AN ACTIONABLE RESEARCH AGENDA FOR INCLUSIVE LOW-CARBON TRANSITIONS FOR SUSTAINABLE DEVELOPMENT IN THE GLOBAL SOUTH

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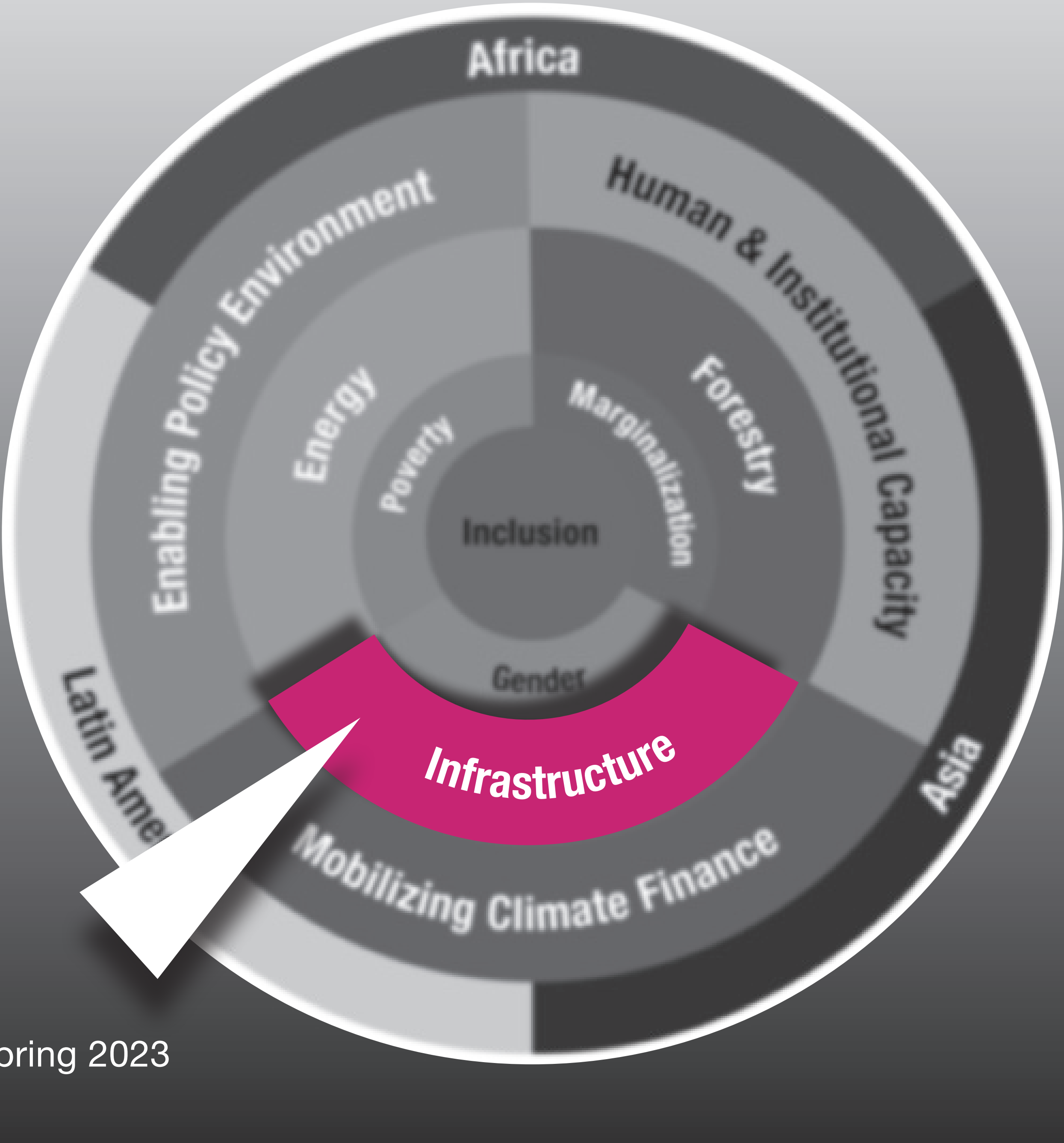
Infrastructure



Spring 2023

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Preface

All countries now face enormous challenges posed by climate change. The consequences of continued greenhouse gas emissions are dire, particularly for countries in the Global South that are both more affected and more vulnerable to climate change at the same time as they have less capacity to adapt (AfDB, 2022). The realization that a low-carbon transition needs to be implemented in countries in the Global South is well established and is also reflected in most countries' ratification of the Paris Agreement and in their Nationally Determined Contributions. In effect, most countries in the Global South are now confronted with the fastest and most dramatic transformation of their economies that they have ever experienced – or at least they would need to be.

The low-carbon transition in the Global South needs to be guided by research since such a transition is inherently a very knowledge-intensive process. This is why the Sustainable Inclusive Economies (SIE) Division of the International Development Research Centre (IDRC) has identified this area as particularly interesting to support. This report is commissioned by SIE as part of a bigger initiative to develop an actionable research agenda that IDRC can support to achieve a low-carbon transition with gender equity in the Global South.

Infrastructure (Transport and Digital) is part of the Research Agenda for Low Carbon Transition and Gender Equity in the Global South series of papers. The consortium that is working on this series of papers is global and consists of 60 researchers from a multitude of universities and institutions. This particular paper has been written by Franklin Amuakwa-Mensah from EfD Global Hub, Gothenburg, Philip Adom from the Ghana Institute of Management and Public Administration, Accra, Amin Karimu from the School of Economics, University of Cape Town, Cape Town, and Jabir Ibrahim Mohammed from the University of Ghana. The EfD Global Hub staff supporting the authors was Alejandro Lopez Feldman.

This paper is based on two systematic literature reviews, one on the impact of digital technologies on the energy system, social inclusion, and household welfare, and the other on the impact of public-private partnerships (PPPs) in the provision of low-carbon transport infrastructure for social inclusion in the Global South. We hope to receive constructive comments on this draft paper from IDRC, our networks and external scholars, and practitioners. We will then revise the paper for validation by policy makers and senior civil servants in the Global South. Based on the reviews and validations we plan to prepare final versions of both the paper and the accompanying High-Level Research Agenda by March 2023. The ambition is that these papers will be useful for both donors and research institutions in supporting an even greater contribution by research to a much needed low-carbon transition with gender equity in the Global South in this crucial Decade of Action.

Gunnar Köhlin
Director, Environment for Development

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Infrastructure (transport and digital)

1.1 Introduction

This paper provides a systematic literature review of i) the impact of digital technologies on the energy system, social inclusion and household welfare; and ii) the impact of public-private partnerships (3Ps) in the provision of low-carbon transport infrastructure on social inclusion in the Global South. The aim is to identify research gaps in these two thematic areas whose closure could inform actionable research in transitioning to a low-carbon economy in the Global South.

Infrastructure, whether hard (or soft), is a catalyst of economic growth. In spite of its recognized importance, most developing countries face an infrastructure deficit with a significant investment gap of US $1-1. 5 trillion. For instance, in the case of Africa, the financing gap range is US $68–$108 billion (African Development Bank, 2018). Furthermore, quality of the infrastructure is low in developing countries relative to developed countries. Estimates based on perception of infrastructure quality suggest a significant gap between developed and least developed countries. Whereas developed countries scored 5.07 out of 7 on the quality index, that of the least developed countries scored 2.58 (World Economic Forum, 2019).

Moreover, the existing infrastructure is either deteriorated or has been exposed to the adverse effect of climate change. The Global Center on Adaptation report (2020), suggests that developing countries should incorporate adaptation to climate change when planning new infrastructure. Examples include investment in climate-resilient infrastructure, such as low-emission energy generation and transport, nature-based solutions (NBS), and the digital economy, especially in urban centers (GCA, 2020).

Digital technology- This is being embraced by many emerging and developing countries, including those in Africa. Globally, investment in digital infrastructure rose during the COVID- 19 pandemic era. It was hoped that this would reduce the negative impacts of the pandemic, and assist the recovery of the world economy (Oldekop, et al., 2020). Digital infrastructure generates multiple effects. It can stimulate economic growth (Roller and Waverman, 2001), increase productivity (Hawash and Lang, 2020), foster knowledge spillovers and agglomeration economies at different scales (Tao et al., 2019), promote employment (Hjort and Poulsen, 2019), and improve the quality of life (Munoz and Naqvi, 2017). For example, there is evidence suggesting that digital infrastructure could have a strong impact on helping women create new businesses. This is certainly crucial in the face of the gender inequality debate. Aside from the above, digital infrastructure can also impact energy footprints and the environment and the argument is inconclusive. First, there is the argument that digital technology can be energy-consuming in many ways - via embodied energy, induced energy, grey energy, and operational energy. In SSA, this is exacerbated by sprawl conditions. According to Jones (2018), digital infrastructure such as Information and Communications Technology (ICT) consumes significant energy, and it is estimated that it will consume more than 20% of the world's electricity by 2030. The second argument is that by improving operational efficiency, digital technologies can facilitate energy efficiency improvement. In this regard, digital technologies have been identified as key to contribute to the low-carbon economy agenda.

The low levels of electrification in the Global South bring a few key questions: (i) what is the impact of digital technologies on the energy system (i.e., demand and supply-side)?; (ii) as energy consumption rises, how can the Global South use digital technologies to assist its transition to low-carbon energy structure and (iii) do the energy-related effects of digital infrastructure have an impact on poverty, inequalities, social inclusion and women's empowerment?

1.2 Digital technologies and Energy Systems in the Global South

The first part of this section is a systematic literature review that addresses three important research questions: (1) What is the effect of digital technologies on energy systems (demand and supply) in the Global South? (2) Do digital technologies promote sustainable energy use? and (3) Do the energy-related effects of digital technologies promote social inclusion and enhance household welfare? Since economic activities require energy, energy sector constraints can neutralize efforts to expand economic activities. This may have severe implications for households and industries in developing counties where there is low or inadequate investment in the energy sector. In the current situation, achieving sustainable growth in the Global South requires not just investment in energy provision, but also an energy transition path that is low in carbon content.

In this regard, an emerging concern in the literature is whether investment in digital technologies can hasten the transition to sustainable energy use and low-carbon energy supply. Addressing the potential digital divide within and among groups could play critical roles in promoting social inclusion and hence general welfare in societies. The current empirical literature is limited, particularly for countries in the Global South, and the results available are inconclusive, indicating that several factors might influence the way digital technologies impact different energy outcomes. For example, women and men, youth and elderly, and urban and rural dwellers differ significantly both in their access to digital technologies and energy resources. These heterogeneities reflect two ideas. First, that the uneven access to digital technology could account for differences in energy access and poverty between groups. Second, that digital technologies can hasten transition to low-carbon energy and improve sustainable energy use.

1.2.1. Digitalization in the Global South: Trends, challenges and opportunities

Knowledge exchange and networks are emerging as critical push factors in combining inclusive economic and welfare growth with environmental sustainability. The period following the financial and economic crisis of 2008-2009 saw the concepts of green industrial revolution and green growth recognized as necessary ingredients when balancing economic growth and environmental sustainability. According to the United Nations Environment Programme [UNEP] (2010, p.g. 5), "green economy consists of the process of reconfiguring businesses and infrastructure to deliver better returns on natural, human and economic capital investments, while at the same time reducing greenhouse gas emissions, extracting and using fewer natural resources, creating less waste and reducing social disparities". According to the UNEP, the main tenets of the green economy initiative include (1) investing in natural capital, (2) de-carbonizing the economy such as transitioning to low-carbon technologies; and (3) creating green jobs.

In recent times, digital technologies have emerged as key instruments for the green economy agenda. At an international level, an important synergy exists between the use of digital technologies and the green economy (IISD, 2010). Both the 2015 World Summit on the Information System +10, and the 2004 Partnership for Measuring Information, Communication and Technology (ICT) to improve ICT penetration in the Global South, were critical policy level discussions that emphasized the need to integrate digital technologies in sustainable development goals.

Among other things, digital technologies can support the green economy agenda directly by dematerialization, virtualization and demobilization. These improve the efficiency of production, distribution and consumption of goods and services, and reduce material or energy demand through partial or whole substitution of virtual products and services for physical equivalents. They can also decentralize human activities and interaction, help transform economic and social structures, and governance processes, and the behaviors, attitudes and values of individuals. For example, within the energy sector, digital technologies can exert great influence on the demand and supply side. According to the Climate Group and the Global e-Sustainability Initiative (2008), proper demand management and monitoring of electricity grids could deliver about a 30 percent energy saving worldwide.

The African Union's Africa SMART initiative in 2013 proposed introducing e-products (i.e. electronic IDs, e-applications, e-education, e-commerce, e-agriculture, e-health, etc.), unifying communication and the cloud-based infrastructure and strengthening broadband connections within the continent (Sausen, 2020). Elsewhere on the continent, the African Continental Free Trade Area (AFCFTA) also committed to expand the digital sphere by pursuing digital trade (i.e. e-commerce) across countries.[1] Within the financial sector, there is introduction of e-money, mobile money platforms, and other electronic payments platforms. In the energy sector, SMART pre-paid meters and electronic payment platforms for energy bills are being introduced.

Despite this progress, considerable unrealized potential remains in the African digital space. The Dalberg Report (2013), surveyed 1300 businesses and 1000 small and medium-sized enterprises in Ghana, Kenya, Nigeria and Senegal. It found significant untapped potential in these countries' digital space. The statistics show that, despite African countries' progress, their achievements were modest between 2017 and 2020. At the end of 2019, 88.4 percent of

[1] https://www.africa-ontherise.com/2019/07/developing-africas-youth-to-respond-to-the-challenges-of-digitization/?fbclid=IwAR0iWXSYuFg_HApmLlkeS-gjjyCVktxrjklG6fQ1xyYq3pU36tchFzTwosj

the population lived within the reach of access to a mobile cellular signal, 77.7 percent were within the reach of a 3G signal, and 44.3 percent were within the reach of a mobile broadband signal (ITU, 2021). The number of individuals having access to internet increased from 24.8 percent in 2017 to 28.6 percent in 2019. The percentage of population with internet access using mobile broadband increased from 25.5 percent in 2017 to 33.1 percent in 2019 (ITU, 2021). Total investment made in telecommunication in Africa amounted to USD 6.7 billion in 2018. About 50 percent of this investment occurred in South Africa and Nigeria (ITU, 2021).

While Asia and the Pacific, South and Central America boast some of the World's top economies in terms of digital technologies and internet speed and internet usage, these regions are very diverse, and there is a considerable digital divide. In Asia and the Pacific, while 90 percent of the developed economies have access to internet, only 15 percent of the least developed economies have access to internet usage (ITU, 2021). Similarly, in South and Central America, 90 percent of the developed economies have access to internet and 30 percent of the least developed economies have access to internet (ITU, 2021). Figure 1 shows subscriptions for the different digital tools for 2021.

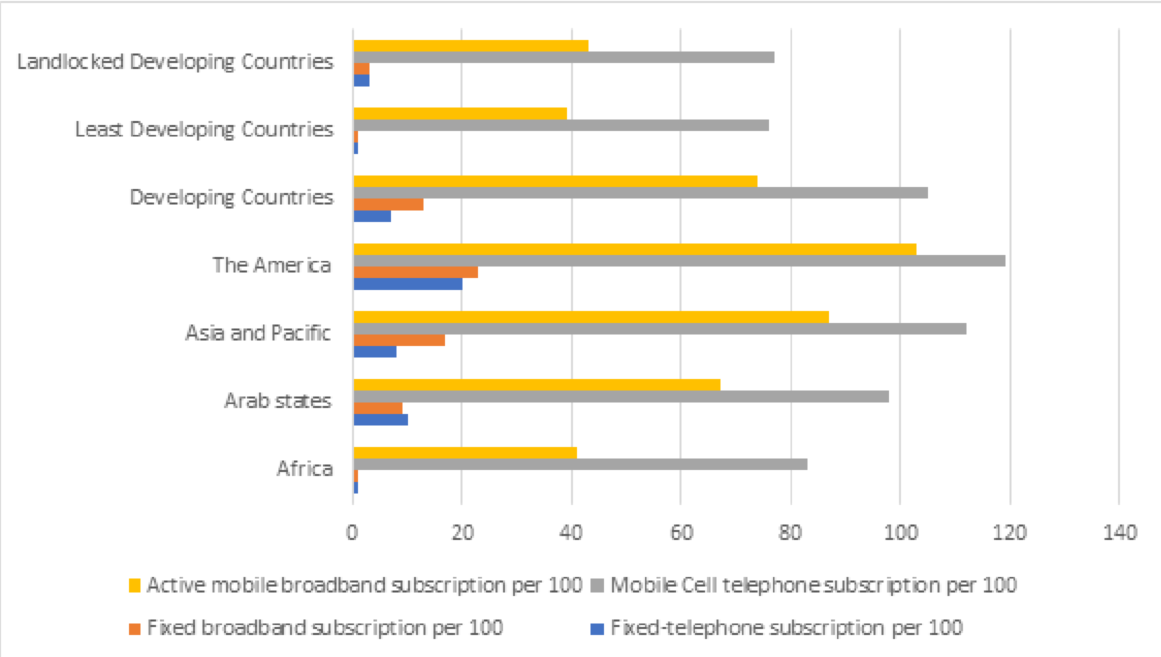
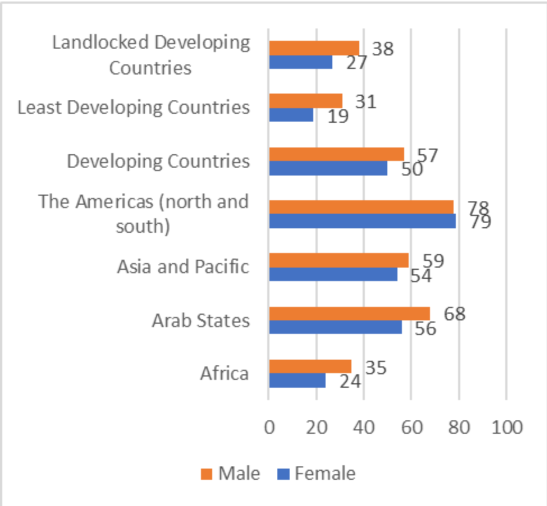
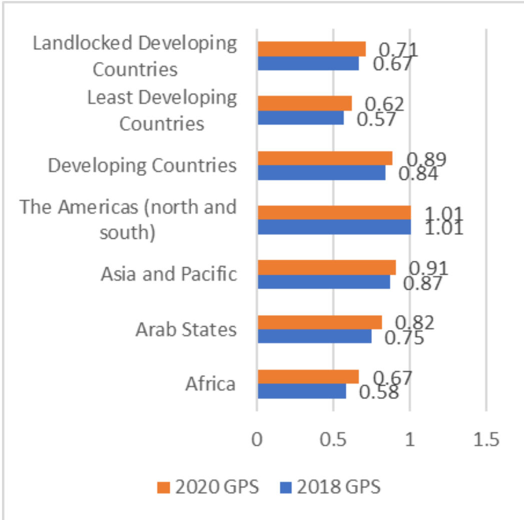


Figure 1: Subscriptions for different digital tools (2021), Source data: International Telecommunication Union, 2021

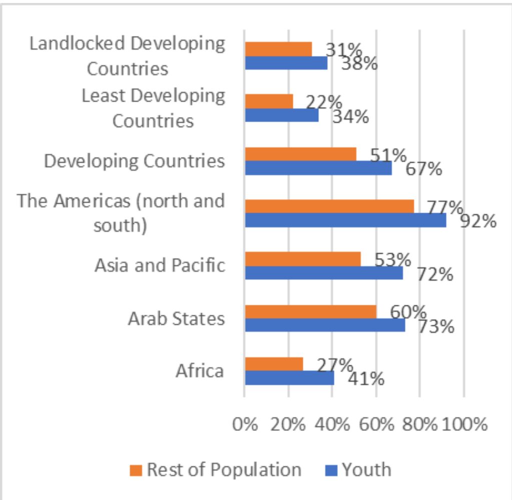
Several factors - explicit and implicit - constrain the digitalization potential in the global south. First, digital divides/ exclusions persist in the Global South (Schopp et al., 2019). According to the International Telecommunication Union (ITU) statistics 2021, gender and youth (ages 15 - 24 years) digital divides are more prevalent in Asia and the Pacific and Africa than in Central and South America. Figure 2 shows the proportion of persons with access to internet by gender, location and age. Clearly digital divides exist for the different classifications but seem more stark for youth versus rest of the population, as well as urban versus rural. Generally, the youth are more well connected to the internet than the rest of the population, while urban areas are better connected than rural areas. In the case of gender, the disparity is narrowing for all regions as demonstrated by the gender disparity score in internet access (panel B of Figure 2). While gender parity seems to be achieved in the Americas, the disparity remains wide in Africa, the Arab States, least developed countries, and landlocked developing countries. The extent of the digital divide in the Global South and its implications for digital revolution and sustainability outcomes remain core issues that deserve serious investigation.



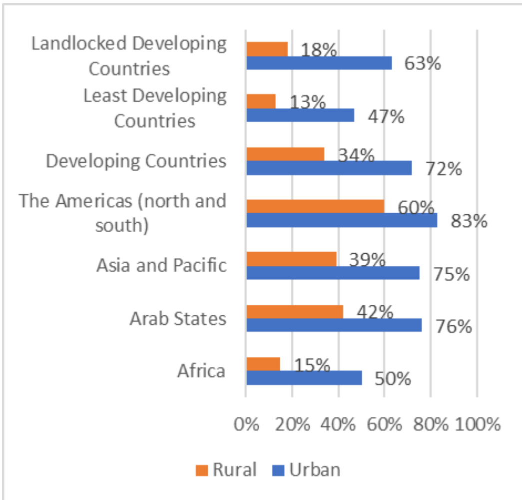
A, Internet access by Gender, 2020



B. Gender Parity Score, Internet access



C. Internet Access by age, 2020



D. Internet access by location, 2020

Figure 2 Facts on digital divide, Source data from ITU

Second, the digital technologies used in the Global South are mainly built by a few technology giants like the United States of America and China (Wakunuma, 2019). This creates a culture of dependency or digital colonialism (Kwet, 2019), and impacts significantly on the civil power of the technology's users (Moore, 2016). As noted by Kwet (2019), digital monopolies give technology giants power over the users of their technologies. Also, according to Michael (2018), proprietors of digital platforms, through their monopolistic nature, can deprive users of due process, equal protection, privacy and other expressive liberties. For example, the banning of Chinese tech giants Huawei technologies and ZTE by the Five Eyes Intelligence Alliance (which includes Canada, United Kingdom, USA, New Zealand and Australia) reflected fear that these telecommunication companies might gain access to useful information in those countries and, if pressured, release it to the Chinese government.

While digital technology gives users tools to support their economic activities, it also gives national governments digital power over users of technology, for example, governments may choose to shut down internet connections (Wakunuma, 2019). The issue of state power is an important ethical issue with digitalization which deserves further attention.

Designing an innovative mechanism that integrates local cultures and language into digital designs and platforms could significantly enhance the use of digital tools by ordinary citizens. This suggests a need for research on how to integrate local cultural values, norms and ideas into the design of digital technologies in the Global South. Such integration should consider all phases of digital technology transition – including design and development phase, construction/implementation phase and operational phase. Obviously, such efforts to localize digital platforms and technologies would require collaborative efforts with the foreign inventors of these technologies. As noted by Segla (2019), integrating local specificities into digital technologies is a vital precondition for promoting equitable opportunities and removing barriers and inequalities, currently exacerbated by globalization.

Third, the high costs of digital tools or technologies impede general access and generate differentials by gender group and social class (ITU, 2021; Rizal et al., 2020; Maxwell and Maxwell, 2014). Within the Global South economies, there exists significant heterogeneities in internet access and quality, cost of internet, and ICT adoption (Keja and Knodel, 2019). For example, in Africa, internet access can use a significant share of household income (Majama 2018; Kemp 2018). In 2020, in Africa as a whole, access to fixed broadband and mobile broadband cost 18.6 percent and 4.4 percent of gross national income per capita, respectively (ITU, 2021). For least developed countries, fixed and mobile broadband costs constitute 20.1 percent and 6.1 percent of gross national income per capita in 2020 (ITU, 2021).

Digital taxes in countries such as Ghana, Uganda, Kenya, Nigeria, Rwanda and Senegal are a key driver of the cost of digital tools (Collaboration International ICT Policy for East and Southern Africa [CIPESA], 2022). Digital taxes, if not set equitably and efficiently, can slow the penetration of digital technologies. Countries that have implemented digital taxation experienced declines in internet access, internet use, and other ICT-related services. Digital taxes affect connectivity, payment and ID platforms, the three platforms needed to support a digital economy (CIPESA, 2021). However, information on the potential impacts of such digital taxes on the digital revolution in the Global South energy sector remains limited.

Fourth, digitalization is constrained by the lack of digital literacy and literacy in the English language. Segla (2019) found that in the Yoruba community in Nigeria, illiterates found it very difficult to use ICT. According to the Web Foundation (2016a), in Africa and Asia, women with secondary level education are more likely to be online than women with primary or lesser education level. A similar study by the Web Foundation (2015) reported that women are 1.6 times more likely than men to report lack of skills as a barrier to internet use. This has been confirmed by several other studies (Web Foundation, 2016b). Disparities in education level can inhibit the binary use of smart phones and the degree to which people can harness the opportunities of smart phones. While the English language remains the main medium of digital literacy, capacity in other local languages is building, but at much slower pace. Understanding the implications of digital literacy on the gender-energy nexus is an interesting research agenda.

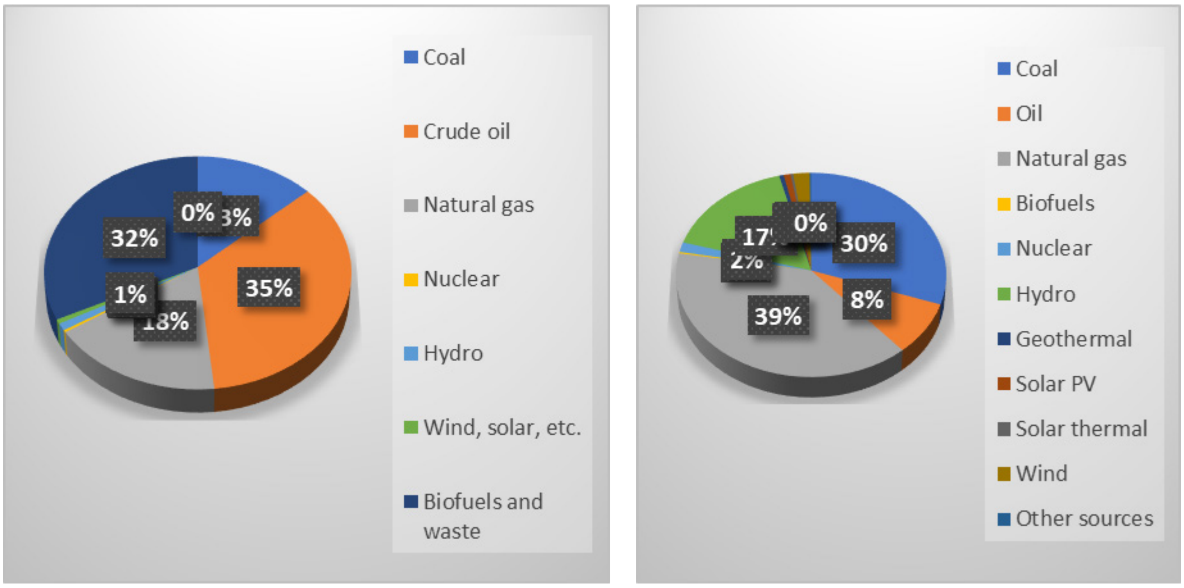
Weak infrastructure systems, structural barriers, and the low expectation of citizens in the Global South, are other important constraints to using digital tools (Mahrenbach, 2018). The Dalberg Report (2013) cites core infrastructure and conditions of usage as the two key pillars for a successfully functioning internet economy.

In the Global South, the introduction of digital technology has outpaced the establishment of state institutions and legal regulations (Schia, 2018). This provides opportunities for ill-intended cyber users, and has bred cyber insecurity issues, especially in economies where development is sluggish and poverty is high (Schia, 2018). Naturally, building capacity in cyber security is important, however, countries' ability to deal with cybercrime vary. Moreover, poor network and infrastructure have made the digitalization process urban-centered, which is creating a digital divide in the Global South. Promoting digitalization requires more than building competencies and capacities; it also requires core hard and soft infrastructure such as electricity, education, and legal frameworks to address the risk of e-fraud and internet crime.

It is important to reiterate that these constraints may not be homogenous for all sectors, due to the unique characteristics sectors may exhibit. For example, digital adoption barriers might differ even along the supply chain of the energy sector. Therefore, more research would be required to unearth the challenges associated with using digital technologies in the whole supply chain of the energy sector in the global south.

1.2.2.Energy Systems in the Global South: challenges, opportunities and the role of Digitalization

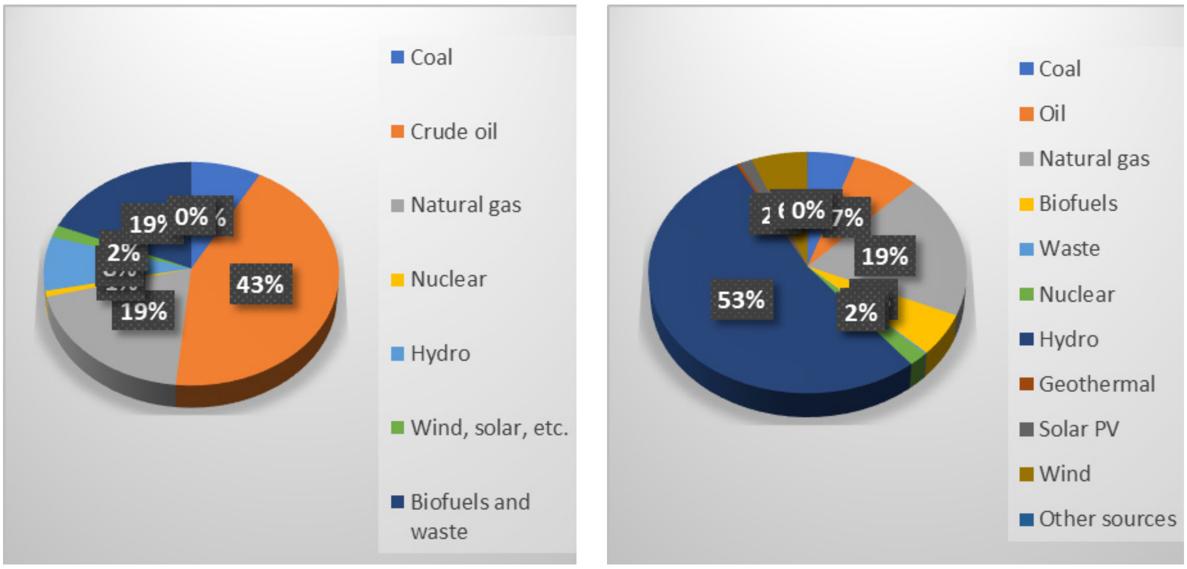
The energy sector in the global south faces a number of challenges. First, unclean energy sources remain dominant, although cleaner energy sources are available (Enerdata, 2019). Coal, biofuels and waste, and crude oil, remain dominant in the total energy supply mixes of Africa (see Figure 3.1), Central and South America (see Figure 3.2) and South-East Asia (see Figure 3.3). Coal and oil contribute significantly to total electricity generation in these regions. As of 2018, 270 million people (i.e. partially or totally) relied on biomass, coal and kerosene for cooking (International Energy Agency, 2018). As a result, there are calls for governments in the Global South to diversify their energy sources and explore the potential contributions of digital technologies in transitioning to low-carbon energy.



Total energy supply, 2019

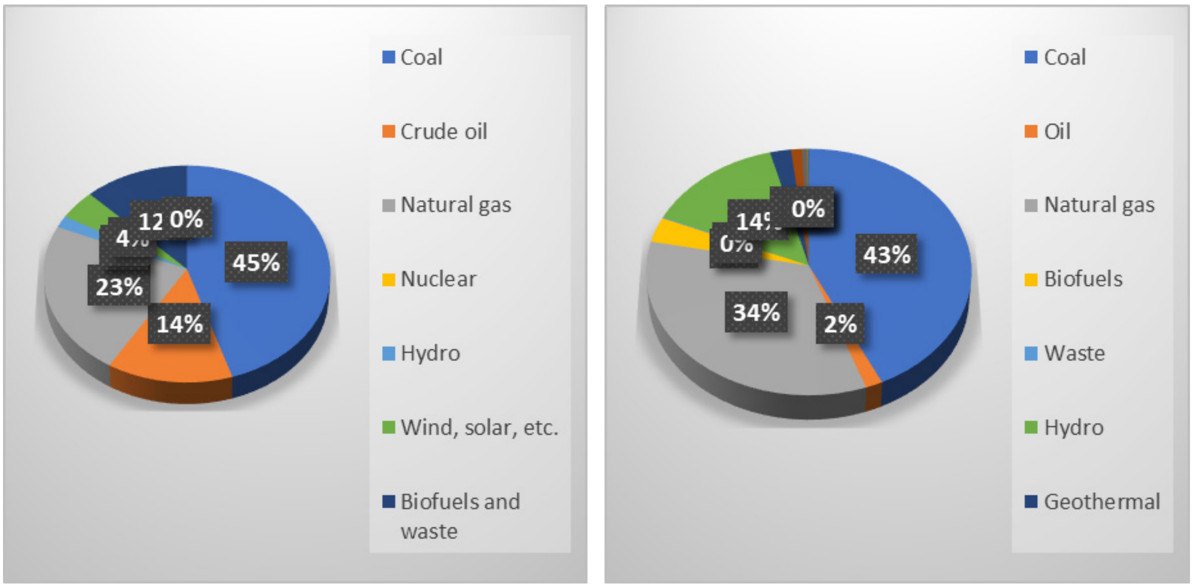
Total electricity production

Figure 3 Energy Supply and Electricity Production Sources for Africa, 2019, Source data: IEA



Total energy supply Total electricity production

Figure 4 Energy Supply and Electricity Production Sources for Africa, 2019, Source data: IEA



Total Energy Supply Total Electricity Production

Figure 5 Energy Supply and Electricity Production sources for South East-Asian countries, 2019, Source data: IEA

Poor access to electricity is another important factor. While in 2020, the access rates for South Asia and Latin America were 95.8 percent and 98.5 percent respectively, only 48.4 percent of the population in sub-Saharan Africa had access to electricity (World Bank Data, 2022). Complementing the above is the prolonged energy deficit in the electricity sector (measured in monetary terms), which averages 1.5 percent of gross domestic product in Sub-Saharan Africa. A significant share of this energy deficit is as a result of technical and non-technical losses (Pistelli, 2020). Kojima and Trimble's (2016) study of electricity utilities in 39 SSA countries found that only Uganda and the Seychelles were able to cover their operational and capital costs with the tariffs charged to customers. The absence of robust financial structures amongst electricity providers makes it difficult to finance investment in generation, transmission and distribution infrastructure. When addressing these challenges, a number of questions should be asked.

The first of these questions is how best to increase the share of renewable energy and other clean energy sources in the total energy mix? Penetration of renewable energy sources is growing faster in non-OECD countries such as China, India and countries in Africa and Latin America. Hydro and wind jointly contribute 64 percent of the growth in renewable energy while solar accounts for 18 percent of growth (Enerdata, 2019). In Africa, investments in wind and solar photovoltaic (PV) projects have increased from 535 MW in 2013 to 6,520 MW in 2018 (Enerdata, 2019). Also, gas-fired generation capacity has doubled from 10.4 GW since 2010 to 20 GW in 2017 in SSA (Enerdata, 2019). Alignment to international norms, energy security concerns, and falling costs, are some of the key factors that are driving the recent transition to cleaner energy sources. Despite these factors, structural, institutional, economic and socio-cultural factors continue to hinder the Global South's effort to fully tap the clean energy sources available.

The second question is how to integrate cleaner energy sources with other energy sources in the total energy mix? Cost and human capacity are two important drivers. Developing countries suffer both from higher costs and lack of human capacity. For example, in Africa, the costly infrastructure and inefficient and unsustainable energy systems make integrating gas and renewable energy sources extremely difficult (Hostettler et al., 2015).

Third, is how to achieve improvements in energy efficiency? Achieving energy efficiency is complex and entails economic, technical, market and regulation considerations. The UN sustainable Development Goal Target 7.3 addresses the issue- by 2030, double the global rate of improvement in energy efficiency. Interestingly, excluding China, most governments in the Global South, particularly, in Africa, have not made financial undertakings to pursue energy efficiency goals aggressively (IEA 2020).

Digital technologies facilitate real time data management which is key to a successful cleaner energy transition, integration of different energy sources and the promotion of energy efficiency. In this regard, digital technologies can speed the transition to clean, efficient energy, and the integration of different energy sources. Among other things, digital technology is a valuable tool for managers trying to improve energy efficiency, coordinate demand and supply in a decentralized electricity system, optimize energy demand management and the management of carbon capture and storage, improve operational efficiency in the energy industry, and facilitate the shift from fossil fuel-based transport towards electrified and automated transportation systems (IEA, 2020).

Unfortunately, certain features of the energy sector might delay the use of digital technologies. First, the expense and long-term nature of energy investment. This requires economic security prior to decision-making, which might be difficult to achieve because of the structural change provoked by energy transition. Second, the highly regulated nature of the energy sector might limit innovation efforts. Third, digital technologies used in the energy sector produce spillover effects; the digitally induced transformation of the energy sector might influence other sectors, which hitherto operated independently.

Although the role that digital technologies can play in the energy sector in the Global South is now well-established, the literature offers very little about how digital technologies facilitate the transition to cleaner energy, improvements in energy efficiency, and the integration of different energy sources within the energy system of the global south. The successful use of digital processes in transforming the energy sector requires suitable economic, political, social and legislative conditions. Research is needed into the effects of economic, political, social and legislative factors on the transformation of the energy sector through digitalization.

1.2.3. Digital technology and the Energy Debate

The impact of digital technologies on energy indicators has been described as broad, complex and uncertain. This is because different opposing forces are at play, and the overall impact of digital technologies on energy indicators depends on the strengths of these opposing forces. In the theoretical discussions of Daly (1990), Ayres (1999), Serrenho et al., (2014), Brockway et al. (2014), Brookes (1978), Khazzoom (1980) and Sorrell (2009), four different effects of digital technologies on energy consumption have been proposed (Lange et al., 2020; Brock and Taylor, 2005). The first is the direct effect, which is the change in energy consumption of the ICT sector. The second is the scale effect- the impact of digitalization on economic growth. The third is the impact of digitalization on energy efficiency, while the fourth is the impact of the sectorial shifts in the economy that result from digitalization.

The direct effect of digital technologies results from the production, use and disposal of digital technologies, and the change in energy intensity (Lange et al., 2020). Internet connectivity and data processing technologies contribute significantly to total household electricity consumption (Morley et al., 2018). The final direction of the direct effect may be ambiguous since advances in digital technologies also improve the energy efficiency of ICT processing units, data transformation and data centers. Koomey et al. (2011) note that the energy consumption of new processing units halves every 1.5 years. Also, energy for data transformation has declined, and is expected to continue doing so in the future (Coroama and Hilty, 2014). Lastly, data centers have also seen efficiency improvements in energy usage.

The second (scale) effect can also be uncertain in its effects. While digital technology is normally seen as a stimulus to economic growth, it also helps rationalize work (Frey and Osborne, 2017) and may be a substitute for cognitive human labor (Brnjolfsson and McAfee, 2012). The resulting rebound effect creates new consumption and products, which contributes to economic growth, but can also increase wage disparities and income inequality (Brnjolfsson and McAfee, 2014). The introduction of digital platforms increases the educational requirement in the labor market (Wolter et al., 2016), causing demand for high-skilled labor to increase at the expense of low-skilled labor. Lange and Santarius (2020) suggest that, because rising inequality is a predictor of low economic growth, digital platforms or technologies might perpetuate low economic growth.

The third effect is about how digital technologies can promote energy efficiency in other sectors. According to Berkhort and Hertin (2001), digital technologies generate both environmental and energy savings benefits. Through digital technologies, production processes can be optimized. Also, digital technologies can help develop intelligent designs, improve the operation of products and services, assist intelligent distribution and logistics (such as supply chain efficiency and alternative distribution structures) and change the seller-buyer relationship through such things as mass customization. Lastly, digital technologies such as teleworking, decarbonization and the shift from analogue books to digital books can help reduce cost and improve the environment.

While these benefits of digital technologies encourage effective and efficient use of resources, particularly in the energy sector, they can also generate rebound effects, which might cause energy consumption to rise. The second and third impacts of digitalization on energy can be classified as the secondary effect, which capture digital technologies' non-energy environmental effects, such as demand for rare metals.

The final effect relates to the differing impacts of digitalization across the various sectors of the economy, the key question being, 'do digital technologies induce tertiarization?' Digital technologies can lead to other adjustments, changes and innovations, which might perpetuate structural shifts or tertiarization in an economy. The bigger question is whether such shifts in the economy would cause energy intensity to fall. Globally, the service sector has an energy intensity of 0.016 kgoe (Enerdata, 2016), the lowest among the economic sectors. Consequently, shifts to the service sector through digital transformations should lower energy intensity and energy consumption. However, digital technologies and services have been found to be very energy intensive. Therefore, expansion of digital technologies - although encouraging tertiarization of an economy - might not lead to lower energy consumption. From the foregoing, the effects of digital technologies are diverse and complex.

1.2.4. Method and Data

This section discusses the methodological processes used to address the primary concern: establishing the boundary of evidence on the emerging topic of digitalization's impacts in the energy sector and identifying gaps in the existing literature. We conduct a systematic review of literature on the topic, and the size and scope of the available evidence. The literature on digitalization in the energy sector is not comprehensively developed. Moreover, the complex nature of the relationships involved, and the context specificity of the evidence, has produced relatively large, complex and heterogeneous evidence.

The following steps were followed. First, we defined the topic broadly and did a search without geographical restriction and year preference using these keywords: digitalization, ICT, social inclusion, energy demand, and ecological footprint. This was to ascertain the depth of the literature on the topic. From the broad definition, we then selected those studies that focused on countries in the Global South - keeping in mind the key research questions for this review:

1. What is the effect of digitalization on the energy sector (i.e. energy demand and supply)?
2. Do digital technologies promote efficient use of energy?
3. Do the energy-related effects of digital technologies impact on social inclusion and household welfare?
4. We adopted the United Nations classification of Global South countries, which consists of 77 countries and China.[2]

2 https://worldpopulationreview.com/country-rankings/global-south-countries

1.2.4.1 Data collection Strategy

The next important step was to select the kinds of studies to consider and where to find them. Although we considered both qualitative and quantitative investigations into the topics, we placed priority on studies that provide quantitative evidence. This was to help establish the methodological advances made in understanding the links between digital technologies and the energy sector, and the spillover effects on household welfare and the social and economic inclusion of different groups. On where to get these studies, different search engines, specifically, Scopus, Web of Science and Google Scholar, using the same keywords described above, were used as the primary search engines. In generating the primary database, data from these search sources were combined and then sorted to deal with duplicates. The bibliographies of these sorted studies were also examined to identify additional grey literature relevant to the topic. Further, additional documents (such as reports, working papers and conference papers etc.) from the internet were also added.

1.2.4.2 Exclusion and Inclusion criteria

In determining the core database for this systematic review, the following inclusion and exclusion criteria were adopted.

Table 1 Exclusion and Inclusion Criteria for selecting the database

Inclusion Criteria	
IR1:	The study considers at least one ICT or digital end-use technology
IR2	The study measures either direct or indirect or both (i.e. higher-order) effects of digitalization on all or either energy indicator, environmental outcome or socio-economic outcome
IR3	The study adopts either a completely quantitative approach or a mixed approach with strong quantitative assessment
IR4	The study includes at least one country from the Global South
IR5	The study contains a clear description of the methods and data
	Exclusion Criteria
EC1	The study is not accessible either at the time of review or due to subscription requirement

1.2.5. Results and Discussion

1.2.5.1 Results on searching and screening of documents

From SCOPUS and Web of science data, the search results produced 3,364 documents comprising journal articles, books and conference papers. The search on Google Scholar produced 22,300 documents. After applying the exclusion and inclusion criteria except IR4), the searched documents were reduced to 218. After further application of the exclusion restriction that the document should focus on the global south (i.e. IR4), only 68 documents (90 percent of which were journal articles) were included in this review. This suggests that the literature on digital technologies' impacts on the energy system, and by extension social inclusion and household welfare in the global south, is nascent and not comprehensively developed. The few existing studies appeared in journals of varying quality. Figure 4 shows the distribution of the publication outlets of reviewed studies. Clearly, over a quarter are in only three journals, but for the rest, there are no obvious leaders as publications are scattered across different journals. Because this section focuses on the impact of digital technologies on the energy system, and by extension social inclusion and welfare in the global south, the remaining sections are organized as follows: (1) digitalization and energy systems, (2) digital technology intervention and sustainable energy use, (3) methodological approaches adopted, (4) area focus of reviewed studies, (4) geographical distribution of the studies, and (5) gaps identified in the reviewed literature.

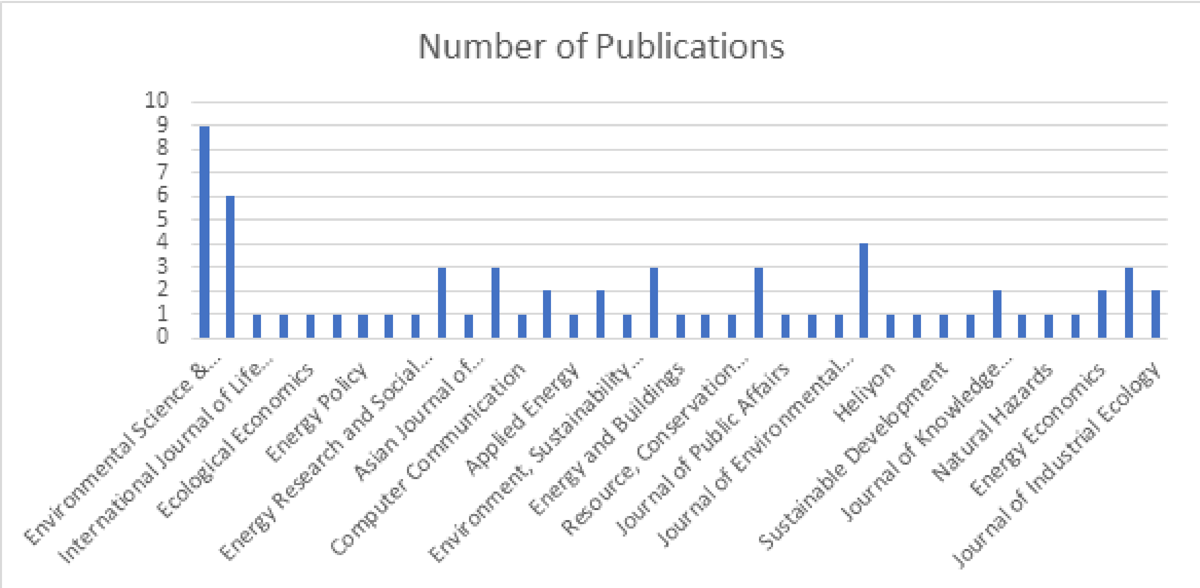


Figure 6 Distributions of Journals

1.2.5.2 Digital technologies and energy systems in the Global South

This section considers studies that investigate the impact of digital technologies on the energy system (demand and supply) in the Global South. It begins with a review of studies on energy demand, which is followed by energy supply and sustainable use of energy (i.e. energy efficiency).

1.2.5.2.1 Digitalization and Energy Supply in the Global South

Digitalization is becoming increasing applicable across wide areas of the energy sector. Digital technologies offer opportunities for the supply chain in the energy sector. In the oil and gas sector, both upstream and downstream, for example, they can improve data management and processing. Real-time information provided by digital technologies can reduce cost, improve safety and increase production and profitability. According to an IEA estimate, digital technology can reduce cost in the oil and gas sector by 10-20%. Similarly, in the power sector, digital technologies can enhance efficiency in generation, transmission and distribution, reducing investment needs, carbon dioxide emissions and fuel consumption and cost (IEA, 2017). Digital technologies allow improved data analytics which assist in predictive maintenance, planning and operating charges (IEA, 2017). They also allow improved connectivity of the power sector, reducing unplanned outages and enhancing equipment or plant lifetime. According to an IEA estimate, digital technologies can save 5% of total annual power generation costs.

Despite the several benefits of digital technologies to the energy supply chain, the literature has little regarding the potential impact of digital technologies on energy supply, particularly in the Global South. This is important given the growing penetration of digital technologies in the energy sectors of LDCs. Anecdotal evidence from the literature shows the potential of digital technologies to improve energy supply systems. Banales (2020) analyzed the extent to which digital technologies enable the decentralization of renewable energy, particularly the possible positive effects of big data, artificial intelligence, internet of things and distributed ledgers, on renewable distributed energy sources and adoption. According to Banales (2020), digital technology constraints, such as limits to the number of transactions per second, could also limit the decentralization of energy production.
Similarly, Priyra and Rekha (2020) underscore the importance of digital technologies (i.e. Software Defined Networking) in optimizing and maximizing the use of renewable energy in Tamil Nadu in India. Shahinzadeh et al. (2019) introduced the notion of an internet of energy that provides platforms to help coordinate renewable energy supply and energy storage. In the case of Nigeria, Chukwuorji et al. (2019) suggest that using a smart grid and distributed generation could improve the generation, transmission and distribution of electric power.

Empirical evidence on the impact of digital technologies on the supply-side of the energy sector is very scant. The few existing studies are highly descriptive, making it difficult to draw causal inferences on the impacts of different digital technologies on the supply chains of the energy system. In the geographical region of focus, at the time of this review, there were no studies that used causal inference techniques to establish the impacts of digital technologies on energy supply chains. At best, only a regression-based kind of study could be found, but this was limited in establishing a meaningful causal relationship between digital technologies and the different aspects of the energy supply chain.

1.2.5.2.2 Digital technologies and Energy Demand in the Global South

Theoretically, digital technologies exert direct and indirect effects on energy consumption. Consequently, the overall or net effect of digital technologies on energy consumption depends on which of the two effects outweighs the other. Ideally, the way to examine the impact of digital technologies on energy demand is to consider both direct and indirect effects. However, the review shows about 90 percent of the reviewed studies focusing on the direct effects of digital technologies. Studies that estimate the overall effect of digital technologies (i.e. direct, indirect and net effects), are rare. Addressing this obviously raises legitimate concerns about the level of methodological complexity involved in evaluating the total effect of digital technologies on energy demand. The following section limits the discussion to studies of the direct effects of digitalization on energy demand.

1.2.5.2.2.1 Direct energy-related effects of digitalization

In terms of the direct effects of digital technologies on energy demand, two key indicators have been largely used, namely, carbon dioxide emissions and energy consumption. Studies using the former are premised on the assumption that energy consumption and production are positively correlated with carbon dioxide emissions. Irrespective of the measure used, studies produced mixed results (see Table 5 in appendix for the lists of studies reviewed and for details on them) - positive, negative, non-linear and no effects.

Even though a large number of these studies find evidence suggesting that digital technologies increase energy consumption and carbon dioxide emissions, the literature is not conclusive. A number of factors - including context heterogeneity, differences in digital technology intervention, methodological robustness and sample range - account for this. For example, studies by Higon et al. (2017) and Danish et al. (2019) suggest that whether or not digital technologies reduce energy demand depends on the level of economic development. In both studies, the authors find that digital technologies reduce energy use in developed economies but increase it in developing economies. This clearly cautions against any attempt to generalize results from one context to another. Moreover, it shows how sensitive the results can be to changes in circumstances.

A thorough investigation into the reasons for the ambiguity in the literature is important for several reasons. Not only will it unravel the important role that local context plays, but also how diversity in technical capability, and differing levels of methodological robustness, drive the results. A meta-analytic technique can help to effectively explain the ambiguity in results. Unfortunately, at the time of this review, there were no studies that researched the reasons for the mixed results in the literature.

An alternative approach to explaining the ambiguity in the results is to conduct sector-specific studies on the impact of digital technologies on energy demand (see Cho et al., 2007; Khayyat et al., 2016). This is very important because of the heterogeneous energy and technology requirements of the different sectors. More so, such studies can help solve the policy challenge of generalizing often associated with economic-wide study. The majority of studies reviewed focused on the economy-wide impacts of digital technologies on energy consumption. This macro approach to the problem risks resulting in a policy conundrum, as homogenous digital technologies could emerge as desirable for all sectors. The few existing studies (largely focused in Asia) that conduct sector-specific investigations into the impact of digital technologies on energy demand suggest that the same digital technology can have differing impacts across the energy footprints of the various sectors.

For example, Zhou et al. (2018) examined the effect of digital technologies on energy demand in Chinese industries. They find that ICT's direct effect is positive but more in the devices sector and less in the services sector. In Iran, Shabani and Shahnazi (2019) find that ICT investments increase energy consumption in industrial sectors but reduce it in the transportation and service sectors. Malmodin et al. (2010) - using global data - compared the energy and carbon emissions requirements of ICT and of the entertainment and media sectors. They found that the ICT sector contributed more (about 3.9 percent) than entertainment and media (about 3.2 percent) to global energy consumption. Malmodin and Lunden (2018) also estimated carbon footprint for the ICT and Entertainment and Media (E&M) sectors from a global sample, found that the energy footprint for ICT had fallen until 2007, but risen sharply thereafter. The share of energy use taken by network operations increased, while that of user devices fell. In the case of the Entertainment and Media sector, the energy footprint expanded until 2010, falling thereafter as a result of improvement in the energy efficiency of televisions.

The transport sector accounts for about 28 percent of global energy needs and contributes to 23 percent of total global carbon dioxide emissions (IEA, 2017). The increasing energy needs of this sector are expected to continue; projections by the IEA suggest that final energy consumption for the transport sector will grow by almost half, to 165 exajoules in 2050, with the highest demand being from road freight vehicles (36 percent) and passenger light-duty vehicles (28 percent). On the other hand, transport systems are becoming increasingly smarter and more connected. The increased deployment of digital technologies (i.e. Intelligent Transport System [ITS]) is making the transport sector more secure and efficient in terms of both cost and energy requirements (US Department of Transportation, 2016). Digital sensors and satellite communication devices installed in commercial flights, rail, road, and ships, are helping to significantly optimize transport and enable large savings in energy. Interestingly, at the time of this review, there were no studies of energy-related effects of digital technologies on transport in developing countries. Understanding the implications of the various digital technologies deployed in the transport sector for future transport systems will be key to achieving a sustainable future in the Global South. Further, studies should investigate the deployment of specific digital technologies such as road traffic detectors, radio-frequency identification, Global Positioning System (GPS), telecommunication devices and automation of transport systems, on transport energy systems in the Global South.

Another important sector worthy of focus is the building sector. Buildings alone account for 55 percent of final global energy demand, and the growth in electricity consumption by occupants of buildings in the last 25 years has accounted for about 60 percent of the total growth in global electricity consumption (IEA, 2017). Again, the IEA predicts that the energy requirements for the building sector will double from 11 PWh in 2014 to 20 PWh in 2040 (IEA, 2017). It has been shown that introducing digital technologies in residential and commercial buildings would reduce total energy consumption by 10 percent (IEA, 2017). The IEA predicts that, globally, between 2017 and 2040, digitalization can result in cumulative energy savings of 65 PWh. Smart energy management technologies, such as light sensors and auto-programming of heating and cooling are helping to improve energy performances in buildings. An investigation into the energy implications of smart energy management technologies for buildings is also critical to achieving a sustainable energy future and development. Interestingly, we note in this review that public evidence on the energy implications of smart energy management technologies on buildings is limited, especially in the Global South. The only exception is the study by Gray et al. (2020), which considered the energy implications of home automation system (HAS) from a global perspective. Their study revealed that home automation systems have a non-trivial impact on global ICT energy footprints, though consuming more than one-third of the annual energy used in mid-sized homes.

Lastly, another important sector worthy of investigation is the industrial sector, which contributes 38 percent of global final energy consumption and 24 percent of total global carbon dioxide emissions (IEA, 2017). With the projected growth in industrial expansion, particularly in emerging economies, the value of digital technologies in advancing material use and energy use efficiency will increase. At the plant level, deployment of digital smart meters and sensors can be used to check the operational status of plants, identify and diagnose system inefficiencies, and develop schedules for operation and maintenance to avoid or minimize system downtimes.

The impact of digital technologies on industrial operations can go beyond the plant level (see Figure 5). Industrial robots and 3D printing are helping improve industrial accuracy and reduce industrial waste. Between 2010 and 2016, the growth in sales of industrial robots averaged 16 percent per annum, and occurred on the back of high demand from emerging economies such as China (IFR, 2016). These digital technologies are optimizing industrial processes and improving energy efficiency. With the help of digital technologies, real industrial plants can be virtually replicated – the digital replica being used to enhance data collection and analytics. When combined with artificial intelligence, digital twining can improve the innovative ability of industries, resulting in significant energy savings. For example, using simulated experiments and optimization techniques, chemical manufactures have reduced the batch time for producing expanded polystyrene by 30 percent, resulting in significant energy savings (World Economic Forum, 2017).

Aside from the impact of digital technologies within an industry, digital technologies can be used to connect an industry to its surroundings. With the help of digital platforms, such as cloud-based collaborative platforms and autonomous closed-loop controls, industries along the supply chain can have their processes connected and controlled to optimize production processes and save energy. Given that for most countries in the Global South, expanded industrialization is key to achieving sustainable development, understanding how specific digital technologies would impact processes, both internal and external is key. Although there exists anecdotal evidence on the impact of digital technologies on the industrial sector, detailed studies of their energy implications on internal and external processes of industries in the Global South are missing. The above suggests more evidence from different geographical locations is needed to understand the 'just in time industry production' dynamics of the energy-related impacts of digitalization.

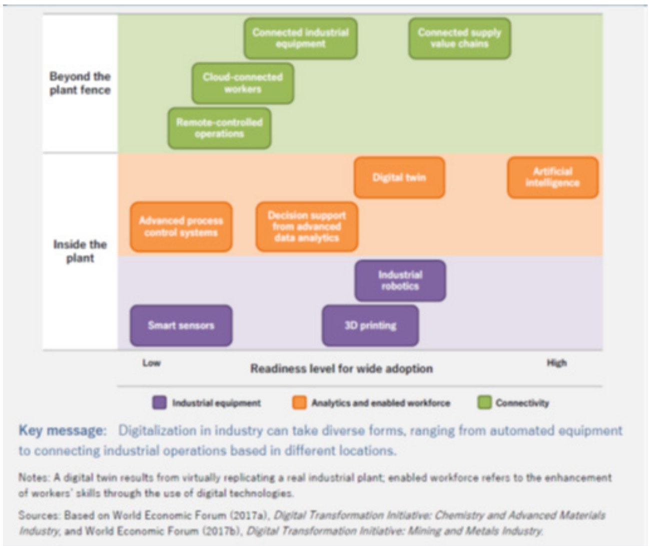


Figure 7 Digital technology effects in industry. Source: Extracted from World Economic Forum (2017a & 2017b)

1.2.5.2.2.2 Indirect Effects of Digital Technologies (Scale and tertiarization)

The indirect effects of digital technologies, like the direct effects, have ambiguous results. The indirect effects of digital technologies include their implications for scale, energy efficiency and tertiarization. We defer the discussion of the energy efficiency effect to the next section. The scale effect posits that the close connection between digital technologies and energy use means that energy cannot be decoupled completely from economic growth. Studies analyzing the scale effect investigate the effect of digital technologies on economic growth and energy use. There is a burgeoning but still limited body of evidence on the scale effects of digital technologies. Additionally, this evidence does not provide a conclusive position on the scale effect of digital technologies. Negative, positive and no scale effects have been reported in the current literature (see Table 5). On whether digital technologies cause a tertiarization effect, our review did not find any such study focusing on the economies of the Global South.

1.2.5.3 Digitalization and Sustainable use of energy (energy efficiency)

Digital technologies can help advance the goals of energy efficiency and hence sustainable use of energy, facilitating the initiation and achievement of environmental and energy targets (World Energy Council, 2018). These are further supported by ICT-based monitoring and environmental management systems that promote transparency (Verma et al., 2020). However, digital tools such as AI, IoT and blockchain can themselves increase energy consumption (Verma et al., 2020). Networks and data centers consume significant amounts of electricity. In contrast, the amount of power used by computers and cellphones is generally not significant thanks to transistors and semiconductors. Thus, a-priori, it is difficult to establish whether or not the use of digital tools stimulates energy consumption efficiency.

The review found few studies on how digital tools influence energy efficiency in the Global South, and the results were inconclusive. Anjana and Shaji's (2017) review study of the features and technologies required for smart grid energy efficiency found that ICT reduces energy costs and improves energy efficiency. Amongst the studies of digital technologies and their capacity to induce energy efficiency Bento (2016) for 227 countries, Wu and Raghapathi (2015) for global data, Murshad (2020) for South Asia and Yan et al. (2018) for 50 OECD, emerging and BRICS countries, all confirmed that digital technology induces energy efficiency. Similarly, Hu et al. (2022), in their review of literature on the energy – ICT relationship, find the net effect of ICT on energy savings, economic growth and emission is generally positive. In contrast, Court and Sorrel's (2020) review found that energy efficiency gains related to digital tools were normally insufficient to compensate for the rise in energy consumption. This result was confirmed by Koot and Wijnbioven (2021) in a simulation study using global data. However, Horner et al.'s (2016) review of the literature found uncertainty in the effects of ICT on energy efficiency. They noted that the indirect effects of ICT were sensitive to assumptions imposed. Generally, even though ICT creates large energy savings, the extent of these depended on user behavior and deployment details.

Other studies report energy efficiency gains of digital technologies that are sector- or technology-specific. Putra et al. (2017) found that Bluetooth communication is about 30 percent more energy-efficient than Wi-Fi communication when transmitting residents' data. Amasawa et al. (2017), comparing the global warming potential of e-book reading to reading only paper books, found that the e-books posed less of a threat. In a similar study, Weber et al. (2010) assessed the climate change and energy implications of different music delivery methods – e-commerce sale of compact discs, digital download services, and traditional sale of compact discs. They found that, although energy and carbon dioxide emissions increased with internet data flows, digital purchase of music was the least energy and carbon dioxide intensive (by 40 percent and 80 percent, respectively).

Zhou et al. (2018) and Hao et al. (2022) stress the sector- or region-specific nature of the energy consumption efficiency gains of digital technologies. Zhou et al. (2018) found that digital technologies improved energy efficiency more in the devices sector than the services sector. On the other hand, Hao et al. (2022) found that although ICT technologies promote energy efficiency in China, the energy efficiency gains of ICT were greater in western China.

The energy efficiency related gains of ICT can also induce rebound effects. If large enough these can compromise any initial gains obtained through energy efficiency. Therefore, a good assessment of the energy efficiency effects of digital technologies should also compute the associated rebound effects. Failure to do so will bias estimates of the energy savings from new efficient technologies. However, the only relevant study in the context of Global South is one using global data by Gavi (2015). The author finds that the energy efficiency effects of ICT cause ICT/electronic device use to proliferate, causing energy consumption to increase. The study estimates this rebound effect to range between 115 percent and 161 percent, which suggests that energy efficiency gains from ICT trigger increases in energy consumption of 15 percent to 61 percent.

There is little literature on the rebound effects of ICT – related energy efficiency gains for the Global South. A number of factors might explain the paucity of research in this area. First of these is the technical constraint that prevents a well-defined method from adequately capturing the true extent of the rebound effect (Kunkel and Tyfield, 2021). Several approaches have been adopted to estimate the rebound effects of the energy efficiency related gains of ICT, but none has proven superior. Environmental approaches have largely relied on life cycle assessment techniques, but these techniques have been described as inadequate as they are more applicable to single service use. From an economic perspective, both experimental and non-experimental techniques have been adopted to quantify the rebound effect, but the appropriateness of these techniques depends on whether only energy efficiency is considered (Rivera et al., 2014). These techniques do not capture time-related rebound effects and are therefore likely to produce bias in the estimate of digital rebound effect. Even the computable general equilibrium techniques used to quantify rebound effects at the global level (Thomas and Azevedo, 2013a and 2013b) did not capture all kinds of rebound effects.

The economic approaches are further weakened when there are high levels of uncertainty regarding the rebound effects. In this case a scenario-based approach may be appropriate. However, Hertwich (2005) argues that scenario-based approaches are insufficient and require refinement. Also, scenario-based techniques only estimate potential rebound effects and not the actual ones. Borjeson et al., (2006) suggest that combining scenario-based approaches with social practice approach – the social practices being related to digital technologies – can capture second-order (rebound) effects. An appropriate technique to capture rebound effects will require a more system dynamic approach that leverages the advantages of the various existing approaches used.

1.2.5.4 Social Inclusion, Welfare and Energy-related effects of Digitalization

Social inclusion can be defined as improving the abilities, opportunities, and dignity of those most disadvantaged in society (World Development Report, 2019). This promotes quality of life for individuals, and the equity and cohesion of society as a whole (Levitas et al., 2007). Energy has been identified as a key driver of economic development and inclusive growth. However, significant disparities exist in access to energy services in the Global South. Particularly, women and girls compared to men and boys, and rural dwellers compared to urban dwellers, are poorly served with energy services.[3] These inequalities in energy service delivery widen social exclusion, which negatively affects the quality of life , social equity and cohesion (see the paper on sustainable energy transitions for a more detailed discussion).

A key strategy here is to find ways to close existing gaps in energy service delivery among people of different socio-economic classes and groupings. In the case of rural areas, popular interventions that have received donor supports (from the World Bank, International Bank for Reconstruction

[3] https://www2.deloitte.com/us/en/insights/topics/social-impact/women-empowerment-energy-access.html/#end-notes

and Development, the USAID, Asian Development Bank, and African Development Bank among others) and research interest include the provision of off-grid electricity, on-grid electricity projects, and the supply of clean cooking technologies (Peters et al., 2019; Williams et al., 2015; Mandelli et al., 2016). Not only is there no consensus regarding the impacts of these interventions on development indicators, (see: Jeuland et al., 2021 & paper on sustainable energy transitions), the extent to which these interventions promote social inclusion by helping close the energy service inequality gap is also unknown.

Technological advances have been argued to promote social inclusion by offering leapfrogging opportunities and empowering vulnerable groups such as women and girls. In this regard, technologies have been developed to help vulnerable groups such as women, girls, the young, the elderly and persons with disabilities to gain meaningful access to public, social and economic services (Hayes et al., 2008; Ashraf et al., 2017). With the aid of these technological innovations, countries can reach out to disadvantaged groups who lack proper access to energy services (World Development Report, 2019).

Juxtaposing the two ideas, it is logical to infer that promoting digital technologies – given their close connection with energy outcomes - can help bridge the energy service delivery gap and promote the social inclusion of disadvantaged groups. In this regard, a significant gap exists in the empirical literature on the role of digital technologies in advancing energy service equity and social inclusion, particularly in the Global South. Any attempt to answer this question from a Global South perspective should consider the prevailing inequalities in accessing digital technologies and the multidimensional nature of the digital divide problem. Proceeding from this, is the important concept of digital social inclusion –ensuring that all persons and communities gain access to digital technologies – and how it advances energy equity and social inclusion.

Another important gap in the literature concerns the energy-related impacts of digitalization on household welfare. Several empirical studies have tried to establish a link between energy and development, but failed to provide a consistent discussion on whether energy service delivery enhances development outcomes (see Jeuland et al., 2021 and paper on sustainable energy transitions). The empirical literature on the energy-related impacts of digitalization - as discussed in this review - is also inconclusive. Notwithstanding these observations, the connections between energy and development, and between energy outcomes and digitalization, suggest that digital technologies may be intermediating the impacts of energy service delivery outcomes on welfare indicators. However, we found no empirical papers testing this claim.

1.2.5.5 Methodological approaches- Digitalization and Energy demand nexus

Two major questions have dominated the literature on the direct and indirect effects of digitalization. The first focused on estimating the energy embodied in digital technologies. In this regard, all the studies reviewed used Life Cycle Assessment (LCA). This is a bottom-up approach that relies on life cycle inventory data to assess the environmental or energy impacts of a product or a digital technology. The bottom-up approach implies that the data requirements of this approach are comprehensive, so its use may be limited where there are data challenges. Additionally, LCA is based on generic rather than specific assumptions, which apply to specific sectors. Although LCA can reveal the energy savings obtained when substituting between or among different digital technologies, it is not able to capture the rebound effects. This means that its use to establish the energy impacts of different digital technologies risks underestimating the potential energy savings involved.

The second question, still related to the direct energy impacts of digital technology, is how does the energy system responds to digital technology? Two main methods have been employed, observational and experimental. More than 90 percent of the studies reviewed in this report adopted observational techniques in the form of regressions or forecasting models. Despite the fact that such methods may be high in external validity, they tend to be weak in internal validity as the researcher cannot control subjects and then observe the attendant effects on outcomes. This indicates that they normally result in bias masking of causality or increase in fake suggestion of correlation. At best, observational techniques can only reveal the level and direction of association between the dependent and independent variables. The appropriateness of observational and experimental techniques should be informed by what the researcher seeks to do, whether to establish causality or association. Only five of the studies reviewed in this report applied any form of experimental approach to the problem, despite such approaches being high in internal validity and strong on causal relationship. Generally, these studies produce results that are inconclusive. Rochd et al. (2021) considered the case of Morocco, and found that adopting AI-based and IoT enabled home management reduces the carbon footprint by 30 percent more than that in equivalent non-AI and IoT enabled homes. Putra et al. (2017) report that Bluetooth communication channels enhanced mobile phone battery life by 1 hour and 52 minutes more than equivalent communications through Wi-Fi. In terms of energy efficiency, Bluetooth communication improves energy efficiency 30 percent more than Wi-Fi communication channels. Hadzone et al. (2020) found that Bosnia and Herzegovina reduced energy consumption significantly by switching from real internet protocol to SDN networks. Papoola et al. (2018) found that energy consumption in Nigeria was sensitive to the meter type. Bento (2016), using global data, reported mobile phone communication having sizeable effects on energy consumption.

1.2.5.6 Geographical distribution of studies and type of digital infrastructure examined

Figure 6 below shows the geographical distribution of the reviewed studies on the energy impacts of digital technologies in the Global South. Amongst the studies focusing on a specific region, the distribution was skewed towards Asia, with relatively few focusing on Africa and Central or South America. This might reflect difficulty with obtaining data on digital technologies in the energy sector in these regions.

This systematic review shows studies investigating impacts of different types of digital technologies on energy systems. They range from digital infrastructure, use, access and skills/knowledge. Others, to a limited extent, use monetary-based measures such as ICT trade (exports and imports) and ICT investment. We note that the choice of what digital technology to examine is informed first by the availability of data and secondly by the focus of the study. Studies interested in specific aspects of the digital process tend to focus on specific types of digital technologies while studies interested in the whole digital process use more comprehensive measures that cover infrastructure, use, access, and knowledge or skill. Studies examining the impact of the whole digital process are limited. Figure 7 shows the distribution of the kind of digital technologies used in empirical studies. The distribution is highly biased towards digital infrastructures, which include ICT, hardware and software. For studies using digital infrastructure, a significant number of the studies reviewed examined the impact of mobile and landline phone ownership, and to a lesser extent computer ownership, on energy consumption. Also, a large number of the studies reviewed examined the impact of internet usage and access (mobile phone and fixed broadband) on energy consumption. About 60 percent of them used a proxy such as ownership of ICT/electronic devices or personal computers, internet connectivity, mobile phone and fixed telephone connectivity, as a measure of digital technologies. Generally, the results look very inconclusive, as none of these digital technologies (i.e., mobile phone subscription, fixed telephone subscription and internet connection) show one definite impact on ecological footprints in the form of energy consumption, energy supply and carbon emissions. A large part of these heterogeneities may be driven by the context, method of inquiry and model specification. One important implication is that no single digital technology infrastructure so far has proven to be effective in helping countries transition to a low-carbon economy and, however promising the digital technology concerned may be, there is always a price to pay as countries adopt low-carbon technologies. The review also shows that very few of the studies reviewed examined the impact of specific digital technologies such as AI, teleworking, SDN, e-materialization, digital smart meters and sensors, and automated processes on energy consumption. In the case of artificial intelligence, we found no study undertaken in a developing country. Gray et al. (2020) examined the influence of adopting a Home Automation Management System and confirmed the energy-reducing effect of HAMS. Hadzare et al. (2010) examined how switching from real internet protocol to SDN influences energy consumption, concluding that SDN improves energy consumption efficiency. Hook et al. (2020), Amasawa et al. (2017), and Court and Sorrel (2020) have all revealed the energy-saving potential of e-materialization and teleworking. In the case of digital platforms such as Uber, Airbnb, Netflix, and FinTech, we did not find any studies examining how these digital platforms influence energy consumption in the Global South.

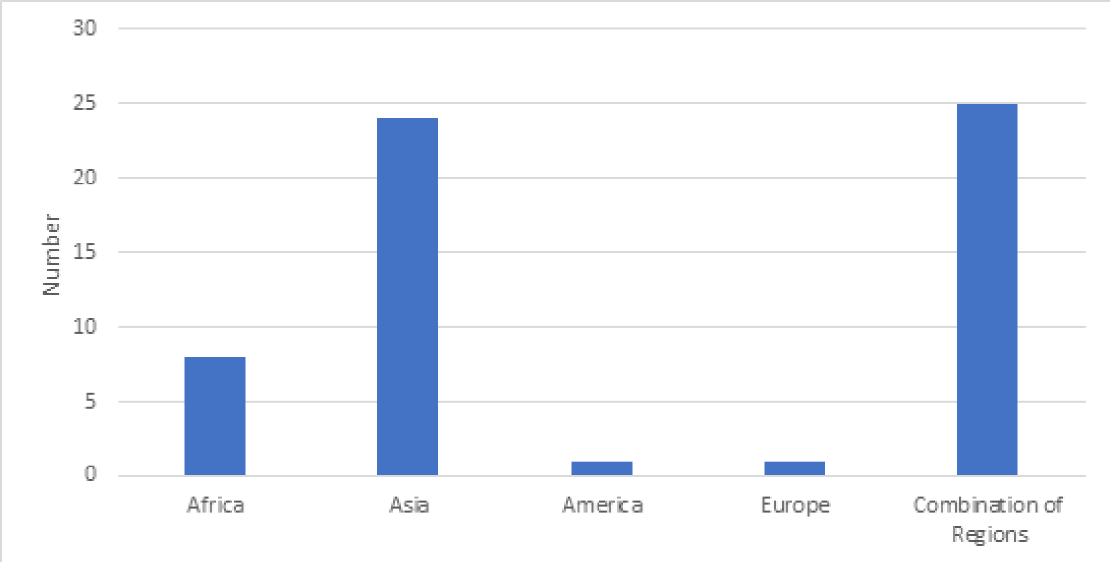


Figure 8 Geographical distribution of reviewed studies

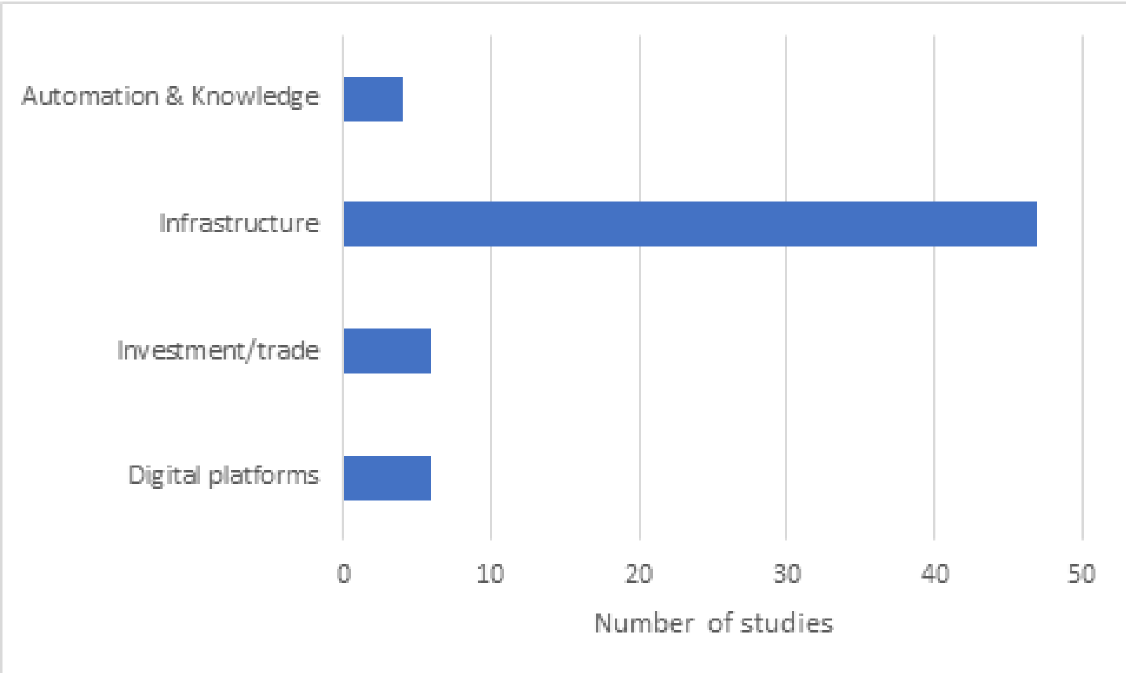


Figure 9 Distribution of indicator of digital technology

1.2.6. Important areas for future research consideration

The above review highlights some important research questions for future consideration:

- What factors could explain the use (adoption) of digital technologies in facilitating low-carbon transition for sustainable natural resources management, consumption, substituting for energy-intensive materials, etc.?
- Identify sector-specific digital technologies to aid an efficient transition to low-carbon and explore the determinants of adoption.
- How is digital exclusion in the Global South impacting inequality in energy service delivery? How to achieve digital inclusion?
- To what extent are digital taxes and social digital exclusion connected, and what is the implication of these on energy service delivery gaps and welfare?

- How can culture and local content be integrated in digital revolution and the implication for closing social digital exclusion and energy service delivery gap?
- What is the extent of digital rebound effects? What factors drive digital rebound effects, and what factors could explain how digital rebound effects affect transition to low-carbon state?
- How are digital technologies impacting within and outside processes in industries to transition to low-carbon processes?
- How does social digital inclusion impact equity in energy service delivery and by extension promote social equity and sustainable outcomes?
- There is the need to address database requirements and technical limitations in designing system based dynamic approaches capable of handling the complexities involved.

1.3 Public-Private Partnerships, Gender and Low-carbon Transportation in the Global South

The fossil-fuel based transport sector contributes significantly to carbon emissions in the Global South, especially in countries such as China and India whose growing middle classes demand personal vehicles. The transport sector accounted for about 60% of global oil demand in 2020 (IEA,2021) and about 20% of global carbon emission in 2020 (Statista, 2022). Increasingly, this is being driven by emerging economies such as China and India. Coupled with the expansion of the middle class in most emerging economies, this suggests that more information on transport infrastructure and behavioral attitudes towards various transport modes will be needed if policies encouraging transition to a low-carbon economy are to succeed in the Global South.

In addition to the high dependence of the transport sector on fossil fuels, both for moving people and goods, there have been low levels of adoption of transportation modes that are less carbon intensive such as public transport systems (coaches), and electric vehicles among others (Ardila-Gomez et al.,2021). As a significant share of the population moves into the middle class, demand for personal vehicles will increase, as will demand for air transport as the population become wealthy. This is already evident in China and some of the emerging countries in the Global South like India, Brazil, and South Africa.

Transforming transport systems requires finance. However, countries in the Global South face financing gaps for their infrastructure development in general and transport infrastructure development in particular. LDCs typically have limited sources of revenue and increasing levels of public debt. Funding infrastructure projects will mean finding other financing options. One such option is the public-private partnership (PPP), a collaboration between government and the private-sector, an example being agreements to finance, build, and operate projects such as transport infrastructure. The advantages such a financing option has over traditional public only or private only financing lies in three key areas. First, a PPP financing scheme, by shifting the financial burden of the project from the public sector to the private sector, frees some resources that can be invested in other areas of the economy. Second, the risks of the project are transferred to the private sector with performance rewards that promote efficiency of the project. Third, it promotes transparency in the bidding process for projects if the PPP scheme is well designed. This sub-section of the paper reviews the literature on transport infrastructure funded by PPP financing with a view to assessing the potential of public-private partnerships in providing low-carbon transport infrastructure to the Global South. It will also review the gender perspective of such infrastructure provision to help identify potential research gaps.

1.3.1. Social economic and environmental impact of a low-carbon infrastructure in the Global South

Infrastructure development is very important for economic growth and development, contributing to a range of sectors from health and education to transport and energy. Infrastructure generally has a long-life period, averaging 10 to 15 years in most cases (Ebinger and Vandycke, 2015). This among other things suggest that there will be a lock-in of carbon emissions for such a long-life period of the current infrastructure's lifespan.

Transitioning to a low-carbon transport infrastructure in the Global South will have social, economic, and environmental impacts. There is significant disparity in the infrastructure sector globally, but worst in the Global South. Globally, about 19 percent of women are in leadership positions in the sector and only 18 percent make up the staff of infrastructure ministries (OECD,2019). These numbers are even higher in the Global South, though poor infrastructure tends to affect women more. In comparison to men, women generally travel shorter distances, travel more during off-peak hours, and rely more on public transport, which expose them to risk of attacks when they are poorly designed and operated with low security measures. Furthermore, poor infrastructure contributes about 60 percent of global carbon emission, contributes to the destruction of the eco-system with significant biodiversity lost, and affects economic activities.

These issues will be discussed in terms of three broad areas-economic growth, improvement in environmental resilience and strengthening social inclusion.

Low-carbon transport infrastructure provision and economic growth

Transport plays a key role in economic activities, facilitating movement of people and goods, but also contributing significantly to environmental pollution and degradation. This is especially true of the existing fossil fuel-based transport system. The OECD (2015) "projects that in the absence of further action to tackle climate change, the combined negative effect on global annual GDP could be between 1.0% and 3.3% by 2060, and as much as 10% by the end of the century". Such costs will have negative consequences on employment, health, and education due to the financial demand of such pollution and degradation on government revenues. Investment in clean public transport, more efficient vehicles, and electric vehicles with renewable electricity systems could create about 23 million additional jobs in a year globally. The likely growth benefits for the Global South are, however, uncertain as several economies in the region depend heavily on export revenues from coal, oil, and gas resources.

Low-carbon transport infrastructure provision and environmental resilience

Evidence from India (Pangotra Prem and Shukla PR, 2012; Pathak Minal and Shukla P R, 2016) has shown that transitioning to less carbon intensive modes of transport such as rail that is powered by clean electricity, reduces emissions of carbon, nitrogen oxides (Nox) and particulate matter (e.g., PM2.5). Investing in electric vehicles and the associated infrastructure, including decarbonizing electricity generation, has a long-term positive impact on carbon emissions, as does improving public transport infrastructure such as bus rapid transport system (Sarkar Debasis and Sheth Anal, 2021).

In addition to improved environmental quality and the health benefits it provides, low-carbon transport infrastructure can promote energy security by reducing dependence on fossil fuels. This is especially important for countries that are net importers of such fuels, as demonstrated by the consequences of the current Russia-Ukraine war.

Low-carbon transport infrastructure provision and strengthening social inclusion

Low-carbon transport infrastructure such as road and rail systems require clean energy sources to support the infrastructure and the associated modes in delivering a transition to a low-carbon transport system in the Global South. The transition to such a clean energy system is likely to require policies such as support for technologies that reduce the unit costs of renewable electricity, removal of fossil fuel subsidies, and the imposition of carbon taxes. To ensure a just transition, however, job opportunities should be integrated into such low-carbon transport infrastructure provision to balance the jobs lost in the "old" technology sectors and provide some inclusivity of the transition process. Transition to a low-carbon economy may contribute to developing local economies which could help enhance local job opportunities, if well designed to cater for all groups in the society.

1.3.2. Overview of transport infrastructure in the Global South

Transport infrastructure in the Global South, as in the developed world, comprises roads, rail, air, water, and sea. However, in SSA, the Middle East and North Africa (MENA) it is poorly developed relative to the other developing regions. Data from Calderón et al. (2018) suggest that road density expressed as a kilometer of road per square kilometer of the land area is about 0.11 for both SSA and MENA in 1990, and compared to 0.13 for Latin America and the Caribbean (LAC), 0.16 for East Asia and Pacific (EAP) and 0.31 for Southeast Asia (SA). These values reflect spatial density and suggest a huge road transport infrastructure gap in these developing regions in terms of spatial density. An earlier report by the World Bank (2009) indicated a significant road density gap (km/1000 people) for most of the developing world relative to North America and Europe. For instance, the road density in SSA is 3.4 km per 1000 people as against the world average of 7.7km per 1000. In Latin America and the Caribbean, Middle East and North Africa, and South Asia the road density values are 6.8 km, 3.88km and 3.19km per 1000 people, respectively. These values are all below the world average and far lower than the value in North America (25 km per 1000 people).

The spatial infrastructure gap in these developing regions is even worse in the case of rail transport infrastructure as suggested by Calderón et al. (2018) and presented in Table 2. The rail infrastructure density in 1990 ranged from 0.003 in LAC to 0.021 in SA and ranged from 0.002 km per square km of surface area in SSA in 2011 to 0.016 km per square km of surface area in SA (Calderón et al., 2018).

Table 2 : Rail and Road Transport Infrastructure Quality in Developing Regions

		SSA	SA	MENA	LAC	EAP
Railroad Density	1990	0.004	0.021	0.005	0.003	0.005
km of road per sq km of land area (median) 2014		0.002	0.016	0.006	0.007	0.003
WEF - Road quality	2006	2.14	2.98	4.18	3.06	4.52
Score (0, worst - 7, best)	2015	3.34	3.95	3.97	3.57	4.53
WEF - Rail quality	2009	1.93	3.24	3.24	1.53	3.57
Score (0, worst- 7, best)	2015	2.23	3.88	2.99	1.89	4.3

Note: EAP= East Asia and Pacific; LAC= Latin America and the Caribbean; MENA= Middle East and North Africa; SA= South Asia; SSA= Sub-Saharan Africa; WEF=World Economic Forum

In 2011, each of the regions experienced an improvement in the road density (spatial density) except for SSA, which experienced a deterioration of the density as depicted in figure 4. The implication of the low road density on carbon emissions is likely to be low because of a combination of factors such as the low motorization rate in Africa, about 42 vehicles per 1000 of the population compared to the global standard of about 180 vehicles per 1000 of the population (OICA,2016). This is coupled with the fact that a sizeable share of the roads are gravel roads, which have a low emission factor as presented in Table 3. However, this is expected to change as demand for paved roads, national roads, expressways, and motorization rate are expected to increase as the economies grow and developed. This will result in a shift from road categories with low emission factors such as rural gravel roads to categories with high emission factors such as national roads and expressways if the existing road infrastructure designs are not fundamentally changed to designs that are capable of delivering low-carbon transportation systems.

Table 3 GHG Emissions of various road categories (tCO2 eq/km)

	Express-way	National road	Provincial road	Rural Road-Gravel	Rural road-DBST
Emission (t CO2 eq/km)	3,234	794	207	90	103
Factor equivalent to Expressway	100	24.5	6.4	2.8	3.2

Source: (IEA,2004)

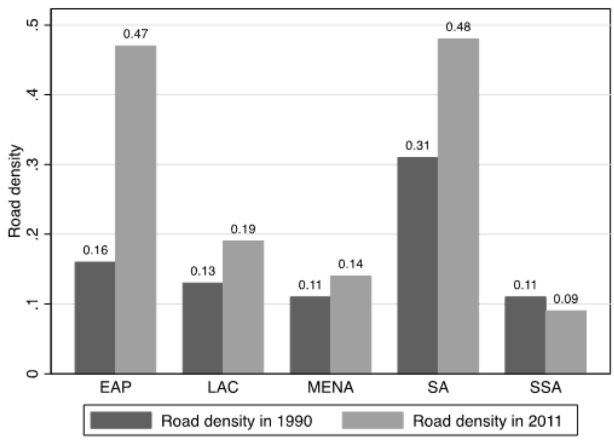


Figure 10 Road density of the developing regions in 1990 and 2011

Source: Authors generated the figure based on data from Calderón et al. (2018). Note: EAP= East Asia and Pacific; LAC= Latin America and the Caribbean; MENA= Middle East and North Africa; SA= South Asia; SSA= Sub-Saharan Africa

Another important metric to assess transport infrastructure, its quality and likely contribution to GHG emissions, is the share of paved roads of the total road network. The global standard is that on average, half of the road density in a region should be paved. Most of the developing world, other than SSA and LAC, has already passed this threshold. Only 17% of the roads in SSA were paved in 1990, and only 18% of LAC roads were paved in 1990 as shown in figure 5.

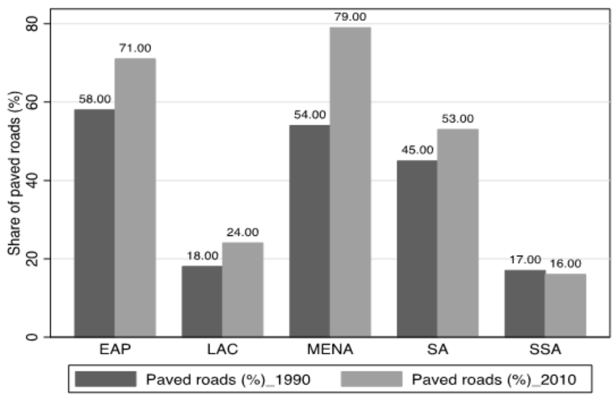


Figure 11 Share of paved roads of the developing regions in 1990 and 2010

Source: Authors generated the figure based on data from Calderón et al. (2018), Note: EAP= East Asia and Pacific; LAC= Latin America and the Caribbean; MENA= Middle East and North Africa; SA= South Asia; SSA= Sub-Saharan Africa

A second scorecard for assessing the quality of transport infrastructure is the World Economic Forum (WEF) quality assessment score, which ranges between 0 and 7. The lowest quality is represented by 0 and the highest by 7 on the score sheet. Of the developing regions, SSA has the lowest quality in terms of road infrastructure. Specifically, in 2015 SSA's road quality score was 3.34, the lowest of the developing regions. For rail infrastructure in 2015, the quality level for SSA (2.24) only betters that of LAC (1.89), as shown in table 2.

The quality of air transport infrastructure in the developing region is also below that of developed regions such as the European Union (EU). The average air transport infrastructure quality score for SSA in 2019 was 3.79, the lowest in the developing region, and compared poorly to the EU, which had an average score of 5.2. The highest score in the developing region was that of South Africa (4.76), which was about 8.5% lower than the EU's quality score (figure 6).

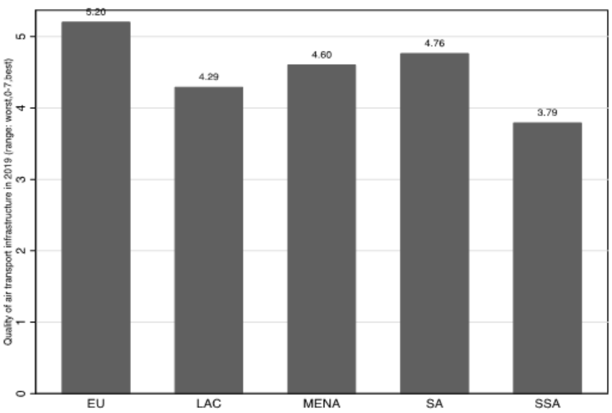


Figure 12 Quality of Air Transport developing regions and EU in 2019
Source: Authors generated the figure based on data from WEF (2022, Note: EU= European Union; LAC= Latin America and the Caribbean; MENA= Middle East and North Africa; SA= South Asia; SSA= Sub-Saharan Africa; WEF=World Economic Forum

The carbon footprint of transport infrastructure in Developing Countries

Globally, the transport sector continues to be a significant contributor to Green House Gas (GHG) emissions. In 2005, it was the second-highest source of global GHG emissions, contributing approximately 14% (IEA,2005). In 2018, it remained the second-highest contributor to global GHG, second to electricity and power generation (IEA,2022), and accounting for 24% of global CO2 emissions. Road transport was responsible for three-quarters of total transport emissions in 2018, with passenger vehicles contributing about 45.1 % and trucks about 29.4%.

In 2018, road transport added 6.4 times more to global emissions than aviation, which was the second-largest contributor to GHG emissions, adding 11.6% of transport emission. Shipping was the third-largest contributor to global transport emissions (10.6%) in 2018, while rail transport accounts for only 1% (IEA,2022).

In the case of developing countries, especially those in Asia, where there is greater road expansion to foster trade and growth, the contribution of road transport to total emissions generated by the transport sector is much higher, between 95-100% (The World Bank, 2011).

The carbon footprint of transportation varies significantly across the various transport modes. For instance, a case study of China by Luo et al., (2018) suggests that the CO2 emission per passenger per kilometer traveled is highest for passenger cars (70.3 grams of CO2) and lowest for common rail (11.7 grams of CO2).

Transport mode	2015	
Cara	70.397	
Coach	14.31	
Short-haul flight (<1000km)	63.376	
Long-haul flight (>1000km)	59.151	
Common rail	11.667	
High-Speed rail	30.438	

Table 4 The carbon footprint of transport mode in China in 2015
Note: Unit of measurement is grams of CO2 per passenger per kilometer (g CO2 PKM).

The car emission estimate assumes three passengers.
b A coach is assumed to have a forty-five-person capacity.
Source: China by Luo et al., (2018)

A short-haul flight has a carbon footprint of 63.4 grams, while the carbon footprint of a long-haul flight is 59.2 grams. These values are reported in Table 4. Given the emission factors for China, as car ownership increases, and if significant numbers of cars run on fossil fuels, the carbon emissions from such a case would be worryingly high. This, among other things, suggests that as personal car ownership increases in most of the developing world, emissions from road transport will rise substantially in the absence of significant technological changes and if cars continue to depend on fossil fuels. Likewise, if there is a shift to electric vehicles but most of the electricity is generated from fossil fuels, especially coal, the global emissions benefit would at best be small due to emissions from the generation of electricity.

1.3.3.Method and Data

This sub-section of the paper reviews studies on public-private partnerships in low-carbon transportation in the Global South and their implications for gender issues in order to identify research gaps.

1.3.7.1 Data Collection Strategy

For this review, the study uses the following data collection approach.

1. Divide the review to key thematic areas that the search should focus on.
2. Apply the data collection approach to broadly retrieve the studies on the thematic areas.
3. Apply inclusion and exclusion criteria to the retrieved data to remove duplicates and less focused studies based on the key research questions of the study.

Applying the data collection strategy outline above, the study retrieved data from three data bases: Scopus, Web of Science and Google Scholar. It used a combination of keywords and phrases such as public-private partnership, low-carbon transport, CO2 and transport, gender and social inclusion, gender, and transport. The search resulted in a total of 520 studies. 49 duplicates were detected and removed, leaving 471 unique studies. The search was limited to start from the year 1990 and end in the year 2022. Figure 7 presents the 471 unique studies generated on our search algorithm based on the various key words and phrases.

Studies that contained "public-private partnership or low-carbon or CO2 or transport" in the title and abstract

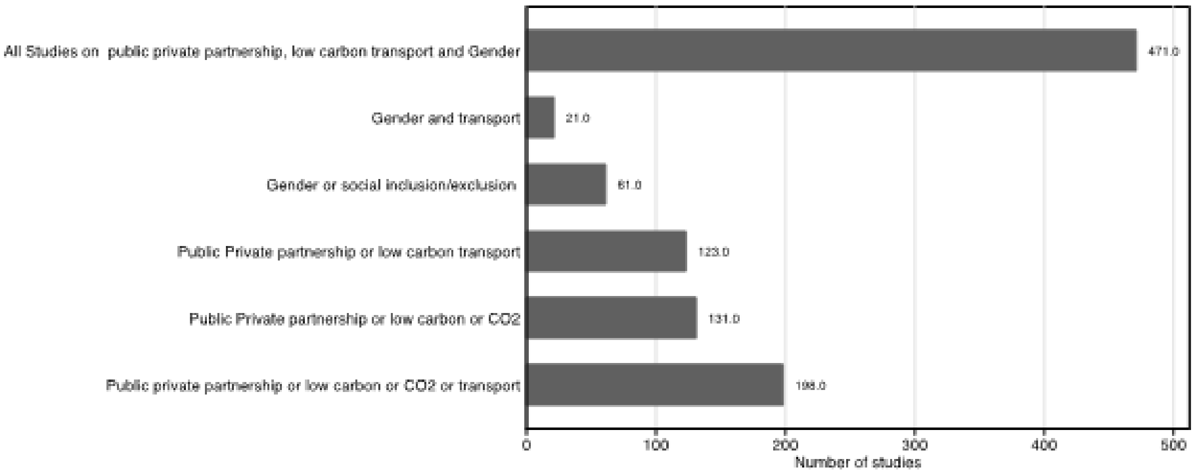


Figure 13 Number of unique publications across various categorizations based on the search keywords

make up the largest number of studies (198), about 42 % of the studies in our dataset. Using only studies with "public-private partnership or low-carbon or CO2" in the title and abstract, the number of publications was reduced to 131. It fell to 123 unique publications when the code was restricted to reflect only "public and private partnership or low-carbon transport".

In the case of gender, there are only 61 unique publications with the words "gender or social inclusion/exclusion" in the title and abstract, about 12% of all the unique studies in our dataset. When we focus on studies that have "gender and transport" in the title and abstract, only 21 unique publications were established (about 4.5%).

1.3.7.2 Exclusion and Inclusion criteria

The study focuses on two key areas, public-private partnership (3Ps) in low-carbon transport infrastructure provision, and gender and low-carbon transportation in the Global South. The data reported in figure 7 was not restricted to studies on the Global South and was not confined to studies that only considered both the 3Ps in low-carbon transport infrastructure provision. In ensuring that the data for the review was consistent with the objectives of the study, we applied the following inclusion criteria to remove all irrelevant studies from the 491 unique studies presented in figure 7.

All the 491 unique studies were coded by country or region of coverage and divided between Global North and South. Thereafter,

- All studies belonging to the Global North were dropped from the data set.
- The abstract and text of each of Global South study was

searched for the term, 'public-private partnership in low-carbon transportation'. Those with it were classified as 1, and those without the phrase in the abstract or text as 0.

- Search through the abstract and text of each of Global South studies for 'gender and low-carbon transportation', classifying those with it as 2 and those without the phrase as 3.
- Drop all Global South studies with 0 and 3 classifications from the data set.

Applying the above inclusion criteria to remove all irrelevant studies from the dataset, left 52 studies on the 3Ps and low-carbon transportation in the Global South, and 7 studies on gender and low-carbon transportation.

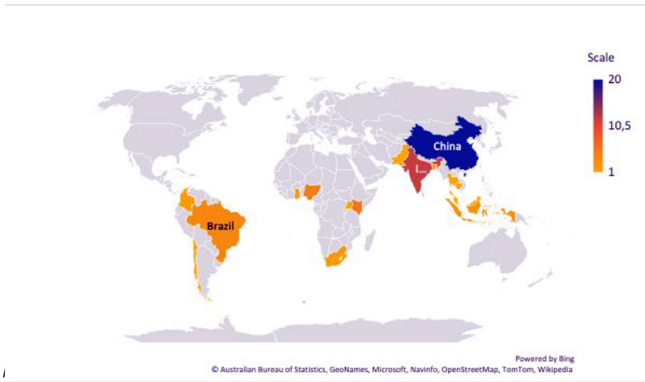
1.3.4.Public-Private Partnership in low-carbon transport infrastructure provision in the Global South

This section reviews the literature on the 3Ps in low-carbon transportation in the Global South. It first presents the distribution of the studies over countries, time of publication, and journals, before presenting a detailed review of the relevant studies.

1.3.4.1 Coverage of public-private partnership in low-carbon transportation articles by geography, time of publication, and journal in the Global South.

Geographical distribution of publications

Narrowing the search to publications that focus on public-private partnerships in low-carbon transportation in the Global South left 52 studies distributed over 19 countries. The distribution of the studies in the Global South is shown in figure 8, which indicates that the 5 countries with the most studies are, China (20 studies), India (12 studies), Kenya (6 studies), Nigeria (5 studies) and Brazil (4 studies). Countries with only one study include Uganda, Cambodia, Pakistan, Thailand, Lebanon, Malaysia, and Chile. Note that a study could cover just one country or a broad range of them.



countries in the Global South

Time of publications

In addition to the distribution of the studies in countries in the Global South, we analyzed the data to have a clear understanding of the distribution of the studies over time. This was to give us a perspective on when issues on public-private partnership in low-carbon transport featured popularly in the literature and the likely gaps in such studies over time in the Global South.

The analysis is summarized in figure 9, which clearly shows that from 1995 to 2012, publications on this area were uncommon, with a study per year during this period. The year with the most publications was 2020 (10 publications). 2021 had the second most (8 publications), and the early part of 2022 (6 publications).

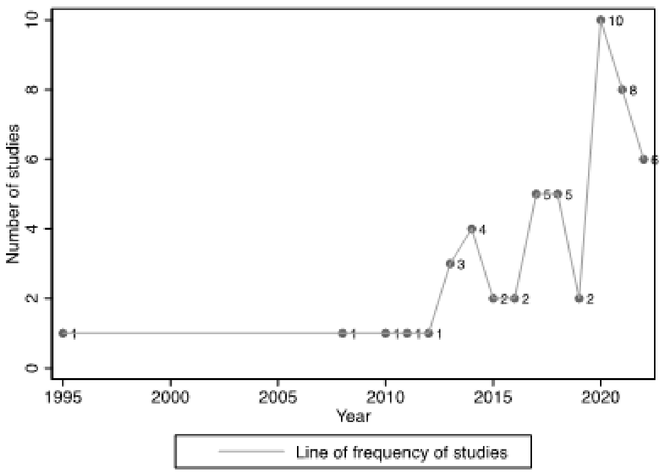


Figure 15 Trends in publication frequency on Public-Private Partnership Studies and Transport in the Global South

Journals of the publications

Of the 52 publications concerning the Global South, 11 were working papers. Only 41 of the studies were published in peer reviewed journals, of which the Journal of Cleaner Production and Transportation Research Part D: Transport and the Environment have the most publications. The distribution is presented in figure 10.

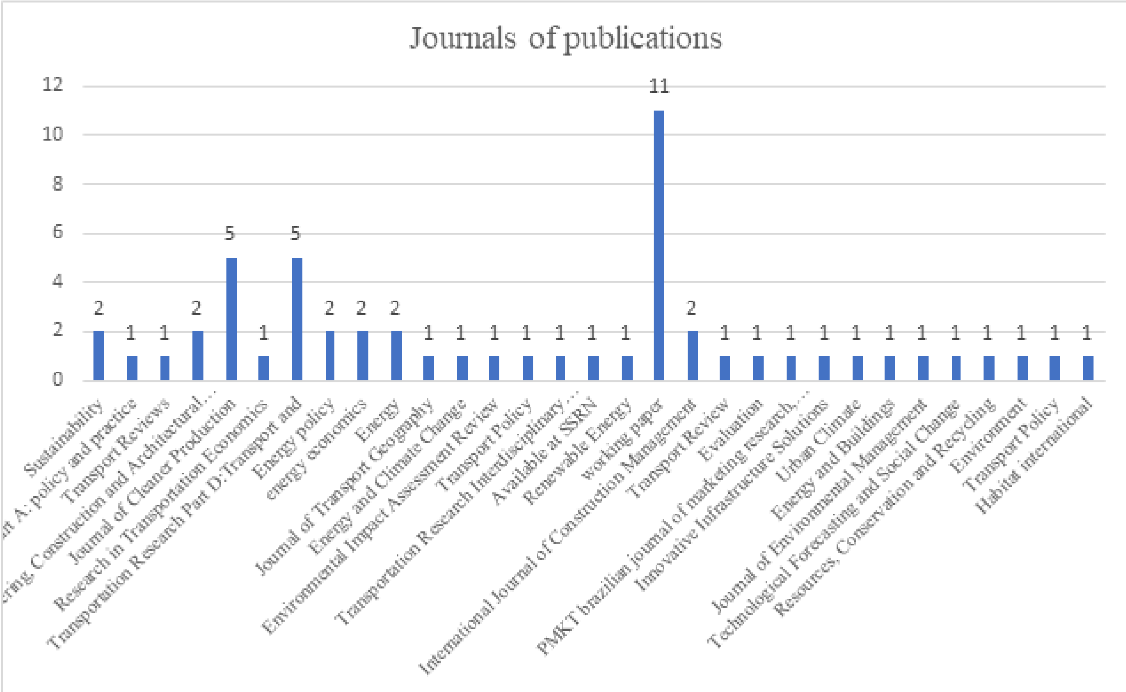


Figure 16 Journals of the reviewed publications

1.3.8.2 Review of studies on 3Ps in low-carbon transport in the Global South

The concept of public-private partnership in the provision of infrastructure, especially in the emerging and developing countries, has been of great interest over the years. Such partnerships have been implemented in some countries since 1984 (in the case of China). In recent years, the limited fiscal space for many countries in the Global South, coupled with a number of competing priority areas that require government investment such as health, education, enabling environment for job creation by the private sector etc., suggested tapping into the private sector to help finance critical infrastructure development.

Transitioning into a low-carbon economy calls for innovative transport infrastructure development that is aligned with the transition process. This will have to be less fossil fuel dependent, and more efficient in its energy use, whilst being inclusive and acceptable to the population. This calls for significant investment in the transport infrastructure, as well as changes in transportation modes and behavioral changes in support of such developments. One way to provide such a low-carbon transport infrastructure is via the 3Ps.

Prior research on the 3Ps in low-carbon transportation in the Global South can broadly be grouped into four themes: 3Ps and infrastructure provision; 3Ps and road transport provision; low-carbon transportation and emission, and low-carbon transport infrastructure provision in large cities. Table 6 in the appendix summarizes the key studies in the literature by geographical area, method of analysis, journal of publication, theme, and the main findings of the study.

The literature reviewed had 11 studies (Anwar et al., 2017; Babatunde et al., 2015; David and Venkatachalam,2018; De Oliveira et al., 2017; Kariuki Ruth W, 2014; Tsunoda Jiro, 2014; Verougstraete Mathieu, 2018; Weisheng Lu et al., 2013; Xiong Wei, 2020); that fell under the 3Ps in infrastructure provision's theme. These studies generally focused on identifying sectors with great 3Ps potential, challenges associated with 3Ps in infrastructure provision, barriers to 3Ps projects, impact of the 3Ps on infrastructure provision, governance issues of 3Ps and projects, efficiency and sustainability aspects of 3Ps projects, and assessing the popularity of the 3Ps in infrastructure provision relative to conventional infrastructure provision mechanisms in the studied countries.

For instance, the study by Anwar, Xiao, Akter, and Rehman, (2017) used case studies in South Asia (the cities of Dhaka and Lahore) to study the development of sustainable infrastructure through Public-Private Partnerships. The study addresses two issues. First, a twofold approach (i.e., grasp urbanization with sustainable infrastructure delivery by sustainable enactment of 3P projects) to achieve urbanization with sustainable infrastructure using 3Ps. Second, to identify the risk factors facing 3P projects in developing countries. They find that there is a lack of policymaking in the domain of 3Ps which may create problems for their prospects. Contractual incompleteness is the major concern of the existing 3Ps. The study adds that to avert this, institutional governance should provide complete contracts like Build Operate and Transfer (BOT), BOOT (build, own, operate and transfer) etc. A further major risk identified is political instability which promotes distrust among the actors of 3Ps leading to the failure of these projects. Other risk factors discovered include lack of governmental attention at both national and provincial levels, inadequate legal frameworks to regulate the area, strong political meddling, corruption and nepotism, persuasive economic events (e.g., advertisement, promotions, political campaigns), and lack in critical models required for 3P projects. These risks are widespread in South Asian countries such as Singapore, China, Bangladesh, and Pakistan.

A study by Babatunde, Perera, Zhou and Udeaja (2015) identified nine key barriers to the implementation of 3Ps in the provision of infrastructure in Nigeria. These were potential conflicts of interests among the stakeholders, the politicization of the concessions or political interference in the procurement process, uncertainty of political environment or political instability, lack of transparency and accountability, poor financial projections and access to funds, the inability of local institutions to provide long term financing or equity financing, foreign investors' perceptions of the country as a high-risk economy, difficulties in securing credit facility from banks, and poor evaluation, monitoring, and due diligence by the public sector.

David and Venkatachalam (2018) document how the 3Ps and green investment banks (GIBs) can be used to finance interventions to mitigate climate change. Their study notes that 3Ps are good for green finance in countries with strong institutions and governance, protection of investments and good dispute resolution mechanisms. Martin et al. (2010) document how China uses 3Ps to fund emission reduction in five larger metropolitan areas in China (Shanghai, Beijing, Shenzhen, Chongqing, and Harbin). The authors noted that China's financial, institutional, and geographical context provides a brighter future for the use of PPP in financing projects that target emission reduction.

In the case of the second theme (3Ps and transport infrastructure provision), 20 studies were found. These are shown in table 6 of the appendix, and tend to explore key issues broadly categorized as: quality of institutions and 3Ps in transport projects, the implications of 3Ps in transport projects for transport CO2 emissions, 3Ps for urban transport infrastructure provision such as bus rapid transit initiatives, t3Ps and road concession systems, 3Ps and road infrastructure development, barriers to implementing 3Ps in road transport projects, economic evaluation of 3Ps in transport projects, and the role of 3Ps in electric vehicles charging infrastructure, and their effect on pricing for the end-user.

Anwar et al. (2021) apply a quantile autoregressive distributive lagged (QARDL) to study the asymmetric relationship between Public-Private Partnership investment in the transport sector and CO2 emissions in China. Their findings show a negative effect of 3Ps in transport infrastructure provision on total transport carbon emissions (TE) in China at the 80th to 95th quantile. Furthermore, they find evidence of environmental kuznets curve (EKC) at the 90th to 95th quantile, suggesting an environmentally unsustainable economic growth pattern in China, which low-carbon transportation system would help. The study findings also show that renewable energy consumption is negatively associated with transport carbon emission (significant at 30th to 95th quantile).

Arata, Petrangeli, and Longo, (2016) use a case study to demonstrate how Colombia engaged an Italian company, ANAS International Enterprise, a subsidiary of the Italian Highway Agency ANAS S.P.A, to structure a 3P concession for a large part of Columbia's Road network. Their activities included the development of a financial model consistent with the rules and the economic parameters of the Colombian market, the assessment of economic and financial feasibility, carrying out studies and simulations for risk analysis, and technical, financial, and legal assessment. They also considered the preparation of tender documentation and delivery of technical support to the National Infrastructure Agency during the 3Ps awarding process. The outcome has been improvements and innovations in construction, transport technology, financial structuring, project financing, and the development and implementation of alternative 3P structure and contract types.

After much discussion and some evidence on the contribution of fossil fuel dependent transportation to carbon emission and given the growing evidence of climate change's impacts, it was natural for researchers to question and assess various transport strategies and their impact on carbon emissions. 16 of the reviewed studies focus on transport and emissions. These are Arioli et al., (2020); Dharmala et al., (2022); Hassan et al., (2021); Hassan et al., (2022); Holler et al., (2020); Jennings & Gail (2020); Jiang et al., (2021); Lee et al.,(2017); Mansour, and Haddad (2017); Shahbaz et al.,(2020); Silva et al.,(2022); Sun and Leng (2021);Wanke et al.,(2020); Wanke et al.,(2021); Yang et al.,(2021); Zhao et al.,(2022); Zhou et al.(2018). The key topics examined by these studies are the role of transport 3Ps in energy projects on CO2 emission, the impact of carbon tax policy on CO2 emission, smart transportation and carbon emission, the impact of macroeconomic variables on issues such as energy consumption and CO2 emission, assessing decarbonization policy, alternatives to passenger transportation, assessment of low-carbon fuel-vehicle strategies, low-carbon transport policy in the Global South and the implications of rail transport for carbon emission.

Arioli et al., (2020) explore the decarbonization of land transportation in four emerging economies (Brazil, India, Kenya, and Vietnam). Their study concludes that achieving 1.5 Degree Celsius (DS) would require dramatic changes in travel patterns, technology and fuels and the intensification of current policy approaches. These countries would have to increase their investment in efficient modes of transport, in near-zero carbon fuels such as clean electricity, in the integration of transport systems, and in urban planning solutions.

Dharmala et al. (2022) document road transport, air pollution and climate change policies in India. They explore policies to reduce CO2 and particulate matter (PM 2.5) emissions using five policy scenarios: fuel efficiency, electrification, alternative fuels, model shifts, and moderation in demand for transport. The study concludes that all the five scenarios are effective, but that an increase in the efficiency of passenger and freight vehicles has the greatest potential to reduce CO2 and PM 2.5 emissions.

Mansour, and Haddad (2017) use a case study from Lebanon to assess the short- and long-term implications of low carbon-fuel vehicles (such as electric and hybrid electric vehicles) as alternatives for road transportation in developing countries. Findings from the study suggest that electric vehicles are only likely to be beneficial in the long term as they require costly charging infrastructure and a clean electricity mix, which will not be available in most developing countries in the short term. Plug-in hybrid electric vehicles are more attractive for the medium term. Gasoline or diesel hybrid electric vehicles are the most feasible and beneficial technologies in the short-term for developing countries.

Silva et al. (2022) explore decarbonization alternatives for passenger transportation in Brazil. Findings from their study indicates that mass transportation approaches such as public buses and carpools (shared mobility) increase system capacity, result in lower vehicle ownership, and reduce energy demand and CO2 emissions at no increased system cost. The authors find that carbon pricing is the most effective policy to reduce CO2, but also the most costly (in terms of abatement cost) of alternatives and results in greater private vehicle use (up to 260%) if expansion of zero-carbon public transportation remains limited due to technology adoption. The policy that reduces emissions the most (by 84%) combines the expansion of renewable electricity generation and implementation of carbon pricing.

Hassan, et al. (2021) used a Non-Linear Autoregressive Distributed Lag (NARDL) model to study the link between public service transportation and environmental pollution in China for the period 1985 to 2018. The results show a positive and negative shock between CO2 emissions and four specific transportation developments that led to an increase in environmental cost in the short run. The results indicate that airline, road, and waterway operational mileage per capita of both positive and negative transportation shocks had worsened the environmental quality in China. The study recommends the support of urban public policies to improve public transport services such as buses and metros. Policy makers can also introduce the sharing of bicycles and automobiles to reduce the use of private vehicles.

Passenger transportation demand in urban areas in most countries in the Global South is increasing due to rising population, income, and urbanization. These developments impose significant pressures on energy demand and emissions intensities associated with conventional transport, threatening sustainability, and energy security. Policies makers are seeking alternative transportation options that could jointly mitigate these risks. Three of the reviewed studies that researched these issues are categorized under "low-carbon transport infrastructure".

A study by Pangotra Prem and Shukla PR (2012) assessed the Delhi-Mumbai dedicated freight corridor (DFC) project on carbon emissions under three scenarios: a business-as-usual (BAU) with DFC project, BAU without DFC project, and low-carbon with DFC project. Findings from the study reveal significant carbon emission reduction from dedicated large projects for such rail transport infrastructure development. Specifically, the Delhi-Mumbai DFC project under the BAU scenario would reduce annual CO2 emission by nearly 81%, and by 97% in the low-carbon scenario. The emission reduction in the BAU with the DFC project is driven by a modal shift of freight traffic from road to rail, and the conversion of all rail freight tracks into electric tracks. The additional reduction in emissions from the LC scenario is due to the further decarbonation of the electricity sector in response to a carbon tax.

Pathak Minal and Shukla PR (2016) apply scenario modelling for sustainable and low-carbon urban transportation in a case study of the city of Ahmedabad, India. In the study the authors considered two scenarios: the business-as-usual (BAU) and a low-carbon scenario (LCS) from 2010 to 2035. Results from their modelling suggest that under the BAU, the demand for energy would increase four-fold, irrespective of vehicle efficiency improvements, cleaner fuel norms and expansion of public transport infrastructure over the period. The LCS reduces oil demand and thereby improves energy security. It also delivers air quality co-benefits, reducing nitrogen oxide (Nox) and particulate matter (PM) from passenger transport in 2035 by 74% and 83% respectively.

Fisch-Romito and Guivarch, (2019) quantify the transportation infrastructure investment needed over time to achieve both development and climate objectives. They build socioeconomic scenarios using the Imaclim-R integrated assessment tool. They find that the expenditure needs for transport infrastructure is lower in countries with low-carbon pathways than in baseline scenarios. They find that rail utilization rates and road construction costs are determining factors for investment in all regions. They note that, by shifting from road to rail infrastructure, countries can reduce the investment needed in the transport area. The study adds that more analysis is needed on energy efficiency or alternative fuel use to fully understand the transport sector in a low-carbon world.

Summary of key findings on the 3Ps and low-carbon transport infrastructure review

Key findings from the above reviews include:

- Most of the studies on 3Ps and low-carbon transition were focused on road and rail infrastructure transport modes. Very little or no evidence exists for air transport.
- Most advanced economies are shifting from fossil fuel transport modes to electric vehicles, electric trains, and cycling modes. Studies on the adaptation, financing and use of such transport modes are lacking in the Global South.
- The review shows a gap in the literature on 3Ps and low-carbon transport infrastructure provision with most of the studies focusing on Asia (China and India) and Latin America and the Caribbean (Brazil, Chile, and Colombia). Very few studies exist in other Global South regions such as Sub-Saharan Africa.
- There is little literature on the quality of institutions needed to ensure good, environmentally friendly 3Ps and transport infrastructure financing.

1.3.5. Gender, social inclusion, and low-carbon transport in the Global South

1.3.9.1 Coverage of gender and low-carbon transportation articles by geography, time of publication, and journal in the Global South.

The presentation under this section is organized as follows: first structure of the data in terms of geographical distribution, time of publication and the journals in which they are published. Next a review of studies on gender and low-carbon transportation in the Global South. Table A3 in the appendix provide a summary of all the gender and low-carbon transport studies.

Geographical distribution of publications

This section provides the geographic coverage of gender and low-carbon transportation articles identified within this theme. Specifically, the distribution consists of Latin America and Caribbean (2), Asia (3), Sub-Saharan Africa (2).

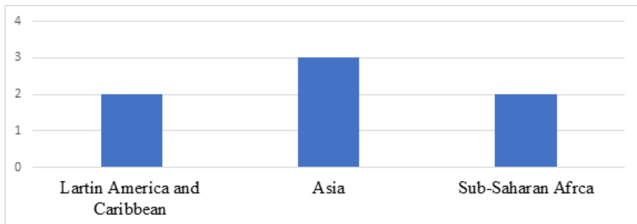


Figure 17 Distribution of studies over regions.

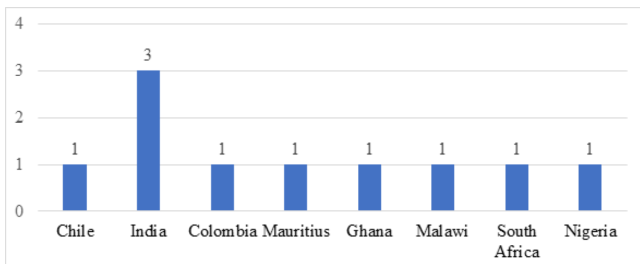


Figure 18 Distribution of studies over countries in the Global South

The figure shows the distribution of studies over countries in the Global South. The study shows that India (3) has the most publications among the Global South Countries. Chile, Colombia, Mauritius, Ghana, Malawi, South Africa, and Nigeria reported 1 study each. This suggests a lack of literature in Global South countries.

Time of publications

In this section, studies for gender and low-carbon transport have been grouped into year of publication. Publications in this area started in 2013 through to 2021. The years 2013 through to 2019 recorded the fewest, the most in any year being 1 publication. The years 2020 and 2021 reported the highest number of publications (2). Figure 13 shows the timing of publications on gender and low-carbon transportation.

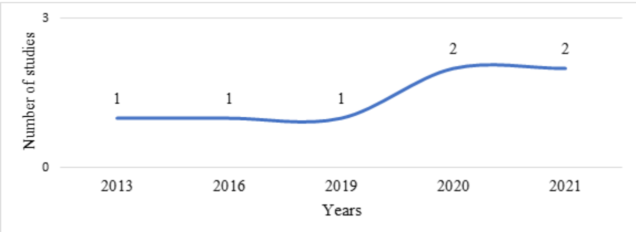


Figure 19 Trends in gender and low-carbon transport

Journals of the publications

The figure 14 below shows the journals in which papers on gender and low-carbon transport in the Global South appeared.

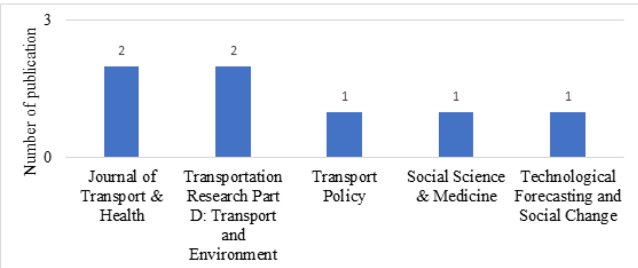


Figure 20 Journals with Gender and low-carbon publications

The findings suggest all 7 studies were published in peer-reviewed academic journals. In all, Journal of Transportation & Health and Transportation Research Part D recorded the highest number of peer-reviewed papers (2) each. Transport Policy, Social Science & Medicine, and Technological Forecasting and Social Change recorded 1 publication each over the period.

1.3.9.2 Review of studies on Gender and low-carbon transport in the Global South

Aguilar-Farias et al. (2019) document the prevalence of cycling by Chilean adults and examine factors associated with such transport choice. The study uses multivariable, multi-level logistic regression to assess correlates of bicycling as the primary transport mode. They find that the association between environmental factors and cycling is stronger in women than in men. Cycling prevalence in Chile is low compared to other Latin American countries. The association between environmental factors and cycling differed by gender.

Mahadevia (2016) investigates gender equity in transport services and a move to low-carbon transport in the city of Rajkot India. The study finds that the trip lengths of women in the city in each of the income groups are lower than that of their male counterparts. The study notes that when incomes increase, the lengths of trips undertaken by persons of both genders increase, but the increase is higher for men than women. With the increase in income, men tend to personal motorized transport while women shift to paratransit. Finally, sustainable climate policies should target retaining the current low ecological footprints of women, allowing the expansion of their mobility by improving the infrastructure they need.

Majumdar et al. (2021) analyzed the determinants of commuters' perceived trip satisfaction in order to guide the formulation of policy instruments in New Delhi. The study uses a set of ordered logit regression models, and finds that gender, age, accessibility, and built-environment characteristics such as streets, level of congestion, availability and existing conditions of sidewalks, bus stop safety, and security, were significant determinants of trip satisfaction. The study also finds that, for both work and non-work-related trips, public transport users were less satisfied than car commuters. The study recommends that policies should target the illumination of roadways, reduction in street congestion, and improvements in public transport systems, to improve commuters' satisfaction.

Montoya-Robledo et al. (2020) study gender stereotypes affecting the mobility of care in Bogotá. The study used focus groups and surveys in four districts of the city of Bogotá. It noted gender differences in travel behavior which are influenced by individual social and physical factors. The study finds that male and female cyclists have different perceptions of safety. Women tend to perform more childcare activities than their male counterparts. Women are more at risk of gender-based violence while cycling with their children. Policymakers are to understand these gender-based stereotypes when designing public policies aimed at increasing urban cycling, especially among women.

Singh et al. (2021) document the use of the E-rickshaw as the new emerging means for e-mobility. The study uses focus group discussions and surveys. The finding suggests that reliability, accessibility, happiness, gender equity, non-polluting, employability, social equity, comfort, and health are embedded in the innovation. These values make the product socially, economically, and environmentally sustainable in the region.

Thondoo et al. (2020) used a mixed methods approach to assess the alignment between urban transport policies and self-reported citizens' needs in Port Louis (Mauritius). The study uses a logistic regression model to study the association between needs and demographic indicators (age, gender, and income). It finds no significant relationship between demographic factors and the unmet need for green space. It does find significant relationships between age, professional and gender indicators, and three needs: improvement in sidewalks, more public space, and centralization of hawkers at main bus stations.

Summary of key findings on gender and low-carbon transport in the Global South

Key findings from the above reviews include:

- There is a lack of studies on the gender inclusion perspective of the 3Ps in low-carbon infrastructure provision. The few studies that exist focus on gender inclusion and low-carbon transport and ignore the 3Ps aspect, which is key to the financing of infrastructure, especially low-carbon transport infrastructure.
- Women's experiences in the mobility of care (especially childcare), an important research direction, is lacking in the Global South, where women play a major role in providing care for their families, particularly cycling children to and from school and farm-based activities.
- Little has been written about the gender impacts of the transition to a low-carbon economy in LDCs. We have found nothing about its impacts on other marginalised groups such as youth, rural dwellers, and participants in the informal sector.

1.3.6. Important areas for future research consideration

The review of studies in 3Ps, low-carbon transport infrastructure, and social inclusion highlights important questions that are not conclusively answered. These include:

- What are the likely behavioral responses to transformational low-carbon transport modes in the Global South?
- Which groups in society are most likely to adopt low-carbon transport modes and which groups are less likely to adopt these modes?
- Among the various low-carbon transport modes, which ones are more likely to be accepted by the population in the various countries in the Global South and by different groups in the society?
- Are women more or less likely to adopt mass transportation modes in the Global South and why (especially in urban centers)?
- How effective are 3Ps as a financing option in providing low-carbon transport infrastructure in the Global South?
- What are the key challenges of 3Ps as a financing option in low-carbon transport infrastructure provision in the Global South?
- Should all social groups be represented in the design, development, and operation of low-carbon transport infrastructure to achieve the intended goals?
- What financing options are best for specific low-carbon transport models in the Global South?
- What are the key investment needs for low-carbon transportation infrastructure if it is to achieve both development and climate objectives in the Global South?

1.4 Conclusion

This paper systematically reviewed i) the impact of digital technologies on energy systems, social inclusion, and household welfare; and ii) public-private partnership (3Ps) in the provision of low-carbon transport infrastructure and its implications for social inclusion in the Global South. Applying various inclusion criteria on the dataset resulted in 68 studies on the impact of digital technologies on defined outcomes in the Global South, 52 studies on 3Ps and low-carbon transportation in the Global South, and 7 studies on gender inclusion and low-carbon transportation in the Global South.

The following are the key conclusions from the review in relation to the impact of digital technologies on energy systems, social inclusion, and household welfare:

- There is paucity of research on how digitalization affects energy systems (demand and supply) in the Global South. The results are not conclusive. The results were found to be generally sensitive to the type of digital technology used, context analyzed, and method used.
- Only 4 of the 68 studies examined the effects of digitalization on energy supply in the Global South, and these were highly descriptive. The remaining studies focused on the demand-side, about 80 percent of these studies considered the direct effects of digitalization while the remaining 20 percent estimated the indirect effects of digitalization (i.e., scale, tertiarization and efficiency effects).
- On the demand-side, there are limited works on how different digital technologies influence energy demand dynamics in specific sectors of the economy. We note

that for key sectors such as the transportation, domestic homes, agricultural, building, and industrial sector – which consume significant amounts of energy – the evidence on the role of digitalization in influencing energy outcomes in these sectors is lacking.

- For both the demand and supply-side, the review showed that the bulk of the studies focused on countries in Asia, leaving a significant literature gap, particularly for Africa. The limited number of studies in Africa and some parts of Central and South America underscores the importance of data challenges and low adoption rates of digital technologies in these economies. Consequently, collecting good data on, and boosting uptake of, digital technologies in the energy sector would be key to advancing knowledge of the role of digital technologies for energy systems in the Global South.
- While there are studies examining the link between digitalization and social inclusion on one hand, and between digitalization and energy outcomes on the other, few studies connect the energy-related effects of digitalization to social inclusion and welfare.
- Important gaps exist in the literature on how social digital inclusion can promote gender equity in energy service delivery, and by extension social inclusion and hence household welfare. Also, an important knowledge gap exists regarding the effects of government policies such as digital taxation on social digital inclusion, equity in energy service delivery, and welfare.
- Because digital technologies mostly originate from other cultures, there is a problem of digital colonization, which can affect the adoption and use of digital technologies. Consequently, it is vital to understand the important role that local content and cultural values and norms can play in the design and implementation of digital technologies and the way they influence the energy service delivery gap between male and female, young and old, and rural and urban in the Global South.
- Quantitative assessment of the impact of digital technologies on energy supply is useful for ascertaining the energy-related effects of different digital technologies. Moreover, with the deployment of renewable energy technologies, it has become necessary to look at best ways to integrate such technologies into the energy system. In this regard, it is important to understand the important role those different digital technologies such as a virtual power plant, can play in ensuring the integration of renewable energy technologies into the national energy system.
- Studies analyzing either the demand or supply side relied on observational techniques that are low in internal validity. Studies adopting experiment-based design were found to be very limited. At best, the current literature presents evidence of an association between digitalization and energy systems and not a causal relationship from digitalization to energy systems. The application of quasi-experimental-based design approaches should be a key concern for future studies that aim to draw a causal inference from digital tools to energy systems. Also appealing would be to use big data and machine learning approaches to understand the link between digital technologies, energy, and social inclusion.
- For quantifying the indirect effects of digitalization, there are technical limitations, such as the absence of well-developed methods that can capture the complex nature of the various relationships involved. Designing rigorous methods that are more integrated in nature is key to unravelling the complex relationship existing between energy efficiency and digitalization. This may require a more inter-disciplinary approach in order to unravel the complex nexus existing between digital technology interventions and energy efficiency.
- Existing studies have shown that some sizeable rebound effects are associated with digital technologies, but the empirical literature remains scanty and subject to technical constraints. No well-defined methods have emerged that accurately capture the exact magnitude of the digital rebound effect. Developing an appropriate methodological approach that takes into account the level of complexity involved in quantifying the size is critical. Estimating the size of the digital rebound effect and what drives it are also critical questions to consider in future research.

In the case of public-private partnership (3Ps) in the provision of low-carbon transport infrastructure and social inclusion in the Global South, the following are the key conclusions from the review:

- On 3Ps and low-carbon transport, we can conclude that most of the studies were focused on road and rail infrastructure travel modes. Little attention was given to 3Ps and low-carbon air transport infrastructure. Air transport infrastructure is becoming more important in the countries of the Global South due to increasing trade and integration. Therefore, studies on how the 3Ps can help to provide air infrastructure are warranted, bearing in mind climate-mitigating measures in the face of increasing climate change in the Global South.

- We have noted a gap in the literature on the shift in travel modes towards low-carbon infrastructure, such as electric vehicles and electric trains with a view to reducing fossil fuel use in the Global South. There is a need for rigorous analysis of investment via 3Ps in such areas, and how such investment may influence the demand for such transport modes.
- The literature does not compare 3Ps in low-carbon infrastructure investments to other investment models that could provide such infrastructure in the Global South. The few studies that exist only evaluated low-carbon transport scenarios with a focus on rail transport for freight. They did not address investments in other transportation modes, nor did they assess the economic and environmental returns of such investments.
- The studies of 3Ps and low-carbon transport infrastructure provision in Asia are dominated by case studies from China and India, with very few studies from other Asian countries. Similarly, in SSA, most studies of road transport were in Kenya, Nigeria, or South Africa. In the Latin America and Caribbean region, Brazil, Chile, and Colombia had most of the case studies. There is a need for a broader range of developing country case studies, for comparative studies from different countries in the Global South, and between developing countries and developed countries.
- The literature on the role of institutions in ensuring good, environmentally friendly 3Ps in transport infrastructure is lacking. Such studies are important for the Global South, given the significant funding gap for adaptation costs associated with climate change in some of the regions in the Global South, such as SSA.
- There is a lack of studies on the gender inclusion aspect of the 3Ps in the provision of low-carbon transport infrastructure. The few studies that do exist focus on gender inclusion and low-carbon transportation but ignore the 3Ps aspect which is key in the provision of shared benefits in financing infrastructure.
- There is little empirical evidence on the impact of low-carbon transition, especially in transportation, on other marginalized groups, such as youth and those in rural areas or engaged in informal economic activities. The activities of these marginalized groups need to be considered for any climate change policy to be successful, especially low-carbon transport infrastructure.
- The experience of women in the mobility of care is an important research topic, especially in SSA and many other developing countries where women play a major role in providing care for their families, particularly transporting children to and from school and farm-based activities. Research should be commissioned in this area, especially on how urban planning can be used to reduce dependence on fossil fuel consumption.
- Further analysis is needed on green finance and low-carbon transition in the Global South. The few studies that exist focus on Asian countries. Empirical research is needed on how banks and other financial institutions can raise green finance for the transition to low-carbon transport in low-income and developing countries, with a particular focus on how banks can raise syndicated green finance for a transition to low-carbon transport.

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Appendix

Table 5 Summary of Reviewed Studies on digitalization

Snr.	Authors	Title of article	Year of publication	Measure of digitalization	Method of analysis	Region/ country of focus	Sector of focus	Key findings
1.	Cho et al.	The impact of ICT investment and energy price on industrial electricity demand: Dynamic growth model approach	2007 (JA)	ICT stock	Dynamic logistic growth model	South Korea	Manufacturing & Services sectors	ICT investment reduces electricity consumption in primary and metal products but increases electricity consumption for services and most of the manufacturing sectors
2.	Gavi, R.	The ICT/Electronics question: structural change and the rebound effect	2015 (JA)-Ecological Economics	ICT/Electronic devices	Energy efficiency elasticity of energy services	Global	Economic-wide	Energy efficiency induced by ICT/electronics cause proliferation of ICT/electronic devices usage, and thereby result in increased energy consumption. Rebound effects associated with digital energy efficiency ranges from 115 percent to 161 percent
3.	Weber, L. et al	The energy and climate change implications of different music delivery methods	2010 (JA)- Journal of Industrial Ecology	e-commerce and traditional sale of compact discs	LCA	n/a	Entertainment sector	Purchasing music digitally reduces energy and CO2 by 40 percent and 80 percent, respectively
4.	Amasawa et al.	Role of e-reader adoption in life cycle greenhouse gas emissions of book reading activities	2017 (JA)- The International Journal of Life Cycle Assessment	e-reader	LCA	Web survey	n/a	E-reading reduces global warming potential per person compared to reading only paper books
5.	Herner et al.	Known unknowns: indirect energy effects of information and communication technology	2016 –(JA)- Environmental research letters	ICT	Literature review	n/a	n/a	ICT generates large energy savings, but this is driven by user behavior and deployment details.
6.	Anjana and Shaji	A review on the features and technologies for energy efficiency of smart grid	2017-(JA)- International Journal of Energy Research	ICT	Literature review	n/a	n/a	ICT reduces energy cost and improves energy efficiency

6.	Sadorsky, P.	Information communication technology and electricity Consumption in emerging economies	2012 (JA)-Energy Policy	Internet connection, mobile phones Subscription and the number of personal computers	Panel regression GMM	Brasil, Colombia, Mexico, Peru, Czech Republic, Egypt, Hungary, Morocco, Poland, Russia, South Africa, Turkey, China, India, Indonesia, South Korea, Malaysia, Philippines, Thailand	Aggregate economy	ICT increases electricity consumption positively in the long run
7.	Afzal and Gow, 2016	Electricity consumption and information and communication technology in the Next eleven emerging economies	2016 (JA)- International Journal of Energy Economics and Policy	Internet connections, mobile phones subscription and ICT imports in total imports	Panel Mean Group estimator	Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, Philippines, Turkey, South Korea and Vietnam	Aggregate economy	ICT positively affects electricity consumption
8.	Khayyat et al.	How ICT investment influences energy demand in south Korea and Japan	2016 (JA)- Energy efficiency	ICT and non-ICT capital investment	Dynamic factor demand model	South Korea & Japan	Industries	ICT and non-ICT capital investment substitutes for labor and energy use and in South Korea, the degree of substitutability is higher for knowledge-based industries than the traditional industries.

9.	Bento, N.	Calling for Change? Innovation, diffusion, and the energy impacts of global mobile telephony.	2016 (JA) – Energy Research and Social Sciences	Mobile telephony	Experimental -Quantitative field trial: uses logistic model to forecast the growth in Mobile phone growth	Global Data – 227 countries	Economic-wide study	Mobile phone communication has a sizeable effect on energy consumption Historically, growth in mobile phone has been astronomical but in the last decade, developing countries have been key contributors Energy consumed in phone charging declined between 2000 and 2008 but has rebounded after. Average consumption was 1.2kWh. Smart phones seem to be reversing the trend in energy consumption due to many functionalities that come with this type. Energy needed to charge all devices during the period globally is estimated at 6-8TWh per year Mobile phone energy efficiency has improved
10.	Longo and York	How does Information, Communication Technology affect energy use?	2015 (JA) – Energy- Internal Journal	Landline phones, mobile phones and internet use	Panel regression	121 -135 countries	Economic-wide energy consumption and supply	Penetration of landline phones positively associated with higher levels of energy and electricity production and consumption Cell phones and internet use not associated with electricity and total energy production and consumption Internet usage has positive significant impact only on prevalence of passenger cars
11.	Chowdhury et al.	Role of information and communication technology in economic progress and increasing demand for renewable energy: evidence from China and India	2021 (JA)- Asian Journal of Technology Innovation	Internet users	Panel GMM	India and China	Economic-wide	ICT has negative and insignificant effect on economic progress. ICT impact positively on renewable energy consumption.
12.	Malmodin et al	Greenhouse gas emissions and operation electricity use in the ICT and Entertainment and Media Sectors	2010 (JA)-Journal of Industrial Ecology	ICT, entertainment and Media	Life cycle Assessment Approach	Global data	ICT, Entertainment and Media sectors	ICT sector produced 1.3% of global GHG emissions and 3.9% of global electricity use in 2007. E&M sector produced 1.7% of global GHG emissions and 3.2% of global electricity use in 2007

13.	Malmodin and Hunden	The energy and carbon footprint of the global ICT and E&M sectors 2010 – 2015	2018 (JA) – Sustainability	ICT, entertainment and Media	Life cycle Assessment Approach	Global data	ICT, Entertainment and Media sectors. 100 of the major global manufacturers, operators, and ICT and E&M service provider	Despite the growth in subscription and data traffic in ICT and E&M, their corresponding footprints have declined from what was previously forecasted. ICT energy footprint declined initially but increased after 2007. While mobile network operations' share of energy footprint increased, that of user devices declined. E&M energy footprint increased from 2007 to 2010 but then declined to 585TWh in 2015 partly due to improvement in energy efficienct televisions.
14.	Hed-deghem et al.	Trends in worldwide ICT electricity consumption from 2007 to 2012.	2014 (JA)- Computer Communications	Communication networks, personal computers and data centers (Mobile subscription. Fixed broadband subscription and fixed line subscription)	Following Lambert et al (2012) subscription representative based sampling and then extrapolating to the world data	Global data	Economic-wide	Communication networks, personal computers and data centres recorded growth rate in electricity consumption of 10%, 5% and 4%, which exceeds the world electricity consumption growth of 4% during the same time frame. In absolute terms, electricity consumption for all three ICT categories is roughly the same.
15.	Haldar and Sethi	Environmental effects of information and communication technology: exploring the roles of renewable energy, innovation, trade and financial development	2022 (JA)-Renewable and Sustainable Energy Reviews	Internet usage	Panel regression	Emerging economies (Argentina, Brazil, China, Columbia, Egypt, Greece, Hungary, Indonesia, Malaysia, Mexico, Pakistan, Peru, Poland, South Africa, Thailand and Turkey	Economic-wide	Internet usage reduces CO2 emissions Interaction between internet usage and innovation reduce CO2 emissions

16.	Koot and Wijnbio-ven	Usage impact on data center electricity needs: A system dynamic fore-casting model.	2021 (JA)- Ap-plied Energy	Data center	System Dynamic forecast-ing mod-el based on a bot-tom-up approach	Global	Econom-ic-wide data centers	The combined growth of data center electricity needs of 286TWh in 2016 to 321TWh in 2030, assum-ing growth factors remain the same. The growth in data center electricity needs is not fully compensated by efficiency gains of data centers
17.	Williams et al.	The energy use impli-cations of 5G: Review whole network oper-ational energy, embod-ied energy and indirect effects	2022 (JA)- Re-newable and Sus-tainable Energy Reviews	5G network	Literature review	N/A	N/A	Few publicly available stud-ies on the energy use im-pacts of 5G
18.	Court and Sorrel	Digitalization of goods: a systematic review of the determinants and magnitude of the im-pacts on energy con-sumption	2020 (JA)- En-vironmental Re-seaerch Letters	e-materializ-ation	Literature review	N/A	N/A	There is potential energy savings from e-materializa-tion but different assump-tions imposed on key vari-ables by studies, leads to different estimates. Digital goods are found to be substitutes for materi-al goods All studies ignored rebound effects, suggesting the energy savings of digitaliza-tion may be overestimated. Due to context specificity, neglect of rebound effect, and optimistic assumption of perfect substitutes, e-mater-ialization may not deliver sig-nificant energy savings now or even in the future.

19.	Zafar et al.	ICT and education as determinants of environmental quality: the role of financial development in selected Asian countries	2022 (JA)- Technological Forecasting and Social Change	Weighted ICT index consisting of fixed broadband, fixed telephone lines and mobile phone subscription	Continuously modified fully modified OLS	Asian Countries (Bangladesh, Cambodia, China, India, Indonesia, Iran, Japan, South Korea, Malaysia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam)	Economic-wide	ICT increases environmental quality. Interactive effect of ICT and education on CO2 emission is negative Unidirectional causality from ICT to CO2 emissions Bidirectional causality between ICT and energy consumption
20.	Shehzad et al.	Asymmetric impact of information and communication technologies on environmental quality: analyzing the role of financial development and energy consumption	2022 (JA)- Environment, Sustainability and Development	Index of computer communications and other services such as worldwide telecommunications and technical services	Non-linear autoregressive distributed lag model	Pakistan	Economic-wide	Positive and negative shocks in ICT negatively affect CO2 emissions Increases in ICT reduce CO2 emissions
21.	Ramzan et al.	Environmental cost of non-renewable energy and economic progress: Do ICT and financial development mitigate some burden?	2022 (JA)- Journal of Cleaner Production	Fixed telephone subscription	Non-parametric causality-in-quintiles	Pakistan	Economic-wide	ICT has significant predictive positive effect on ecological footprint
22.	Kahouli et al	Understanding how information and communication technologies enhance electric power consumption and break environmental damage to reach sustainable development	2022 (JA)- Energy and Buildings	Fixed telephone, mobile phone subscription and internet usage	Autoregressive distributed lag model	Kingdom of Saudi Arabia	Economic-wide	Found only internet usage to have a significant positive effect on energy demand in the short and long run
23.	Weili et al.	The impact of information and communication technology, financial development and energy consumption on carbon dioxide emissions: evidence from the Belt and Road Countries	2022 (JA)- Environmental Science and Pollution Research	Fixed telephone users, mobile telephone users, internet use and fixed broadband subscription	Panel GMM	Belt and Road Countries	Economic-wide	Fixed broadband subscription reduce CO2 emissions Mobile phone users, internet use and fixed telephone users increase CO2 emissions

24.	Ruiz et al.	Life Cycle inventory and carbon footprint assessment of wireless ICT networks for six demographic areas	2022 (JA)- Resource, Conservation and Recycling	Wireless ICT network for 4G mobile technology	Dynamic Life Cycle Inventory	Peru	Six demographic areas in Peru	Estimates carbon footprints of between 81 and 103kg CO_2 eq/subscription/year, equivalent to 1.35 – 1.73kg CO_2 eq./Gb About 68% to 86% of the carbon footprint correspond to end user devices Operational emissions account for one-third and this is primarily derived from electricity consumed by end user devices and to a lower extent by access networks and data centers Linear correlation exists between operational embodied carbon emissions and the number of subscription For small ICT networks in sparsely populated areas, energy consumption and CO_2 per functional unit generated by access and IP network components are higher
25.	Charfeddine and Kahia	Do information and communication technology and renewable energy use matter for carbon dioxide emissions reductions? Evidence from the Middle East and North Africa	2021 (JA)- Journal of Cleaner Production	Mobile phone subscribers and internet users	Panel VAR	Middle East and North Africa (MENA)	Economic-wide	ICT produce first-order effects by deteriorating environmental quality Bidirectional causality exists between ICT and CO_2 emissions Positive shocks in ICT have 1 to 7 years lasting effect on CO_2 emissions
26.	Sahoo et al.	Does information and communication technology and financial development lead to environmental sustainability in India? An empirical Insight.	2021 (JA)- Environmental Science and Pollution Research	Internet connection and mobile phone subscription	ARDL regression	India	Economic-wide	Internet connection and mobile phone subscription reduces CO_2 emissions.
27.	Caglar et al.	Testing the role of information and communication technologies and renewable energy consumption in ecological footprint quality: evidence from World top 10 pollutant footprints countries	2021 (JA)- Journal of Cleaner Production	Mobile cellular subscription	Panel GMM	China, Brazil, Germany, Indonesia, India, Japan, Mexico, Russia, USA and UK	Economic-wide	ICT significantly improves environmental quality only in the long run

28.	Shobande, O.A.	Decomposing the persistent and transitory effects of ICT on environmental impacts assessment in Africa: Evidence from Mundlak Specification	2021 (JA)- Sustainability	Internet penetration	Mundlak regression specification	32 African countries	Economic-wide	Internet penetration has a positive transitory and negative persistent effect on CO2 emissions Internet penetration affects the environment via its positive effects on energy consumption
29.	Usman et al.	The effect of ICT on energy consumption and economic growth in South Asian economies: An empirical analysis	2021 (JA)- Telmatics and Informatics	Mobile phone subscriptions	ARDL regression	India, Pakistan and Sri Lanka	Economic-wide	ICT has positive effect on economic growth only in India in the short and long run ICT reduces energy consumption in India both in the short and long run In Sri Lanka, ICT increases energy consumption both in the short and long run
30.	Sharma et al.	Nexus between energy consumption, information and communication technology and economic growth: An enquiry into emerging Asian Countries.	2020 (JA)- journal of Public Affairs – an International Journal	Internet users, mobile cellular subscription and medium and high technological exports	FMOLS regression	Bangladesh, Cambodia, China, India, Indonesia, Malaysia, Nepal, Philippines, Sri Lanka and Thailand	Economic-wide	Bidirectional causality between ICT, energy consumption and economic growth Internet users and mobile phone subscription has positive effects on economic growth only for some countries
31.	Jafri et al.	Physical infrastructure, energy consumption, economic growth and environmental pollution in Pakistan: an asymmetric analysis	2021 (JA)- Environmental Science and Pollution Research	Mobile cellular subscription	ARDL	Pakistan	Economic-wide	ICT positive affects CO2 emissions ICT has negative effect on economic growth
32.	Ahmed and Phong	Linking information communication technology, trade globalization index and CO2 emissions: evidence from advanced panel techniques	2021 (JA)- Environmental Science and Pollution Reseaerch	Internet penetration, mobile subscription, fixed telephone subscription	Continuously updated FMOLS	Malaysia, Philippines, Indonesia, Thailand, Vietnam and Singapore	Economic-wide	ICT reduces CO2 emission. Unidirectional effect from ICT to CO2 emissions Unidirectional effect from ICT to energy consumption
33.	Thayere et al.	Information communication technology access and use towards energy consumption in selected sub-Saharan Africa.	2021 (JA)- International Journal of Energy Economics and Policy	Mobile phone subscription	Pooled OLS regression	Sub-Saharan Africa	Economic-wide	ICT has positive effect on energy consumption

34.	Amari et al.	ICT development, governance quality and the environmental performance: avoidable thresholds from the lower and lower-middle-income countries	2022 (JA)- Management of Environmental Quality	Basic services, phone penetration and internet penetration	Panel GMM	Lower and Lower-Middle-Income countries	Economic-wide	ICT reduces energy consumption and CO2 emissions
35.	Murshad, M.	An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia	2020 (JA)- Environmental Science and Pollution Research	ICT trade	Panel cointegration regression	Bangladesh, India, Pakistan, Sri Lanka, Nepal and Maldives	Economic-wide	ICT trade increases renewable energy consumption and renewable energy share ICT trade reduces energy intensity ICT trade facilitates adoption of clean cooking fuels ICT trade reduces CO2 emissions
36.	Hook et al.	A systematic review of the energy and climate impacts of teleworking	2020 (JA)- Environmental Research Letters	Teleworking	Literature review	N/A	N/A	Out of the 39 studies reviewed, 26 of the studies found that teleworking reduces energy use while 8 found that teleworking either increases or has a neutral impact on energy use
37.	Arshad et al.	The role of ICT in energy consumption and environment: an empirical investigation of Asian economies with cluster analysis	2020 (JA)- Environmental Science and Pollution Research	Fixed telephone and mobile telephone subscription	Panel mean group Regression combined with cluster analysis	South and South-east Asia (Pakistan, India, Bangladesh, Iran, Vietnam, Sri Lanka, Nepal, Cambodia, Indonesia, the Philippines, Malaysia, Brunei, Singapore, and Thailand)	Economic-wide	ICT deteriorates environmental quality in Pakistan, India, Sri Lanka, Indonesia, and Brunei but improves environmental quality in Bangladesh, Nepal, Cambodia, Vietnam, the Philippines, Singapore, and Iran. Unidirectional causality from ICT to CO2 emissions
38.	Avrom et al.	ICT and environmental quality in sub-Saharan Africa: Effects and transmission channels	2020 (JA)- Technological Forecasting and Social Change	Mobile phone subscription and internet penetration	Panel regression	21 SSA countries	Economic-wide	ICT use directly stimulates CO2 emissions ICT exerts indirect positive effect on CO2 emissions via energy consumption The total effect of ICT on CO2 emissions is positive
39.	Bieser and Hilty	Conceptualizing the impact of information and communication technology on individual time and energy use	2020 (JA)- Telematics and Informatics	N/A	Conceptual framework	N/A	N/A	The net impact of ICT use on energy depends on the direct and indirect energy requirements of the activities performed before and after adoption of the use case.

40.	Nguyen et al.	Role of information and communication technologies and innovation in driving CO2 emissions and economic growth in selected G-20 countries	2020 (JA)- Journal of Environmental Management	ICT imports and ICT exports	Quintile panel regression	Canada, Argentina, China, France, Germany, Italy, Japan, Mexico, Republic of Korea, Russia, Turkey, UK and USA	Economic-wide	ICT impacts on economic growth positively ICT contaminates the environment.
41.	Faisal et al.	Does ICT lessen CO2 emissions for fast-emerging economies? An application of heterogeneous panel estimations	2020 (JA)- Environmental Science and Pollution Research	Internet usage	Panel regression	Brazil, India, China and South Africa.	Economic-wide	ICT has inverted U-shaped effect on CO2 emissions
42.	Hadzone et al	Reduction of energy consumption based on replacement of routers with SDN switches. (CP)	2020 (CP)- IEEE	Real internet protocol and software defining network (SDN)	Experimental by observing changes in energy consumption	Bosnia and Herzegovina	Economic-wide	Switching from real internet protocol to SDN networks reduces energy consumption
43.	Gray et al.	'Smart is not free': Energy consumption of consumer home automation system	2020 (CP)-IEEE	Home automation system (HAS)	Bottom-up approach	Global	N/A	On average, HAS may consume over one-third of the annual energy used in a mid-sized home, with non-trivial impact on the global ICT energy footprint.
44.	Chimbo, B.	Energy consumption, information and communication technology and economic growth in an African context.	2020 (JA)- International Journal of Energy Economics and Policy	Internet penetration	Pooled OLS regression	19 African countries	Economic-wide	ICT has positive effects on economic growth, but result is sensitive to the estimation technique.
45.	Atsu et al.	ICT, energy consumption, financial development, and environmental degradation in South Africa	2021 (JA)- Heliyon	Fixed telephone subscription	ARDL regression	South Africa	Economic-wide	ICT increases CO2 emissions

46.	Mekhum, W.	Smart cities: Impact of renewable energy consumption, information and communication technologies and e-governance on CO2 emissions	2020 (JA)-Journal of Security and Sustainability Issues	Number of software used in different departments and internet systems (3G, 4G and 5G)	Panel GMM and PCE regression	Asia (Pakistan, India, China, Bangladesh, Nepal, Afghanistan, Iran, Turkey, Maldives, Indonesia, Saudi Arab, Kazakhstan, Syria, Qatar and Iraq	Economic-wide	ICT has positive effect on CO2 emissions but only in the PCE regression
47.	Chimbo, B.	Information and communication technology and electricity consumption in Transitional economies	2020 (JA)- internal Journal of Energy Economics and Policy	Internet use penetration	Panel regression	Asia, America and Africa	Economic-wide	Depending on the model, positive significant and insignificant effect of ICT on electricity consumption was found
48.	Mirza et al.	The impact of information and communication technologies, CO2 emissions and energy consumption on inclusive development in developing countries	2019 (JA)- Environmental Science and Pollution Research	Mobile phone subscription and fixed broadband internet penetration	Panel regression	81 developing countries	Economic-wide	ICT has net negative effect on CO2 emissions ICT positively impacts inclusive development in an unconditional manner When ICT complements CO2 intensity, it positively impacts on inclusive development
49.	Danish et al.	Towards cross-regional sustainable development: the nexus between information and communication technology, energy consumption and CO2 emission	2019 (JA)- Sustainable Development	Fixed telephone subscription, mobile phones subscription, internet broadband subscribers and ICT investment	Panel regression	Low, middle and high-income countries	Economic-wide	ICT reduces CO2 emission in high- and middle-income countries but increases CO2 emissions in low-income countries
50.	Shabani and Shahnazi	Energy consumption, carbon dioxide emissions, information and communication technology and gross domestic product in Iranian economic sectors	2019 (JA)- Energy – the International Journal	ICT capital stock	Panel regression	Iran	Agriculture, Industry, service and transport sectors	ICT has positive effect on CO2 emissions in industry and negative effect on CO2 emissions in transportation and service sectors ICT increases energy consumption in industry sector
51.	Lu, W.	The impacts of information and communication technology, energy consumption, financial development and economic growth on carbon dioxide emissions in 12 Asian countries	2018 (JA) - Mitigation and Adaptation Strategies for Global Change	Fixed telephone subscription, internet users and mobile cellular subscription	Panel regression	10 Asian countries	Economic-wide	ICT has negative effect on CO2 emissions.

52.	Amri, F.	Carbon dioxide emissions, total factor productivity, ICT, trade, financial development, and energy consumption: testing environmental kuzents curve hypothesis for Tunisia	2018 (JA)- Environmental Science and Pollution Research	Mobile phone and fixed telephone subscription	Time series regression	Tunisia	Economic-wide	ICT has insignificant effect on CO2 emissions
53.	Yan et al.	ICT development and sustainable energy consumption: A perspective of energy productivity	2018 (JA)-Sustainability	ICT knowledge stock indicator based on patent-quality selection, patent application number, IP5 patent families	Panel regression + decomposition index method	50 countries	Economic-wide	ICT improves energy productivity
54.	Zhou et al.	How does information and communication technology affect China's energy intensity? A three-tier structural decomposition analysis	2018 (JA)- Energy –the international Journal	ICT devices - Manufacture of Computers, Communication and Other Electronic Equipment ICT services - Information transmission, software and information technology services	Decomposition technique	China	31 economic Sectors	ICT contributes 4.5% increment in energy intensity, but the input substitution effect of ICT helps reduce energy use ICT effects on energy intensity are more significant in the services and technology-intensive sectors Direct ICT effect on energy intensity high in devices sector and minor in services sector There are significant linkage effects (positive in other sectors but negligible in heavy manufacturing and energy sectors
55.	Saidi et al.	Causal dynamics between energy consumption, ICT, FDI and economic growth: case study of 13 MENA countries	2015 (JA) – journal of Knowledge Economy	Internet users	Panel granger causality	13 Middle East and North Africa countries	Economic-wide	No causal relationship exists between ICT and energy consumption Bidirectional causality between ICT and economic growth only in the long run
56.	Popoola et al.	Data on energy consumption in an ICT-driven University	2018 (JA)- Data In brief	Digital energy meters	Experimental -Observing energy readings from meter for 12 consecutive months	Nigeria	Covenant University in Nigeria	High degree of variability in energy consumption
57.	Dabbous, A.	The impact of information and communication technology and financial development on energy consumption: a dynamic heterogeneous panel analysis for MENA countries	2018 (JA)- International Journal of Energy Economics and Policy	Internet users, mobile phone and fixed telephone subscriptions	Panel regression	11 MENA countries	Economic-wide	ICT has a positive effect on energy consumption

58.	Higon et al.	ICT and environmental sustainability: A global perspective	2017 (JA)- Telematics and Informatics	Internet users, fixed broadband internet (use and intensity), fixed telephone subscribers, mobile phone subscribers and personal computer owners (readiness)	Panel regression	116 developing and 26 developed economies	Economic-wide	ICT has inverted u-shaped relationship with CO2 emissions Many of the developed economies have attained the threshold level of ICT development that triggers lower CO2 emissions
59.	Putra et al.	Comparison of energy consumption in Wi-Fi and Bluetooth communication in a smart building	2017 (CP)- IEEE	Mobile phones data transmission via Bluetooth and Wi-Fi communication devices	Experimental – used internal logging of energy consumption in mobile phone to observe energy consumption differences in mobile phone data transmission between Wi-Fi and Bluetooth	N/A	Smart buildings	Bluetooth communication is about 30% more energy efficient than Wi-Fi communication in transmitting occupancy data Mobile phone has 16 hours and 38 minutes of battery life when running on BLE communication scheme and 14 hours and 46 minutes in Wi-Fi communication.
60.	Han et al.	Effect of information and communication technology on energy consumption in China	2016 (JA)- Natural Hazards	Non-ICT services – flow of productive services by non-ICT assets ICT capital services – computer hardware and equipment, telecommunication equipment and computer software and services	ARDL regression	China	Economic-wide	Non-ICT capital services have positive effect on energy consumption ICT capital services have U-shaped effect on energy consumption
61.	Shahbaz et al.	The role of information and communication technology and economic growth in recent electricity demand: Fresh evidence from combine cointegration approach in UAE	2015 (JA)- Journal of Knowledge Economy	Mobile phone subscription, internet connection and number of personal computers	Time series regression	United Arab Emirates	Economic-wide	ICT has an inverted U-shaped effect on electricity consumption

62.	Regmi and Pandey	A regression analysis into Nepal's ICT's energy consumption and its implications	2015 (CP)- IEEE	Number of landline telephone subscription, number of mobile phone subscribers and number of ICT users	Logistic growth model + ridge regression	Nepal	Economic-wide	ICT has a significant positive impact on energy consumption
63.	Wang et al.	Threshold effect of ICT investment on electricity consumption	2016 (JA) – ICIC Express Letters, Part B: Applications	ICT investment	Panel regression	30 provinces in China	Economic-wide with state-specific focus	ICT investment increases electricity consumption in Beijing but reduces electricity consumption in other provinces
64.	Khayyat, N.	Energy demand in Industry: what factors are important	2015 (JA)- International Journal of Energy Economics and Policy	ICT capital services and non-ICT capital services	regression	25 Korean Industries	Industry level	ICT, capital and labor are substitutes for energy ICT capital services decrease the variability of energy demand Non-ICT capital services increase the variability of energy demand Comparatively the elasticity for ICT is the smallest among all input factors
65.	Wu and Raghupathi	The strategic association between information and communication technologies and sustainability	2015 (JA)- Journal of Global Information Management	ICT factors (access, quality, affordability and application	Panel regression	116 countries	Economic-wide	ICT factors have positive association with environmental sustainability (i.e. energy consumption efficiency, transport infrastructure, economic development and education)
66.	Rochd et al.	Design and implementation of an AI-technology and IoT-enabled Home Energy Management system: A case study in Benguerir - Morocco	2021 – (JA)- Energy Reports	AI-based and IoT-enabled Home Energy management System (HEMS)	Simulation & experimental	Morocco	Case study of Benguerir	AI-based and IoT-enabled Home Management System leads to limitations of CO2 emissions by 30% compared to non-HEMS deployment.
67.	Ren et al.	Digitalization and energy: How does internet development affect China's energy consumption?	2021 – (JA)- Energy Economics	Internet development index – internet popularity, internet infrastructure, internet information sources and internet application	Panel regression	China	Provinces in China	Internet development has positive effect on energy consumption and this is driven by the positive effect of internet development on economic growth Internet development reduces energy intensity via R&D investment, human capital, financial development and industrial structure

68.	Xu, Zhong & Li	How does digitalization affect energy? International evidence	2022 – (JA)- Energy Economics	Digitalization index: digital infrastructure (infrastructure of the world, mobile phone ownership, computer ownership, average international internet broadband users), digital application (number of internet users, number of fixed internet users, number of mobile internet users, and internet development speed), and digitalisation skill	Panel GMM	109 countries	Global Data	Digitalization has direct negative effect on energy consumption and energy intensity and this is driven by the channels of technological innovation. There is direct positive effect of digitalization on energy structure driven by technological innovation and human capital. Results differ per region. The negative direct effect of digitalization on energy is greatest in Asia-Pacific and Africa and least in Europe and America Digitalization has strong impact on energy in low-income and underdeveloped economies, and small impact in high-income countries.