative, multi-topic survey that conducted two rounds of surveys in 2005 (IHDS-1) and 2011–2012 (IHDS-2). By matching urban household IDs across both rounds, we have created panel data. Our sample size is restricted to 22,146 urban households in the case of panel data and 13,442 urban households for the second round of the IHDS.

We model the probability of owning an appliance as a function of women's bargaining power, the neighbourhood effect, household characteristics, and residence characteristics using second-round IHDS survey and panel data. We estimate using logit (logistic) regression for IHDS-II and random effects logistic model for panel data. The model specification for IHDS-II (Equation 1) and panel data (Equation 2) is given below:

$$Y_i = \left[\log \frac{pr(OWN=1)}{1-pr(OWN=0)} \right]_i = \beta + \theta_1 Property\ Ownership_i + \theta_2 Decision_i + \theta_3 Education_i + \theta_4 Permission_i + \theta_5 Household\ Size_i + \theta_6 Per\ capita\ monthly\ consumption_i + \theta_7 Occupation_i + \theta_8 Religion_i + \theta_9 Caste_i + \theta_{10} Building\ type_i + \theta_{11} Electricity_i + \theta_{12} Number\ of\ rooms_i + \theta_{13} Neighbourhood\ effect_i + State_i + \varepsilon_i \quad (1)$$

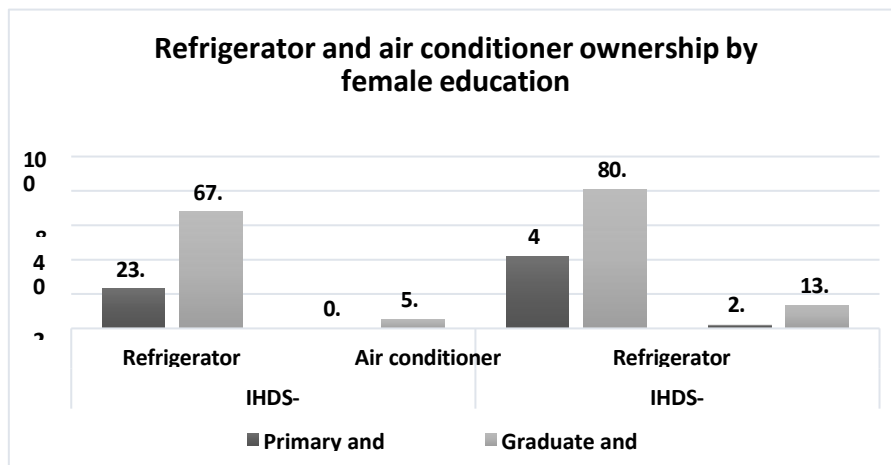
$$Y_{it} = \left[\log \frac{pr(OWN=1)}{1-pr(OWN=0)} \right]_{it} = \beta + \theta_1 Property\ Ownership_{it} + \theta_2 Decision_{it} + \theta_3 Education_{it} + \theta_4 Permission_{it} + \theta_5 Household\ Size_{it} + \theta_6 Per\ capita\ monthly\ consumption_{it} + \theta_7 Occupation_{it} + \theta_8 Religion_{it} + \theta_9 Caste_{it} + \theta_{10} Building\ type_{it} + \theta_{11} Electricity_{it} + \theta_{12} Number\ of\ rooms_{it} + \theta_{13} Neighbourhood\ effect_{it} + Year_{it} + State_{it} + \varepsilon_{it} \quad (2)$$

Where Y_i and Y_{it} is the binary dependent variable describing the ownership of refrigerators and air conditioners for the i th households and t is the period. θ_i and θ_{it} in equations 1 and 2 are the parameters to be estimated. ε_{it} is the random effect that follows a normal distribution.

3.2 Dependent and Independent variables:

The variable ownership of a refrigerator and an air conditioner is a binary dependent variable describing if the household *i* owns a refrigerator and air conditioner or not. We have included four gender-related variables: education, mobility, women owning property in their own name, and decision-making power to study their relative influence on the ownership of refrigerators and air conditioners (See table 1).³ The first variable is women's educational qualifications because it allows them to allocate resources within households, enables them to have a say in decision-making (e.g., purchase of appliances and jewellery), and has agency in making choices (Samarakoon & Parinduri, 2015). We found that appliance ownership was higher among women who had completed their graduation than those with primary and secondary education (see figure 1). The IHDS-2 shows that 81% and 13% of graduated women have refrigerators and air conditioners. Thus, the educational status of women can be used as a proxy for their bargaining power and has been shown to have a positive effect on appliance ownership. The second variable is decision-making authority, which studies whether the subject has a say in purchasing expensive items (e.g., fridges, air conditioners). Since men and women have different preferences, women are expected to exercise greater authority in purchasing decisions, especially when buying home appliances, improved cookstoves or selecting clean fuel (Schmidt, 2012; Choudhuri & Desai, 2020). In many communities, social and cultural norms may impose restrictions on women's free mobility, which impairs their development, empowerment, and access to goods and services (Choudhuri & Desai, 2020). So, the autonomy/mobility of women within the community is the third indicator of women's bargaining power we include in our study. To test the impact of women's autonomy on appliance ownership, we constructed a binary variable that takes the value zero if a woman visits any of the following places: a friend's house, hospital, grocery shop, or a short distance without taking the permission of other household members. The last binary variable is whether the woman holds any property rights, which investigates whether these rights affect the woman's bargaining power in purchasing appliances. Economic theories propose that women's access to land strengthens their financial security and improves their bargaining power within the household (Agarwal, 1994). Mishra and Sam (2016) empirically examined the impact of land ownership on the empowerment of women in Nepal. They found that women's land ownership significantly increases their bargaining power, mainly defined by decision-making regarding major household purchases.

Fig.1 Refrigerator and Air conditioner ownership by female education level for IHDS-1 and IHDS-2



Source: Authors' figure

While we included indicators of women's bargaining power, there is a high possibility that some indicators are dependent on the values of another indicator. For example, women's decision-making authority and education may be positively correlated, as educated women are more likely to meet their livelihood needs without depending upon their spouses (Acharya et al., 2010). Therefore, explaining the main effects of the indicators on appliance ownership would be incomplete without considering the statistical significance of the interaction between women's decision-making authority and their educational qualifications. We address the problem by including an interaction term or the hypothesis that the relationship between owning an appliance and a woman's decision-making authority is different for women with graduate levels of education than women with primary and secondary levels of education. Lastly, we have included the spatial neighbourhood effect⁴, where we hypothesise that the higher the adoption of an appliance in the neighbourhood area, the higher the probability of a household purchasing the appliance.

To improve the precision of our estimates, possible confounders have been identified from the literature and included in the model (table A2)⁵. Table 2 provides the details of the control variables used in the study. The control variables have been divided into (1) household characteristics and (2) residence characteristics. Under household characteristics, the study includes per capita monthly expenditure as a proxy for household affordability, the number of persons in the family/household size, religion and caste, and the occupation of the household head. We control for the number of persons in the family because it can either positively affect appliance ownership when the family's total

income increases due to household size or negatively affect ownership when household expenses increase because of a large family (Leahy & Lyons, 2009; Lyons et al., 2010; Sakah et al., 2019). We used logarithmic per capita monthly expenditure to proxy for households' affordability. Evidence suggests that income or households' affordability is a predominant driver of appliance ownership (O'Doherty et al., 2008; Matsumoto, 2016; Dhanraj et al., 2018; Richmond & Urpelainen, 2019; Sakah et al., 2019; Ramakrishnan et al., 2020).

Table 1 Summary Statistics

Round II (2012)		Panel (Round I & II)			
Description of the variables	Type of the variables	N	Mean (SD)	N	Mean (SD)
Explained variables					
Ownership of refrigerator	Dummy	13434	.504 (0.500)	22108	.412 (0.492)
Ownership of Air conditioner	Dummy	13429	.048 (0.213)	21074	.029 (0.169)
Household-related variables					
Household Size	Continuous	13442	5.282 (2.333)	22146	5.479 (2.489)
Per capita monthly consumption expenditure	Continuous	13441	10.17 (0.653)	22126	8.465 (1.798)
Occupation of Household head	Categorical	13435	2.263 (0.955)	22142	2.245 (0.950)
Religion	Dummy	13442	1.777 (0.415)	22146	1.771 (0.419)
Caste	Categorical	13401	1.879 (0.758)	22108	2.507 (0.631)
Building-related variables					
House Type	Categorical	13391	2.011 (0.326)	21977	1.931 (0.418)
Access to electricity	Continuous	13102	17.747 (6.283)	21287	17.843 (6.334)
Number of Rooms	Continuous	13428	2.926 (1.733)	21923	2.844 (1.698)
Neighborhood Effects					
Neighborhood effect of	Continuous	13442	50.427	22146	41.469

refrigerator			(23.428)	(23.708)
Neighborhood effect of air conditioner	Continuous	134421.244	22146	0.896
			(1.021)	(0.953)
Gender-related variables				
Female having a property	Dummy	12935.193	20753	0.177
			(0.394)	(0.381)
Highest educated female in the house	Dummy	134351.922	22068	1.824
			(0.713)	(0.712)
Female's involvement in the purchase decision of appliances	Dummy	13383.795	21159	0.757
			(0.404)	(0.428)
Permission	Dummy	13407.944	21176	0.860
			(0.231)	(0.346)

Note: SD – Standard Deviation

Source: Authors' Table

The relationship between households' source of income and appliance ownership is also analysed in the study. We assume that household heads working in business/salaried/other professions are more likely to own an appliance because of their accessibility to credits than those engaged in the agricultural sector. We also controlled religion as religious norms, customs, and beliefs influence consumption behaviours. For example, Rao and Ummel (2017) demonstrate that the likelihood of owning a refrigerator is high among the Sikh community because of their high milk consumption. Similarly, we include caste as ownership of appliances and assets provides lower caste people with an opportunity to redefine their social status; therefore, it is hypothesised that lower caste households are more likely to own appliances (Ramakrishnan, 2020). Ramakrishnan et al. (2020) argue that beyond a certain threshold income, households in emerging countries become more concerned about their relative income levels than their absolute income levels. They make efforts to meet the average consumption standards of their community or social group, among whom the ownership of appliances is a significant status marker. Thus, the pursuit of higher social status and recognition has led to the ownership of appliances. The literature review finds that building characteristics such as the number of rooms, access to electricity, and type of house are also crucial in determining home appliance ownership. Richmond and Urpelainen (2019) found that prolonged electricity access increases the probability of owning appliances in rural areas. The descriptive statistics show that households in urban areas get 18 hours of electricity on average.

4. Results and Discussion

The cross-sectional and panel data analysis may feature multi-collinearity problems, leading to erroneous hypothesis tests about the significance of the predicted coefficients. We calculated the variance inflation factor (VIF) to check for multi-collinearity. The mean value of the VIF for all the independent variables is calculated as 1.28 for cross-sectional data and 1.25 for panel data, respectively. The calculated values are between 1.14 and 6.82, suggesting the absence of a multi-collinearity problem. We also used clustered standard error to account for the situation in which observations within each group are not independently and identically distributed.

Tables 2 and 3 report the step-wise regression results for Eq. (1) and (2). The results show that women graduates are more likely to own refrigerators and air conditioners by 1.09 and 1.10 percentage points (see columns 6 of Table 2 and 3). Samarakoon and Parinduri (2015) also find that completing one more year of education and completing senior high school increase the likelihood of women owning household appliances by 5 per cent and 22 per cent, respectively. Thus, education as a proxy for women's bargaining power is a significant determinant

Table 2 Marginal effects of ownership of refrigerator

	IHDS- 2012		IHDS I-II			
	(1)	(2)	(3)	(4)	(5)	(6)
Gender-related variables						
Property Ownership		0.038***	0.010	0.665***	0.325***	0.209***
	0.085***					
	(0.131)	(0.009)	(0.009)	(0.092)	(0.069)	(0.060)
Decisions	-0.011	0.005	0.005	-0.138	-0.112	-0.033
(Purchases)	(0.012)	(0.009)	(0.010)	(0.086)	(0.084)	(0.080)
Education:	0.360***	0.170***	0.121***	2.563***	1.332***	1.086***
Graduation &	(0.016)	(0.012)	(0.011)	(0.164)	(0.097)	(0.072)
above		0.020	0.020	-0.252*	-0.182	-0.040
Permission	0.039					
	(0.043)	(0.030)	(0.022)	(0.153)	(0.148)	(0.126)
Household-related characteristics						
		0.035***	0.020***		0.219***	0.142***
Number of persons						
		(0.002)	(0.002)		(0.021)	(0.018)
Per capita monthly	0.289***	0.220***			2.160***	1.805***
consumption	(0.011)	(0.010)			(0.113)	(0.105)
Occupation:	0.176***	0.145***			1.440***	1.287***
Business	(0.013)	(0.012)			(0.968)	(0.107)
Occupation:	0.199***	0.151***			1.501***	1.261***

Salaried		(0.012)	(0.011)		(0.092)	(0.010)
Occupation: Others		0.199***	0.155***		1.504***	0.286***
		(0.020)	(0.020)		(0.124)	(0.133)
Hindu		-0.007	-0.020*		-0.143	-0.293***
		(0.012)	(0.010)		(0.099)	(0.099)
Other Backward		-0.046***	-0.022***		-0.407**	-0.257*
Classes (OBC)		(0.013)	(0.011)		(0.159)	(0.142)
Scheduled Caste &		-0.071***	-0.050***		-0.436***	-0.291**
Scheduled Tribe		(0.011)	(0.010)		(0.150)	(0.141)
Building-related variables						
Bungalow and			0.009			0.442**
Shared walls			(0.045)			(0.204)
Flat			0.051			0.785***
			(0.041)			(0.190)
Electricity			0.002**			0.017**
			(0.001)			(0.007)
No of Rooms			0.047***			0.336***
			(0.003)			(0.029)
Neighbourhood effect						
Neighbourhood			0.006***			0.050***
effect			(0.000)			(0.002)
Constant	0.560	-21.032***	-21.286***	-0.024	-17.685***	-19.380***
	(0.639)	(1.410)	(1.280)	(1.081)	(1.459)	(1.248)
Observations	12834	12786	12426	20603	20554	19515
Pseudo R2	0.16	0.32	0.37			
Number of ID				11019	11010	10799
Rho				0.54	0.28	0.27
YEAR				YES	YES	YES
STATE	YES	YES	YES	YES	YES	YES

The author's computation is based on IHDS-2 and IHDS panel (2005-2012) data. Standard errors in parentheses are clustered standard errors with *** p<0.01, ** p<0.05, * p<0.1.

Table 3 Marginal effects of ownership of air conditioner.

AIR CONDITIONER OWNERSHIP	IHDS-II			IHDS I-II		
	(1)	(2)	(3)	(4)	(5)	(6)
Gender-related variables	0.030***	0.016***	0.007	0.730***	0.435***	0.270
Property Ownership	(0.007)	(0.006)	(0.005)	(0.123)	(0.161)	(0.185)
Decisions (Purchases)	-0.000	0.000	-0.000	-0.046	0.035	0.156
	(0.006)	(0.005)	(0.005)	(0.208)	(0.212)	(0.225)

Education: Graduate & above	0.096*** (0.007)	0.040*** (0.005)	0.030*** (0.004)	2.160*** (0.152)	1.267*** (0.151)	1.103*** (0.148)
Permission	0.011 (0.009)	0.009 (0.009)	0.019** (0.008)	0.104 (0.290)	0.169 (0.307)	0.448** (0.322)
Household-related variables						
Number of Persons		0.006*** (0.000)	0.002*** (0.000)		0.199*** (0.026)	0.129*** (0.029)
Per capita monthly consumption		0.056*** (0.005)	0.048*** (0.002)		1.898*** (0.140)	1.747*** (0.145)
Occupation: Business		0.037*** (0.010)	0.028** (0.010)		1.419*** (0.406)	1.110** (0.431)
Occupation: Salaried		0.020** (0.007)	0.012 (0.008)		0.899** (0.370)	0.573 (0.404)
Occupation: Others		0.022*** (0.008)	0.013 (0.009)		1.021*** (0.382)	0.723 (0.448)
Hindu		0.001 (0.006)	-0.006 (0.006)		0.280 (0.217)	-0.032 (0.222)
Other Backward Classes (OBC)		-0.023*** (0.005)	-0.018*** (0.005)		0.160 (0.260)	0.141 (0.268)
Scheduled Caste & Scheduled Tribe		-0.027*** (0.006)	-0.019*** (0.006)		-0.453* (0.266)	-0.379 (0.278)
Building-related variables			0.031***			0.997**
Bungalow and Shared walls			(0.005)			(0.449)
Flat			0.040*** (0.007)			0.358*** (0.453)
Electricity			0.000 (0.000)			0.005 (0.012)
No of Rooms			0.009*** (0.000)			0.260*** (0.039)
Neighborhood effect						
Neighborhood effects of Air conditioner			0.048*** (0.002)			0.704*** (0.160)
Constant	- 3.162*** (0.790)	- 20.825*** (1.350)	- 25.197*** (1.058)	-5.740*** (1.104)	- 22.016*** (1.735)	- 25.097*** (1.875)
Observations	12704	12656	12298	19384	19332	18321
Pseudo R2	0.17	0.28	0.38			

Number of ID				10886	10877	10661
rho				0.43	0.38	0.33
YEAR				YES	YES	YES
STATE	YES	YES	YES	YES	YES	YES

The author's computation is based on IHDS-2 and IHDS panel (2005-2012) data. standard errors in parentheses are clustered standard errors with *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

of appliance ownership. But women's decision-making authority and the interaction variable have an insignificant effect on appliance ownership. Women who take permission to travel any short distance are seen to increase air- conditioner ownership by 0.01 and 0.4 percentage points at a significance level of 5 per cent, but it has no significant effect on refrigerator ownership (see columns 3 and 6 in Tables 2 and 3). The relationship between air conditioner ownership and women's autonomy implies that women who do not have autonomy are more likely to own air conditioners, which is difficult to explain in the current context. However, the results for refrigerator ownership partially support the findings and observations of Choudhuri and Desai (2020), who do not find a relationship between women's autonomy and fuel choice. They observed that women's role in the household is limited to 'the boundary of the house regarding what to cook,' and they are not exposed to the domain of livelihood and budgetary allocation. Thus, they do not actively participate in fuel selection. However, in our study, property ownership by women has a positive relationship with appliance ownership at a significance level of one and ten per cent. Women owning property in their name increases the probability of buying a refrigerator by 0.20 percentage points (see column 6 of Table 2). It confirms the previous findings that women's property rights support purchasing female-centric products at home. Thus, women who derive the intrahousehold bargaining power through their education level or owning property are highly influential determinants for owning home appliances.

Studies on neighbourhood effects are a growing area of research because of their massive impact on individual, social, and economic outcomes (Lupton, 2003). Zhu and Liu (2013) believe that households in some regions share similar socio-economic and demographic characteristics and are more likely to have similar preferences. Also, due to the power of societal influence, families are more likely to buy the same appliances as their neighbours. In this paper, we studied how the concentration of refrigerator and air conditioner ownership in the nearest district affects a household's likelihood of owning the same or similar appliances. In line with previous works, the study finds a statistically positive and significant relationship between the neighbourhood effect and the ownership of air conditioners and refrigerators. The result confirms the impact of societal influence on households.

The household size is directly related to appliance ownership, as ownership increases with the number of household members. Per capita monthly expenditure increases the probability of owning a refrigerator and an air conditioner. We disentangle households' sources of income to study the relationship between income and the ownership of refrigerators and air conditioners. The results show that households earning an income from business and other sources are more likely to own an air conditioner than salaried households. However, all the types of occupation show a relationship with refrigerator ownership. Regression estimates for appliance ownership reveal that caste and religion have significant negative effects. Across appliance categories, the probability of ownership decreases if a household belongs to the other backward class category (OBC) or the scheduled caste (SC) and scheduled tribe (ST) categories, confirming prevailing hierarchies in society. Hindus are found to have a negative relationship with appliance ownership than other religions, including Christianity, Muslim, Sikh, Jain, and others. Ganesan and Vishnu (2014) reveal that the average per capita income of Christian and other religious households is higher than that of Hindu households, which could be a possible explanation for the negative relationship.

Additionally, we controlled for hours of electricity access to the household. We find that the availability of electricity significantly affects refrigerator ownership only. With every hour of access to electricity, the ownership refrigerator is shown to increase by 0.2 and 1.7 percentage points (see columns 3 and 6 of Table 2). However, access to electricity does not have a significant relationship with air conditioner ownership. The cost of air conditioners could be a major barrier for which households with quality electricity supply are more likely to own refrigerators than air conditioners (Richmond & Urpelainen, 2019). Moreover, air conditioners in India are still a luxurious commodity for middle-class households and are used seasonally. This could also explain the insignificant relationship between the two. In addition, the results also indicate a positive and highly significant relationship between house type, the number of rooms, and ownership of appliances. The study includes three categories of houses: slums and chawl houses, bungalows, shared buildings, and flats. It indicates that living in bungalows and flats increases the probability of owning air conditioners by more than one per cent because such homes provide spaces and other conducive physical settings. This implies that housing type is a significant determinant for larger electrical appliances like air conditioners and refrigerators.

5. Conclusion

The present study sheds light on the relationship between women's bargaining power and appliance ownership because it provides a useful approach for analysing the impact of intra-household dynamics with regard to appliance ownership. The nature of the intra-household power relations between women and men is highly complex. In this study, we have tried to capture the complex

nature of intra-household power relations by assuming a collective household bargaining model. We included a range of non-labour income measures that determine bargaining power and estimate their impact on appliances ownership. The evidence from the present study is consistent with the theory. Among the four bargaining power measures, two, i.e., women having property rights and education are positively correlated with appliance ownership. Thus, the findings of the study strongly suggest the bargaining power of women is a crucial determinant in appliance ownership. The study also looked at the neighbourhood effect as a determinant of appliance ownership because households in the same neighbourhood tend to own similar appliances due to homogeneous socio-economic characteristics and preferences. The study finds that appliance ownership increases when there have been more purchases of electrical appliances in the neighbourhood. We took household and residence characteristics as explanatory variables and found that they have a highly positive and significant relationship with ownership of refrigerators and air conditioners in urban India, except for caste and religion. Per-capita monthly consumption expenditure is found to influence appliance ownership strongly. Household size, building type, and the number of rooms are the most consistent indicators that increase the probability of owning refrigerators and air conditioners.

Shrestha (2021) states that women play a pivotal role in adopting sustainable energy practices at the household level as they are the primary energy users. As women are the real energy users, their participation in appliance ownership also reveals their role in energy-related decisions. The findings of the study suggest that appliance ownership is gendered in nature, depending on women's bargaining power. Therefore, policies aiming to reduce energy demand need to target urban women to encourage them to buy energy-efficient appliances. A better understanding of the sensitivity of gender differences in appliance ownership can add to realising energy-related SDGs (Shrestha, 2021). The neighbourhood effect emphasises that households like to follow their neighbours' preference patterns, which policymakers can consider while formulating energy-saving policies. For instance, feedback-based techniques or community programmes can be used to target households and check the growth of appliances. However, in this study, we failed to explore the impact of women's bargaining power and neighbourhood effect on investment on energy efficiency due to the unavailability of information in survey data.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX

Table A1 Review of the determinants of appliance ownership

SL NO	Study	Country	Appliance	Sample Size	Independent variables		
					HC	RC	GV
1	Leahy & Lyons, 2009	Ireland	Energy using appliances	–	*	*	
2	O'Doherty et al., 2008	Ireland	Energy using appliances	40,000	*	*	
3	Lyons et al., 2010	Ireland	Water-using appliances	–	*	*	
4	Matsumoto, 2016	Japan	Energy using appliances	39,136	*	*	
5	Rao and Ummel, 2017	Brazil, India, S.Africa	Refrigerator, television, washing machine	India, (41554; 42152); * Brazil, (48470; 55,970); S.Africa, (21,144; 25,328)		*	
6	Mahapatra & Simon, 2017	India	Modern cookstoves	25427	*	*	*
7	Dhanraj et al., 2018	India	Refrigerator	42383	*	*	*
8	Debnath et al., 2019	India	Energy using appliances	1224			*
9	Richmond & Sakah et al., 2019	India	Energy using appliances	5115	*	*	*
10		Ghana	Energy using appliances	420	*	*	
11	2019 Ramakrishnan et al., 2020	India	Car and electric appliances	14,000	*	*	
12	Wang et al., 2018	Tokyo	Energy efficient appliances	159	*	*	

Note: 1. HC- Household characteristics, RC-Residential Characteristics, GD-Gender-related variables

2. Energy using appliances include a washing machine, dishwasher, refrigerator ("fridge"), deep freezer, fridge-freezer, microwave oven, vacuum cleaner, tumble dryer and home computer, video player/recorder, portable television, and CD player

Table A2 Findings of previous studies

Independent variables	Significant positive effect on appliance ownership	Significant negative effect on appliance ownership	No effect on appliance ownership
Household Size	Matsumoto,2016; Rao & Ummel, 2017; Ramakrishnan et al., 2020; Wang et al., 2018	Lyons et al., 2010	Sakah et al., 2019; Leahy & Lyons, 2009
Number of children			
HH Income	Dhanraj et al., 2018; Richmond & Urpelainen, 2019; O'Doherty et al., 2008; Sakah et al., 2019; Matsumoto,2016; Rao & Ummel, 2017; Ramakrishnan et al., 2020; Leahy & Lyons, 2009; Lyons et al., 2010		
HH Income source	Ramakrishnan et al., 2020; Lyons et al., 2010; Wang et al., 2018		Leahy & Lyons, 2009
HH Education	Rao & Ummel, 2017;		Ramakrishnan et al., 2020
HH Age	O'Doherty et al., 2008 Sakah et al., 2019	Leahy & Lyons, 2009	Leahy & Lyons, 2009; Wang et al., 2018
Electricity access	Dhanraj et al., 2018; Richmond & Urpelainen, 2019		
Years at the address	Leahy & Lyons, 2009; Wang et al., 2018	O'Doherty et al., 2008; Lyons et al., 2010	
Tenure type (Owned Vs Rented)	Matsumoto,2016; Wang et al., 2018	O'Doherty et al., 2008; Ramakrishnan et al., 2020; Leahy 2010	Leahy & Lyons, 2009; Lyons et al., 2010

Building type	Matsumoto, 2016; Rao & Ummel, 2017;	& Lyons, 2009	
(detached/semi-detached/others)	Ramakrishnan et al., 2020; Debnath et al., 2019; Leahy & Lyons, 2009; Lyons et al., 2010	O'Doherty et al., 2008	Wang et al., 2018
No of Rooms	Leahy & Lyons, 2009		
Gender (decision making,	Dhanraj et al., 2018; Richmond & Urpelainen, 2019; Debnath et al., 2019		

Notes

¹ Table A1 provides the summary of studies reviewed on the determinants of appliance ownership

² Although not all of these studies focus on women's "bargaining power" per se, the underlying concepts such as agency, autonomy, empowerment, status, etc., under scrutiny are similar (Seymour & Peterman, 2018).

³ Following the approach of Choudhuri and Desai (2020), we have captured those indicators which will reflect the economic, personal and social dimensions.

⁴ The spatial neighbourhood effect is also called the 'neighbourhood effect' which is defined in terms of geographical proximity such as households within a neighbourhood or geographical radius or postal code (Wolske et al., 2020). In this paper, we calculated the percentage of households owning refrigerator and air conditioner for every district to measure the spatial neighbourhood effect

⁵ Table A2 enumerates the positive or negative or insignificant effects of determinants of appliances ownership found in previous studies.

Innovation Environment and Entrepreneurial Intentions among Undergraduate Students in Nigeria

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Abstract

Entrepreneurship is instrumental to job creation, innovation and labour market competitiveness. Attention has now been drawn to the importance of entrepreneurship, more so in developing economies. Hence, an understanding of the factors that would steer its development in the country is essential. Undergraduate students are drivers of mass entrepreneurship and innovation. The effect of innovation environment on entrepreneurial intentions among undergraduate students in Nigeria was investigated. The findings established that innovation environment of undergraduate students matter for entrepreneurial intention/entrepreneurship. It added that improvement in innovation environment alone does not promote interest in entrepreneurship, rather entrepreneurial education with a favourable innovation environment facilitates interest in entrepreneurship. This study provides suggestions on appropriate interventions that can build and develop youth entrepreneurial intentions in the country. It emphasized the role of entrepreneurial education in terms of skills acquisition and entrepreneurial development in fostering decent employment among youths in Nigeria. The need to stress that there is a growing awareness of the need to combine skills acquisition with technical and academic achievement in order for young people to realize their potentials in the workplace and their development in all domains of life.

Keywords: Innovation Environment, Entrepreneurial Intentions, Entrepreneurial Education, Undergraduates, Nigeria

Introduction

Background

Employment challenges of vulnerable groups, especially women and youth, remain a major global concern. Nigeria has the largest youth population in Africa, and most of them engage in insecure and low-income informal sector jobs. Youth accounts for 68 percent of Nigeria's combined unemployed and underemployed population. Increases in the number of youths entering the labor market, massive shortfall of jobs and skills shortages have stiffened youth employment opportunities, and consequently, the precarious state of youth development in Nigeria (NBS, 2016; BPSR, 2017).

Entrepreneurship as a major economic driver is instrumental to job creation, innovation and labour market competitiveness (Barba Sánchez et al., 2022). Attention has now been drawn to the importance of entrepreneurship, more so in developing economies. Hence, an empirical evidence on how the university environment encourages entrepreneurship for economic development is essential. Undergraduate students are drivers of mass entrepreneurship and innovation (Luo et al., 2022). These students are best placed to study and understand the developmental and societal needs by identifying problem areas through entrepreneurial practice and with a clear focus. According to Luo et al. (2022), innovation and entrepreneurship is instrumental to an innovation-driven strategy that will drive scientific and technological innovation and economic transformation. There is therefore the need to support entrepreneurship among undergraduates in a country like Nigeria with high youth unemployment rate.

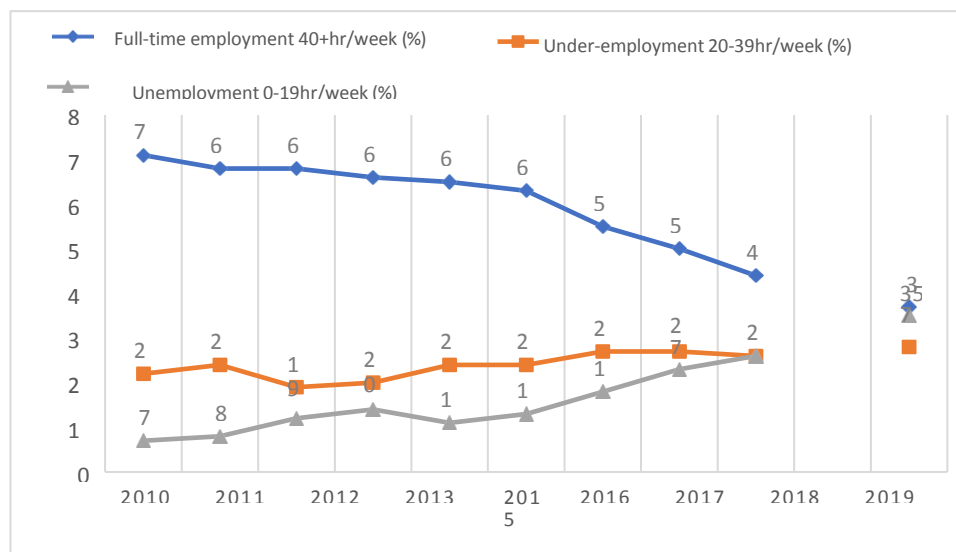
Entrepreneurial intention has received major attention in recent times. Entrepreneurial activities and behavior are contingent on the intention to act. Hence, a key factor influencing action is intention (Sølesvik, 2013). To foster future entrepreneurialism among University students in the country, a study of this nature is crucial. A key component of entrepreneurship is entrepreneurial intention (Linán and Fayolle, 2015). It is described as having more than just the desire to start something; it also includes a genuine motivation and willingness to participate in an entrepreneurial venture (Osadolor et al., 2021). So, while students are still in school, it is important to look at the factors that cause students to want to engage in entrepreneurship.

In Nigeria, the government through several initiatives and programmes has tried to build entrepreneurship among youths in the country. Some of these

efforts and initiatives are evident through the establishment of agencies such as the National Directorate of Employment (NDE), Small and Medium Enterprise Development Agency of Nigeria (SMEDAN), the Development Bank of Nigeria (DBN), National Youth Service Corps-Skills Acquisition and Entrepreneurship Development (NYSC-SAED), N-Power among others. Also, a policy adopted by the Nigerian government in 2006 imposed a requirement on all Nigerian universities to build entrepreneurship development centers (EDCs) and offer all disciplines required entrepreneurship courses. The policy was designed and monitored by the National Universities Commission (NUC). These programs, policy and initiatives were to develop and foster entrepreneurship in the country and most especially among youths. However, they have not been significant drivers of the entrepreneurship intentions of youths (undergraduates) in the country, specifically, examining the effect of the innovation environment. In addition, in spite of the advent of entrepreneurship courses, there is still a steady rise in unemployment rates and the number of start-ups among recent graduates remains underwhelming (Osadolor et al., 2021). Thus, it is imperative to understand the effect of innovation environment on entrepreneurial intentions among undergraduates in Nigeria. In light of the nation's rising unemployment rate, this has become imperative.

The rising youth unemployment rate in the country remains a major concern in the country. It is further hinged on the pressing need to foster an innovation-driven and knowledge-based economy. In a recent policy report, the Nigerian Youth Employment Action Plan (NIYEAP) (2021-2024), it was reported that the economic growth has not translated to poverty reduction and decent job creation for youths and rapidly growing labour force. Available data from the Nigerian Bureau of Statistics revealed that youth unemployment rates from 2010 to 2020 continues to be on the rise. As of second quarter of 2020, youth unemployment (15-34 years old) was put at 35%. Furthermore, 28% of young people in the labour force were considered underemployed, i.e., those working 20-39 hours a week and 37% who worked full time. The report added that the impact of the COVID-19 pandemic on labour market outcome further added pressure on youth employment.

Figure 1: Trend in Youth Unemployment in Nigeria



Source: NBS (2017); NBS (2018); NBS (2020)

The business environment in Nigeria, according to Osadolor et al. (2021), does not provide much assistance to young adults in terms of starting their own businesses. It thus implies that there is the need to understand the factors influencing entrepreneurial intentions in the country so as to isolate the major drivers of youth entrepreneurial intentions.

A number of studies have been carried out on entrepreneurial intentions among higher education students. However, limited studies have been carried out in Nigeria on the subject. Osadolor et al. (2021) investigated the mediating influence of the demand for independence on the connection between entrepreneurial self-efficacy and entrepreneurial intention among graduate students in Nigeria. Olofinyehun et al., 2017 provided evidence on the presence of a potential pool of educated entrepreneurs in the country. They also looked at how mandatory entrepreneurship education affected the development and sustenance of entrepreneurial attitudes among youths. These studies did not consider how the conditions of the innovation environment can affect the entrepreneurial intentions of students. The study also employed the latest available dataset on entrepreneurial characteristics of undergraduate students in Nigeria.

Many entrepreneurship models and theories exist in examining entrepreneurial intentions. Maheshwari et al. (2022) in a systematic review of factors affecting students' entrepreneurial intentions reported that the theory of planned behaviour (TPB) model as mostly been used in literature to study entrepreneurial intentions of students. However, the theory of planned action

does not account for all the factors that influence university students' entrepreneurial aspirations, including those related to their education, their context, their environment, their psychology, and their personalities. This study will therefore examine the effect of innovation environment on entrepreneurial intentions taking into consideration the moderating role of entrepreneurial education on the relationship between the two issues.

By offering theoretical and practical contributions, this research will contribute to the growing body of knowledge on the factors affecting college students' intentions to begin their own enterprises. The study's recommendations will be helpful to educational institutions in encouraging and supporting students with entrepreneurship and innovation aspirations, and also for policymakers who will be better able to understand how to promote the expansion of entrepreneurship that will ultimately support the country's economic development. This study will provide suggestions on appropriate interventions that can build and develop youth entrepreneurial intentions in the country. The need to stress that there is a growing awareness of the need to combine skills acquisition with technical and academic achievement in order for young people to realize their potentials in the workplace and their development in all domains of life. This study will also strengthen Nigeria's capacity to contribute to the attainment of the Sustainable Development Goals 8 (the promotion of sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; Aspiration 6 of Africa Union's Agenda 2063 (focused on promoting a people-driven development that relies on the potential of African people, especially its women and youth); and employment and job creation objective of the Medium Term National Development Plan (2021-2025). Also, it will also assist in the achievement of the objectives of the Nigerian Youth Employment Action Plan, NIYEAP (2021-2024) which focuses on four priority areas to complement and assist young people obtain decent, productive, and freely chosen work (Employability, Entrepreneurship, Employment, and Equality and rights), strengthen current policy objectives, national development priorities, and related efforts.

Against this background, certain germane questions are pertinent. What makes up the innovation environment of undergraduate students in Nigerian Universities? How does the university innovation environment affect interest of undergraduate students to engage in entrepreneurship? What is the moderating effect of entrepreneurship education on the relationship between innovation environment and entrepreneurial intentions?

Objectives

The study broadly examines the effect of innovation environment on entrepreneurial intentions among undergraduate students in Nigeria. The specific objectives of the study are:

1. Profile the innovation environment of undergraduate students in Nigeria.
2. Determine the innovation environment index of undergraduate students
3. Examine the effect of innovation environment on entrepreneurial intentions of undergraduate students in Nigeria
4. Examine the moderating role of entrepreneurship education on the relationship between innovation environment and entrepreneurial intentions

Literature review

Theoretical Framework

This study employed two theories, the entrepreneurial intention model (EIM) and the Lüthje and Franke Model (LFM).

- a. The Boyd and Vozikis model of entrepreneurial intention (1994). It was further developed from model of entrepreneurial intentionality by Bird in 1988. Bird (1988) demonstrated that both external factors and individual traits influence entrepreneurial ambitions. Politics, society, and the economy are examples of contextual factors that might affect how someone thinks. Personal characteristics are in the form of background and ability. In addition to this, the model added the dimension of self-efficacy as another critical factor affecting an individual's entrepreneurial intention.
- b. The Lüthje and Franke Model (LFM) was developed by Lüthje and Franke (2003). The model clarified the importance of personality characteristics (risk-taking propensity and internal locus of control) and entrepreneurial behavior in determining an individual's entrepreneurial intention. They also added that personal attitudes, social norms, contextual (perceived support and barriers) and economic factors are also influential factors in this process. Nabi et al. (2010) concluded that the integration of personal and environmental factors in the theory further makes it applicable to broad range of factors that influence entrepreneurial intentions of individuals.

Innovation environment in Nigeria and its link to entrepreneurship

Innovation can be described as a procedure of bringing ideas to market. In other words, it explains the procedure for enhancing thoughts. Innovation is a major motivator of competitiveness, job growth, and increase in living standard for future generations (Uguru et al., 2016). Many authors have defined the concept of entrepreneurship in which there is no generally established definition because it is loosely used (Omede and Aghanenu, 2021).

There is an enabling environment in Nigeria to captivate current innovation and production structures, particularly in the services sectors. Nigeria's production system is inefficient and switching to more contemporary and effective production methods, particularly in the service sector (Radwan, and Pellegrini, 2010). Entrepreneurs can be viewed as modernizers within the firm

because they provide the necessary framework for staff to exhibit behaviour intended at recognizing and developing novel concepts, novel approach to trade expansion, and novel approach to managing an already established business (Rivera, 2017). Entrepreneurs and small firms in Nigeria must accept the aforementioned fact if they want to survive and perform better in the face of an increasingly hostile economic environment. As a result, they should proactively develop ways to capitalize on the inventive and entrepreneurial potential that exists within their workforce (Innovation Booster, 2017).

The linkage between innovation environment and entrepreneurship can be described as both a procedure and equivalent outcome (Brazeal and Herbert, 1999). Thus, the final stage of a new technology is simultaneously the starting point for entrepreneurship (Mets, 2005). Entrepreneurship (new organizations and developing organizations) and improvement (patents, R&D and high-tech industries) assist in establishing an avenue anywhere development can healthily exist (Joshi, 2017). The relationship between entrepreneurship and improvement consists of individual and group energies to gather and employ resources to realize the worth of new concepts. These novel concepts could be contemporary for brand-new goods, services, and procedures. The deeper the signal of integration between the two toward the region's prosperity, the closer the connection. The major vehicle for mingling invention into a realistic realm, according to those who spend extensively in it, is entrepreneurship (Joshi, 2017). Therefore, it is crucial to promote innovation and entrepreneurship development in the country.

Intention can be described as the conceptual state that inspires a person to a precise aim (Sharaf et al., 2018). In addition, Fayole et al., (2006) opined that intention is the collective depiction of human's drive toward a definite attitude or character. An entrepreneurial goal plays a pivotal part in the arithmetic advancement of developing an entrepreneurial (Sharaf et al., 2018). It is a key factor that aims in the emergence and development of entrepreneurship; it promotes independence and inspires projects. Entrepreneurial intention can be said to be a mindset concluded by people desire to start an enterprise or a new venture of business.

Entrepreneurial education and entrepreneurial intentions

Many countries have found it appropriate to establish and fund entrepreneurship courses at universities in the hopes of fostering more entrepreneurship in society (Brush et al., 2003). Entrepreneurship education intended at generating graduate who may think of entrepreneurship self-employment as possible career options (Miriti, 2020). The main aim of entrepreneurship is to advance learners' understanding, permit them to progress their entrepreneurial abilities, impart them how to place concepts into reality, and help them recognize entrepreneurship as a viable career route.

Entrepreneurship education had been found to positively influence entrepreneurial intention (Miriti, 2020).

Empirical evidence exists on the relationship between entrepreneurial education and intention to start a business. According to Hattab (2014) students who offer courses that are related to businesses learn about entrepreneurship. This eventually improves their thinking and encourages them to come up with and implement new business concepts and become self-employed. Entrepreneurial education is important due to its positive strengthening towards learners and motivation in embarking into entrepreneurs. Entrepreneurship education significantly contributes to students' ability to adopt a supportive mindset toward business goals. More so, entrepreneurial education is mandatory in advancing a particular custom of students, which are a progressive sign of their entrepreneurial goals. Therefore, it is vital in this era that universities offer entrepreneurial courses to stimulate the desire and competence in learners/students to start their own enterprises.

Review of empirical studies

Del Brio Gonzalez et al., (2022) established that being environmentally conscious has a favorable and significant impact on one's aspirations to start a business. Additionally, it was discovered that the relationship between environmental consciousness and entrepreneurial zeal is affected by how important consumers perceive ecological consumption to be. Jiang et al. (2022) in a related study also reported that family, education, social and policy factors do not statistically have effect on an individual's intention to begin a business but serve as a buffer between different influences. Miriti (2020) in a study of University students in Kenya reported that student's attitude and sense of self-efficacy have a big influence on their intentions to begin their own business. It was added that there is a significant influence of entrepreneurial experience on entrepreneurial intention.

Kisubi, et al., (2020) revealed that there is no substantial difference between business and non-business students in their plans to start their own business. The study reported that students' entrepreneurial education was significantly predicted by their entrepreneurial mindset. Liu et al., (2019) revealed that entrepreneurial education positively influenced college students' entrepreneurial intentions in China. Entrepreneurial self-efficacy improved entrepreneurial attitude and ambition. Ndofirepi (2020) in a study on the relationship between entrepreneurship education and entrepreneurial goal intentions using psychological traits as mediators revealed that a positive significant association between the influence of entrepreneurship education and desire for attainment, tendency for taking risks, interior locus of regulator, and aspirations to pursue entrepreneurial goals. The association was slightly influenced by the demand for accomplishment.

De Maraes et al. (2017) investigated the effect of entrepreneurial characteristics and university environment on entrepreneurial goal. It was reported that inferred that the university atmosphere, attitudes toward taking risks and self-efficacy, and students' entrepreneurial intentions are all subjective. Further evidence suggests that student traits related to planning, leadership, and innovation invariably increase self-efficacy. Romero-Galisteo et al., (2022) investigated entrepreneurial goal, potentials of success and self-efficacy in undergraduate students of health sciences. The primary data collected from undergraduate health sciences students. The findings indicate that perceptions of desirability and viability were both effective and substantial predictors of entrepreneurial intention.

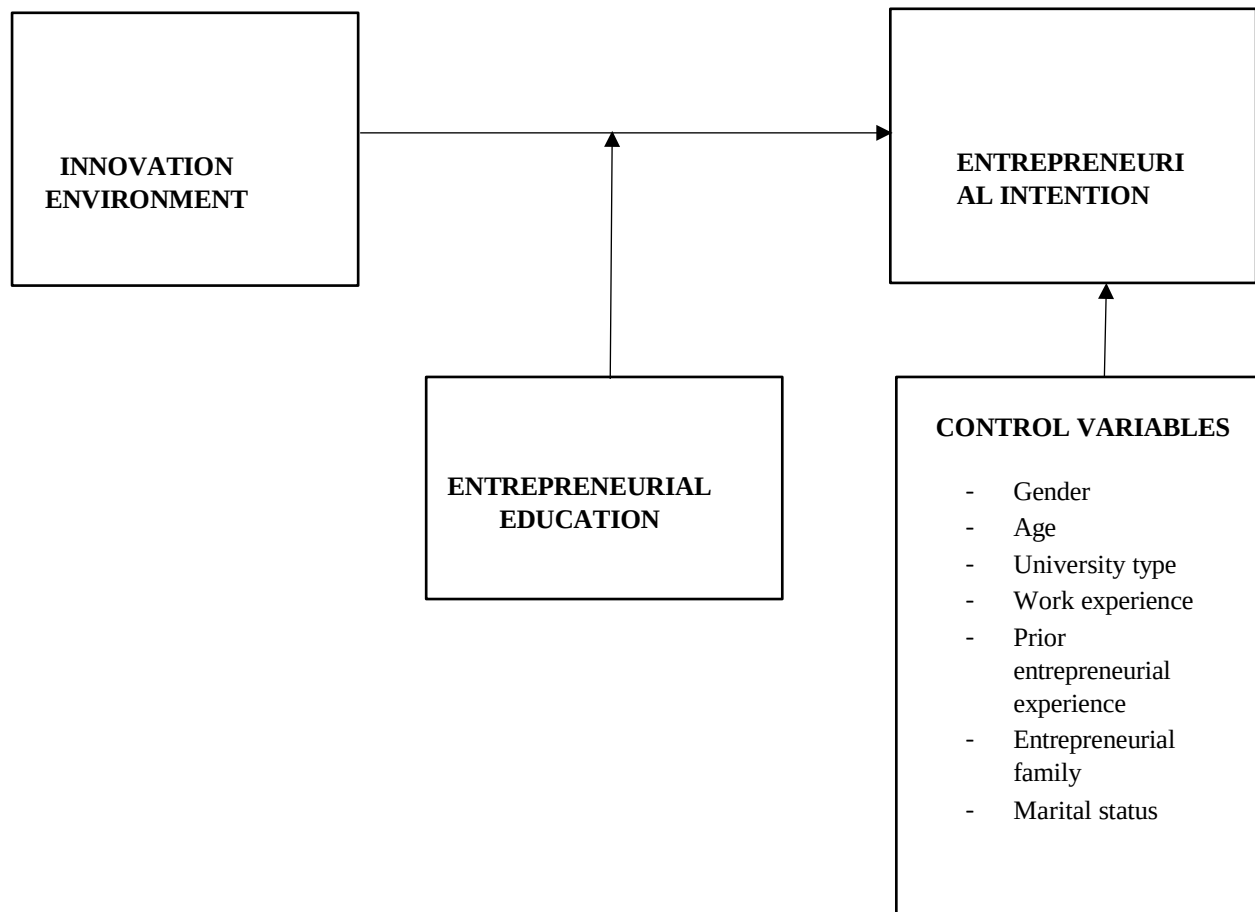
Kaki et al. (2022) investigated the entrepreneurial goal amid undergraduate agricultural learners in the Republic of Benin. The primary data collected among final year students of Agriculture were evaluated using descriptive statistics and binary regression model. The findings revealed that age, specialization, university attained, and prior know-how in agribusiness are substantial aspects that impact agricultural learners' entrepreneurial purpose in agribusiness. Sharaf et al., (2018) examined factors that affect entrepreneurial goal within University learners in Egypt. The primary data gathered from undergraduate learners were evaluated using descriptive statistics, structural equation model, confirmatory factor analysis and linear regression analysis. The findings found that the insolence toward entrepreneurship has a favourable, substantial consequence on entrepreneurial intention. Further evidence indicates that subjective standards and apparent behavioural control have negligible influence on entrepreneurial intention. Additionally, the psychological characteristics of entrepreneurs had a negligible impact on their purpose.

Sata (2013) assessed the entrepreneurial goal amid undergraduate business learners. The data gathered from final-year students was analyzed by Descriptive statistics, Correlation analysis, T- test and Linear Regression Model. The findings found that there exist a positive association between university students' intentions to pursue entrepreneurship and the aspects of entrepreneurship. Further finding indicates that perceived self-efficacy and family business background explain difference in students' targets to launch a new trade. Kuttim et al. (2013) identified the content entrepreneurship education at university level and students' entrepreneurial intents. The primary data gathered from students was evaluated by Descriptive statistics and a Binary Logistic Regression Model. The outcomes establish that although lectures and seminars are more frequently presented, students are more likely to anticipate networking and coaching activities than the courses that are actually offered. Further evidence reveals that involvement in entrepreneurship education was establish to inert progressive influence on entrepreneurial intents.

Conceptual Framework

Entrepreneurial intention plays a vital role in entrepreneurship. Understanding the drivers of entrepreneurial intentions of undergraduate students is important as it will allow researchers and policy makers to plan on necessary actions to motivate youths to start business. Entrepreneurial intention is explained as the interest of the student to start a business. Improving the entrepreneurial intentions of University students is also dependent on the innovation environment in which these students operate. The innovation environment in this study is conceptualized with a set of variables. These variables are: 1. The atmosphere at my university enables me to develop new ideas; 2. favourable climate for becoming an entrepreneur exist at my University; 3. students are encouraged to engage in entrepreneurial activities; 4. adequate laboratories and equipment for skill acquisition; 5. exposure to practical approach to entrepreneurship and businesses in my department; 6. adequate lecture halls for teaching and learning of entrepreneurship education at my University. It is expected that the innovation environment will have influence on the possibility that these students will become entrepreneurs. This study primarily explores the effect of innovation environment on entrepreneurial intentions of undergraduate students in Nigeria as shown in Figure 2. With respect to the moderating role of entrepreneurial education, it is believed that entrepreneurship education enhances entrepreneurial confidence of the students and this influences entrepreneurial intentions. Entrepreneurial education helps the students garner the requisite knowledge and skills that will boost their understanding, awareness and interest about entrepreneurship. This education also affects innovation environment. Additionally, individual heterogeneity may influence the interest as exemplified by the control variables.

Figure 2: Conceptual Framework showing the effect of innovation environment on entrepreneurial intentions



Methodology

Data sources and description

Data was sourced from the National Centre for Technology Management (NACETEM), Ile-Ife, Nigeria. The data was collected at four periods (2007, 2010/11, 2016 and 2020/21) from undergraduate students in six selected Universities in Nigeria (Olofinyehun et al., 2021). A sample of 12, 615 undergraduates were sampled across three disciplines namely the social sciences, sciences and engineering disciplines (Olofinyehun et al., 2021). for this study, only the 2020/21 wave was used as it is the only dataset with indicators of innovation environment as captured in this study. The dataset includes variables on parental entrepreneurial experience, entrepreneurial experience, education, motivation and interest/attitude; entrepreneurship training; university entrepreneurial context and potential; personal entrepreneurship characteristics.

Analytical Techniques

Objective one, which is to profile the Profile the innovation environment of undergraduate students in Nigeria was analysed using descriptive statistics. Objective two, on the innovation environment index was estimated using the weighted sum of the innovation environment variables. The innovation environment variables were likert scale responses. The variables were operationalized as never (0), rarely (1), sometimes (2), usually (3), always (4). Objective three and four was analysed using a logit regression. Table 3.1 provides the variable description and definition.

In order to explore the effect of innovation environment on entrepreneurial intentions among undergraduate students in selected Universities in Nigeria, this study employed a logit regression model. The logit regression is applicable because the dependent variable is a binary variable.

The regression model is expressed as follows in equation (1):

$$Eli = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \dots + \beta_nX_n + \varepsilon_i \quad \dots \dots \dots eq (1)$$

Where Eli is defined as

$$Eli = \begin{cases} 1 & \text{if student has interest in starting a personal business and} \\ 0 & \text{Otherwise} \end{cases}$$

The explanatory variables are:

X_1 = Innovation index

X_2 = Sex of the student (1= Male; 2 = Female)

X_3 = Marital status (1 = single; 2= married; 3 = divorced/separated)

X_4 = Course level (1 = 100L; 2 = 200L; 3 = 300L; 4 = 400L; 5 = 500L)

X_5 = Parent engagement in business (1 = Yes; 0 = No)

X_6 = Taken course on entrepreneurship (1 = Yes; 0 = No)

X_7 = Parent education (Father's level of education*Mother's level of education)

X_8 = Present CGPA (1 = 1.0+; 2 = 2.0+; 3 = 3.0+; 4 = 4.0+; 5 = 5.0+; 6= 6.0+; 7= 7.0)

X_9 = Student engagement in business (1 = Yes; 0 = No)

Ei = Error term

The structure of the logit regression model is expressed in equation (2).

$$\text{Prob}(y_1 = 1) = \text{Prob}(\varepsilon_i > -\beta'x_i) = 1 - F(-\beta'x_i) \quad \text{equation (2)}$$

If the cumulative probability function of error term ei is assumed to have a logistic distribution, we have the logit model:

$$F(-\beta'x_i) = \frac{\exp(-\beta'x_i)}{1 + \exp(-\beta'x_i)} = \frac{1}{1 + \exp(\beta'x_i)} \quad \text{equation (3)}$$

Hence,

$$1 - F(-\beta'x_i) = \frac{\exp(\beta'x_i)}{1 + \exp(\beta'x_i)} \quad \text{equation (4)}$$

Variable	Variable definition
Entrepreneurial intention	Interest in starting a personal business
Innovation environment	a. University atmosphere inspires me to develop new ideas b. Adequate laboratories and equipment for skill acquisition c. Exposure to practical approach to entrepreneurship and businesses in my department d. University climate is favourable for becoming an entrepreneur e. Adequate lecture halls for teaching and learning of entrepreneurship education at my University f. Students' engagement in entrepreneurial activities in the university
Entrepreneurial education	Taken any entrepreneurship course Knowledge gained from the course
Control variables	Gender Age University type Work experience Prior entrepreneurial experience Entrepreneurial family Marital status

Results and discussion

Socio-economic Characteristics of Undergraduate Students

This section presents the socio-economic characteristics of the sampled undergraduate students in Nigeria. The characteristics presented as shown in Table 2 were age, sex, marital status, religion, ethnic origin, name of institution, discipline, present level of study, present CGPA, level of education of father and mother. Findings revealed that the age of students ranged from below 16 years of age to above 40 years. Most of the students were between age 21-25 years (50.8%), followed by those between 16-20 years of age (36.1%). About 10.5% were between 26-30 years of age, while the least were those below 16 years and 40 years of age (0.4% respectively).

The sampled undergraduate students were mostly male as they comprised of 53.7% of the sampled students. Female students were about 46.4% of the sample. Most of the students were single (92.8%), while about 7% were married. This is as expected as most undergraduate students in Nigeria are unmarried youths. About 73.6% of the sampled undergraduate students reported to be of the Christian religion, while 25.8% practiced Islamic religion. With respect to

ethnicity, the sampled undergraduate students were mostly Yoruba (49.1%), followed by Igbo (14.2%) and Hausa (12.1%).

The proportion of sampled undergraduate students by Universities were also presented. About an equal proportion of undergraduate students were sampled across the five selected Universities in Nigeria. From the five Universities, only one was a private University (Covenant University). About 19.3% of the undergraduate students were from Covenant University, followed by University of Lagos (17.3%), Ahmadu Bello University (16.9%), Obafemi Awolowo University (16.8%), Federal University of Technology, Minna (16.2%) and Federal University of Agriculture, Abeokuta (13.5%).

The sampled Undergraduate students were from various disciplines from Technology-based, Science-based, Social science-based and other disciplines. About 44.8 of the sampled Undergraduate students were Science-based, followed by Technology-based (25.7%) and Social science (25.4%). Other disciplines were only 3.2% of the sample. With respect to the present level of sampled undergraduate students, they were chosen from 200 level to 500 level. About 30.5% of the sampled undergraduate students were in 500 level, followed by 400 level (29.7%), 300 level (28.6%), while the least were students in 200 level (11.2%). 100 level students were not included in the sample as most entrepreneurship courses in Nigerian Universities are introduced from 200 level. The present cumulative grade point average (CGPA) of the sampled undergraduate students revealed that most sampled students had a CGPA of 4.00+ (43.6%), followed by 5.00+ (28.7%) and 3.00+ (25.3%). The results reflect a normal distribution of student performance in the country as most students clustered around the average and fewer students with 6.00+ and 7.00. The same also goes for those at the lower boundary (1.00+, 2.00+ and less than 1).

Parental education also matters for entrepreneurship intentions of undergraduate students. In this case, father's and mother's education were reported. Findings revealed that most fathers had a B.Sc. degree (25.4%), followed by M.Sc. (16.6%), secondary education (12.4%) and those with Ph.D. (10.6%). Others were fathers with HND (8.2%), technical college (8.0%), NCE (5.2%), primary education (5.0%), OND (4.3%) and no formal education (4.2%). The same trend also holds for mothers, although slight variations in some cases. Most mothers had B.Sc. degree (25.6%), followed by those with secondary education (16.2%), M.Sc. (12.3%), NCE (10.1%), HND (8.6%), and primary education (6.7%). The distribution of other levels of mother's education is shown in Table 2.

Table 2: Socio-economic characteristics of undergraduate students in Nigeria

Characteristics	Frequency	Percentage
Age		
Below 16	15	0.40

16-20	1370	36.08
21-25	1930	50.83
26-30	397	10.46
31-35	38	1.00
36-40	32	0.84
above 40	15	0.40
Total	3797	100.00
Sex		
Male	2045	53.65
Female	1767	46.35
Total	3812	100.00
Marital status		
Single	3436	92.84
Married	258	6.97
Divorced/Separated/Widowed	7	0.19
Total	3701	100.00
Religion		
Christianity	2612	73.45
Islam	917	25.79
Others	27	0.76
Total	3556	100.00
Ethnic origin		
Hausa	451	12.13
Igbo	528	14.21
Yoruba	1825	49.10
Others	913	24.56
Total	3717	100.00
Name of institution		
ABU	649	16.87
Covenant	744	19.33
FUNAAB	521	13.54
FUTMinna	623	16.19
OAU	646	16.79
UNILAG	665	17.28
Total	3848	100.00
Discipline		
Tech-based	1007	26.66
Science-based	1691	44.77
Social science-based	958	25.36
Others	121	3.20
Total	3777	100.00
Present level of study		

500 L	1151	30.52
400 L	1121	29.73
300 L	1078	28.59
200 L	421	11.16
Total	3771	100.00
Present CGPA		
Less than 1	1	0.03
1.00+	6	0.17
2.00+	69	1.96
3.00+	890	25.30
4.00+	1535	43.63
5.00+	1011	28.74
6.00+	2	0.06
7.00	4	0.11
Total	3518	100.00
Father's highest level of education		
No Formal Education	152	4.20
Primary	182	5.03
Secondary	449	12.41
Technical college	289	7.99
NCE	187	5.17
OND	157	4.34
HND	295	8.16
B.Sc	920	25.44
M.sc.	602	16.64
PhD	384	10.62
Total	3617	100.00
Mother's highest level of education		
No Formal Education	195	5.45
Primary	240	6.71
Secondary	578	16.16
Technical college	200	5.59
NCE	361	10.09
OND	166	4.64
HND	309	8.64
B.Sc	916	25.61
M.sc.	441	12.33
PhD	171	4.78
Total	3577	100.00

Entrepreneurial Characteristics of Undergraduate Students in Nigeria

This section explains the entrepreneurial characteristics of undergraduate students in Nigeria as shown in Table 3. Majority of the students reported that at least one of their parents have initiated or run a business before. This was put at 82.3% of the sampled undergraduate students. This is most likely to stimulate these students to become entrepreneurs. Interestingly, about 76% reported that the business is still ongoing. This could further fuel the interest of the students in entrepreneurship.

The sector of entrepreneurship business was mostly trading, as 62.1% of the students reported this. This is followed by the service sector (30.4%), agriculture (19.8%), manufacturing (12.0%). The students were also asked if they are presently engaged in any business. Only 39.1% of the students reported that they were presently engaged in a business. A higher proportion of them were not engaged in any business (60.9%). This rather high proportion of non-engagement in business could be attributed to a number of factors, of which the innovation environment is a factor. Others could be parental experience, entrepreneurship environment/atmosphere in the country.

About 46.0% were involved in trading and 37.6% involved in services. Only 12.2% of the students engaged in business were in the manufacturing sector and agriculture was 11.0%, others (14.3%). This implies that most students were not engaged in productive sectors of the economy. With respect to the level of business involvement, 63.4% of the students were initiators of the business. and 36.8% were also partners in the businesses engaged in. This has an influence on the entrepreneurial intentions of these students.

Table 3: Entrepreneurial characteristics of undergraduate students

Entrepreneurial characteristics	Frequency	Percentage
has any of your parents initiated or run a business before?		
No	666	17.71
Yes	3095	82.29
Total	3761	100.00
Is the business ongoing?		
No	787	24.03
Yes	2488	75.97
Total	3275	100.00
Type of parental business		
Manufacturing	260	11.98
Service	693	30.39
Trading	1719	62.08
Agriculture	448	19.81
Others	174	8.11
Present engagement in business?		

No	2293	60.90
Yes	1472	39.10
Total	3765	100.00
Type of student business*		
Manufacturing	144	12.22
Service	484	37.55
Trading	627	46.04
Agriculture	129	10.95
Others	165	14.34
Level of business involvement*		
Initiator	954	63.35
Partner	553	36.84
Motivation for involvement*		
Parents	309	23.90
Siblings/relative	154	12.69
Personal interest	944	61.54
Events	73	6.23
Peers	116	9.91
Others	42	3.66

* Multiple responses

Entrepreneurial Education

Entrepreneurial education shapes the behavior of entrepreneurs (Gary, 1997). This would invariably influence the attitude and skills acquisition of the individuals (Walter and Joern, 2016). In this study, about 74.6% of the students have taken entrepreneurship courses before and they reported on several gains from the course taken. This can be seen in Table 4. the gains from the course varied among students. Ability to identify business opportunities (73.8%), practical management skills (65.3%), increased understanding of entrepreneurship (64.5%^), increased understanding of attitude, value and motivation of entrepreneurs (64.4%), ability to develop a network (53.7%) and ability to grow business (50.5%). These gains are likely to stimulate the interest of the students in entrepreneurship. It can be seen here that entrepreneurial education has helped in improving the thought process of the individual, skills and help to achieve a deeper recognition and consciousness of entrepreneurial activities and assist the students in solving practical entrepreneurial problems. for instance, Ma and Bai (2015) noted that in China, the core of entrepreneurship education consisted of a task designed to foster the development of innovative talents by honing their entrepreneurial awareness and practical skills

Table 4: Entrepreneurship course and gains

	Frequency	Percentage
Taken entrepreneurship course before		
Yes	2819	74.56
No	962	25.44
Gains from entrepreneurship course		
Ability to identify business opportunities	1919	73.8
Ability to develop network	1207	53.7
Practical management skills	1598	65.3
Increased understanding of attitude, values and motivation of entrepreneurs	1555	64.4
Increased understanding of entrepreneurship	1584	64.5
Ability to grow a business	1209	50.5

Innovation Environment of undergraduate students in Nigeria

Innovation Environment Characteristics

Innovation is a crucial indicator of a nation's overall strength because innovation is fundamental to the economy's rapid expansion. Innovation is the key to development, and talent is the key to innovation. Governments all over the world have developed a number of unique entrepreneurial support systems in accordance with the needs of college students on the basis of the current situation in order to address the issue of the high rate of youth unemployment in the world and encourage university students to invest in entrepreneurship (Keinänen et al., 2018). The innovation characteristics of undergraduate students in Nigeria is presented in Table 5. Results revealed that 31.1% of the students reported that the university atmosphere helps to develop new ideas. This is followed by students who reported that always and usually inspires to develop new ideas (20.3% and 20.1% respectively). Only 29% of the sampled students reported that the university climate sometimes favour entrepreneurship. About 24.3% of the students alluded that the university climate usually favours entrepreneurship. Students are encouraged to engage in entrepreneurship activities as about 28.8%, 26.4% and 24.3% affirmed that it always, sometimes and usually does respectively. With respect to adequate entrepreneurial laboratories and equipment for skill acquisition, 36.9% of the

students alluded to the fact that they never and rarely have adequate equipment and skills for entrepreneurship. About 24.3% reported that they were sometimes exposed to practical to entrepreneurship business. Adequate lecture halls for teaching and learning entrepreneurship education always (27.0%), usually (22.7%), sometimes (21.4%) available to the students. Only 10.3% of the sampled students said it was never available.

Table 5: Innovation environment characteristics

Innovation environment characteristics	Never	Rarely	Sometimes	Usually	Always
University atmosphere inspires me to develop new ideas	427 (11.5)	622 (16.8)	1159 (31.3)	745 (20.1)	753 (20.3)
University climate is favourable for becoming an entrepreneur	220 (6.0)	764 (20.7)	1070 (29.0)	896 (24.3)	734 (19.9)
Students' engagement in entrepreneurial activities in the university	206 (5.6)	553 (15.0)	973 (26.4)	895 (24.3)	1060 (28.8)
There are adequate entrepreneurial laboratories and equipment for skills acquisition	421 (11.5)	929 (25.4)	858 (23.4)	806 (22.0)	649 (17.7)
We were exposed to the practical approach of entrepreneurship or businesses	666 (18.3)	743 (20.4)	885 (24.3)	704 (19.4)	640 (17.6)
There are adequate lecture hall for teaching and learning of entrepreneurship education	378 (10.3)	689 (18.7)	788 (21.4)	835 (22.7)	994 (27.0)

Innovation Environment Index

This section presents the innovation environment index of undergraduate students in Nigeria. Findings revealed that 35.9% had innovation environment index between 0.401-0.6. This was followed by those between 0.601-0.8, which was put at 25.1%. About 18.2% had index between 0.201-0.4. This is shown in Table 6. The average innovation environment index was 0.538. This implies that the state of the innovation environment is slightly above average. Obviously, there is still room for improvement in the innovation environment that supports entrepreneurship among students in the country.

The average innovation environment index was used to categorize the respondents into those more innovation environment and less innovative

environment. Using the mean as a cutoff, about 53.1% of undergraduate students have a more innovative environment that supports entrepreneurship, while 46.9% had less innovative environment (see Table 7).

Table 6: Innovation Environment Index

Index	Frequency	Percentage
0.0-0.2	293	7.61
0.201-0.4	699	18.17
0.401-0.6	1382	35.91
0.601-0.8	967	25.13
0.801-1.0	507	13.18
Total	3848	100.00
Mean	0.538	
Standard deviation	0.235	

Table 7: Innovation Environment status of undergraduate students

Innovation environment status	Frequency	Percentage
less innovative environment	1803	46.86
More innovative environment	2045	53.14
Total	3848	100.00

Effect of innovation environment on entrepreneurial intentions of undergraduate students in Nigeria

This effect of innovation environment on entrepreneurial intention of undergraduate students in Nigeria is presented in Table 8. The diagnostics showed that $\text{prob} > \chi^2$ was 0.000, showing that the model was significant at 1%. Findings revealed that innovation environment has a positive relationship with entrepreneurial intentions of undergraduate students. However, this not significant. Recall that in earlier sections, the innovation environment index was 0.538, which is slightly above average. This therefore, implies that the innovation environment in Nigerian Universities is not favourable enough to bring about the desired significant change in entrepreneurial intentions of students. Efforts should be geared at improving the innovation environment as this would drive a positive change in entrepreneurship development in the country and it would be a step in the right direction for the government and policy makers towards addressing unemployment among youths, most especially.

Other variables that significantly influence entrepreneurial intentions of undergraduate students are marital status, course level, parental engagement in entrepreneurship business, entrepreneurship education, students CGPA, parent's education and presently engaged in any business.

Being a married or divorced/ separated student decreases the likelihood of having interest in entrepreneurship. This implies that undergraduate students that are married or divorced/separated are less likely to have interest in entrepreneurship. This could be as a result of the several demands marriage and divorces poses in a developing economy like Nigeria, where access to credit and the supposed entrepreneurial environment is not supportive and encouraging for would-be entrepreneurs. As the course level of a student increases, the likelihood that such a student will have interest in entrepreneurship increases. Being in 300 level increases the likelihood of this interest at 1% significant level. Being in 200 level, however decreases this probability at 10% level of significance. This result could be due to the fact that as the student advances in level, he/she becomes more aware and conscious of the country realities after graduation, and as such seeks for opportunities and ways not to be caught in the unemployment conundrum the country as found itself. In that wise, the student begins to think of what to engage in during school or immediately after graduation. for undergraduate students whose parents are involved in entrepreneurship, the likelihood increases entrepreneurial interest at 1% level of significance. This is so because the student already has his/her parents as guide in entrepreneurship, and this is somewhat important for would-be entrepreneurs so as to gain confidence and have the required motivation to engage in any business of their own. It could also serve as a leverage in terms of financial empowerment for the student. Undergraduate students who have taken entrepreneurship courses are more likely to have interest in entrepreneurship at 1% level of significance

The coefficient of student's CPGA was negative and significant. As the CGPA of a student increases, such student is not likely to have interest in entrepreneurship. It was significant at 5% and 1% for students with CGPA of 2+ and 3+ respectively Parent education was negative and significant at 1% with interest in entrepreneurship. The likely reason for this is that given our contextual background, educated parents would prefer their children to have white-collar jobs as against these students venturing into businesses of their own. Student engagement in business was positive and significant with the probability of having interest in entrepreneurship. This implies that a student involvement and engagement in business would likely spur the student's interest in entrepreneurship. This is because the student already has a foretaste of what is involved in business and can use the accumulated experience to succeed also as an entrepreneur

Table 8: Effect of innovation environment on entrepreneurial intentions of undergraduate students in Nigeria

Entrepreneurial intention	Coefficient	Standard error	t	p
Innovation index	0.041	0.273	0.15	0.879
Sex				
Female	-0.196	0.12	-1.64	0.102
Marital status				
Married	-1.098***	0.193	-5.68	0.000
Divorced/Separated	-2.584*	1.461	-1.77	0.077
Course level				
400 L	0.123	0.149	0.82	0.410
300 L	0.338**	0.165	2.05	0.04
200 L	-0.358*	0.197	-1.82	0.069
Parent engagement in business				
Yes	1.901***	0.128	14.87	0.000
Taken course on entrepreneurship	0.504***	0.138	3.65	0.000
Parent education	-0.008***	0.003	-2.95	0.003
Present CGPA				
2.00+	-0.824**	0.403	-2.05	0.041
3.00+	-0.803***	0.169	-4.74	0.000
4.00+	-0.146	0.158	-0.92	0.355
Student engagement in business	2.065***	0.188	10.96	0.000
Constant	0.08	0.289	0.28	0.783
Prob > chi2= 0.000				
Number of observations = 2900 Pseudo r-squared = 0.272				
Chi-square = 711.877				

Moderating role of entrepreneurship education on the relationship between innovation environment and entrepreneurial intentions of undergraduate students in Nigeria

This section presents the moderating effect of entrepreneurial education on entrepreneurial intentions of undergraduate students in Nigeria. The interaction of entrepreneurial education with innovation environment index provides an estimate of how the entrepreneurial intention is affected by entrepreneurial education. The coefficient of the interaction term (entrepreneurial education and innovation environment) is positive but not statistically significant (Table 9). This suggests that even though the conditions of the innovation environment in Nigerian Universities is fair, the taking entrepreneurship courses alone does not necessarily imply that undergraduate

students will be interested in entrepreneurship. In other words, a student who is currently in any Nigerian

University is likely to be interested in entrepreneurship and remain interested because he/she took courses in entrepreneurship and operates in an innovative environment. In addition, the interaction of entrepreneurship education with innovation environment revealed that the effect of innovation environment observed earlier disappeared in the presence of entrepreneurial education. This hints at a moderating effect of entrepreneurial education on entrepreneurial intentions. In other words, compared to other students who operate in the same innovation environment, the students who in addition took courses in entrepreneurship are only more likely to be interested in entrepreneurship. This is a particularly interesting result that lends support to policy on education that emphasizes the inclusion of entrepreneurship courses in University curriculum. Thus, even if such policies have under-performed historically, they are still necessary; policymakers only need to find ways to make them work.

Table 9: Moderating role of entrepreneurship education on the relationship between innovation environment and entrepreneurial intentions of undergraduate students in Nigeria

Entrepreneurial intention	Coefficient	Standard error	t	p
Innovation index	-0.399	0.489	-0.82	0.414
Sex		.	.	.
Female	-0.199*	0.12	-1.66	0.096
Marital status		.	.	.
Married	-1.092***	0.193	-5.65	0.000
Divorced/Separated	-2.582*	1.449	-1.78	0.075
Course level		.	.	.
400 L	0.124	0.15	0.83	0.406
300 L	0.341**	0.165	2.06	0.039
200 L	-0.348*	0.197	-1.77	0.077
Parent engagement in business		.	.	.
Yes	1.89***	0.128	14.75	0.000
Taken course on entrepreneurship		.	.	.
Yes	0.177	0.332	0.53	0.594
Parent education	-0.008***	0.003	-2.95	0.003
Present CGPA		.	.	.
2.00+	-0.823**	0.403	-2.04	0.041
3.00+	-0.789***	0.17	-4.65	0.000
4.00+	-0.141	0.158	-0.89	0.371
Student engagement in business	2.068***	0.188	10.98	0.000
EE*IE	0.635	0.584	1.09	0.276

Constant	0.297	0.353	0.84	0.401
Number of observations = 2900 Chi-square = 713.064 Prob > chi2 = 0.000 Pseudo r-squared = 0.272				

*** p<0.01, ** p<0.05, * p<0.1

Conclusion and recommendations

The effect of innovation environment on entrepreneurial intentions among undergraduate students in Nigeria was investigated. the study established that innovation environment of undergraduate students matter for entrepreneurial intention/entrepreneurship. It added that improvement in innovation environment alone does not promote interest in entrepreneurship, rather entrepreneurial education with a favourable innovation environment facilitates interest in entrepreneurship. The study established that innovation environment of undergraduate students matter for entrepreneurial intention/entrepreneurship. The conditions of the University innovation environment is slightly above average and undergraduate students have shown interest in entrepreneurship. It added that improvement in innovation environment alone does not promote interest in entrepreneurship, rather entrepreneurial education with a favourable innovation environment facilitates interest of undergraduate students in entrepreneurship. Parental education and engagement in entrepreneurship also matter for entrepreneurial interest. This study provides suggestions on appropriate interventions that can build and develop youth entrepreneurial intentions in the country. The study recommends that:

1. Universities and relevant stakeholders should improve innovation environment for entrepreneurship. This could be done by creating an atmosphere that enables students to develop new ideas, engage in entrepreneurial activities and exposed to practical approach to entrepreneurship and businesses.
2. The National Universities Commission and other relevant stakeholders should emphasize the important role entrepreneurial education in University curricula.
3. Concerted efforts should be geared at improving the innovation environment as well as education of entrepreneurship in Nigeria.
4. Additionally, students should be exposed to entrepreneurship early enough and educated parents should encourage their children to engage in entrepreneurship.

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