SUSTAINABILITY, INCLUSIVENESS AND GOVERNANCE OF MINI-GRIDS IN AFRICA (SIGMA) RESEARCH PROJECT

ARE MINIGRIDS SOCIALLY INCLUSIVE? A LITERATURE REVIEW

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DISCLAIMER

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FEEDBACK

If you have any comments, suggestions, or feedback, please send them to the SIGMA project lead by email: s.c.bhattacharyya@surrey.ac.uk

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ABSTRACT

This study explores the potential of mini grids as tools for inclusive innovation to address energy poverty in the Global South. We adopt the concept of inclusive innovation—which emphasizes the use of innovation to mitigate social exclusion and improve the well-being of marginalized populations—to systematically assess the literature on minigrids in the Global South. We explore the extent of inclusiveness in the aspiration, design, procurement, deployment and impact of mini-grids. Our findings reveal that mini-grids have played a transformative role in bringing electricity to off-grid, marginalized communities in the Global South, offering the potential for income generation, a platform for local decision-making and ownership, opportunities for capacity building and skill development thus empowering individuals and communities. However, the inclusivity of mini-grids is not universal and often masks underlying socio-economic disparities. The community's role in the design, financing, procurement, and deployment of mini-grids is found to be minimal, highlighting the need for more democratic ownership and governance models. Further, mini grids often privilege middle- and upper-income households, mostly headed by men who possess the technical know-how and financial resources for effective mini-grid utilization. This leaves behind the poor, especially women, thereby exacerbating existing socio-economic divides. The structural and post-structural inclusivity of minigrids is limited, with traditional, top-down approaches still prevalent. To enhance inclusivity, policies should foster community ownership, equitable access, and capacity building among marginalized groups, encouraging exploration of alternative governance models aligned with energy justice principles. This shift towards participatory frameworks could make minigrids truly inclusive innovations, empowering communities and contributing to sustainable development in the Global South.

Key words: minigrids, inclusiveness, consumption, impact, innovation process, structural inclusion, Global South.

1.0 INTRODUCTION

Inclusive innovation as an approach to address the social and economic disparities within societies by focusing on the development, implementation, and distribution of innovations that are accessible, affordable, and adaptable to the needs of marginalized and vulnerable populations. When applied to energy systems in the global south, inclusive innovation aims to bridge the energy access gap, foster sustainable development, and promote social equity.

One of the primary challenges in the global south is energy poverty, characterized by a lack of access to modern, reliable, and affordable energy services. This challenge disproportionately affects rural and impoverished communities, and this curtails local economic development (Amin et al., 2020), adversely affects educational outcomes and compromises access to efficient health care services (Banerjee et al., 2021), exacerbates gender inequalities e.g. by disproportionately burdening women (Moniruzzaman & Day, 2020), and fosters environmental degradation due to over reliance on biomass (Sovacool, 2012). Inclusive innovation, in this context, emphasizes the need for energy systems that cater to the specific needs and circumstances of marginalised communities, thus empowering them, and contributing to broader sustainable development objectives.

The discourse on inclusive innovation falls at the intersection between innovation, development and poverty (Arocena et al., 2018; Baud, 2016; Cozzens & Kaplinsky, 2009; Pansera & Martinez, 2017). Inclusive innovation has been described as an approach or strategy that aims to improve the social and economic well-being of marginalized or disenfranchised groups in society through the development and implementation of novel ideas, technologies, products, or services (George et al., 2012; Heeks et al., 2014). Inclusive innovation emphasizes affordability, accessibility, and relevance to the socio-economic context of the target population. By fostering inclusivity, this approach attempts to ameliorate social inequalities and contribute to sustainable development. Recent framings of inclusive innovation emphasize its collaborative, participatory, multistakeholder approach that prioritizes the agency of marginalized groups, ensuring that solutions are not only beneficial but also culturally and contextually appropriate (Hoffecker, 2021; Onsongo & Knorringa, 2020; Pansera & Owen, 2017; Patnaik & Bhowmick, 2020; Smith et al., 2023).

Mini-grids, as a decentralized energy solution, have the potential to serve as an inclusive innovation in the context of energy systems in the global south. By providing localized and reliable electricity access to communities that are often excluded from centralised grid systems, mini-grids can address the energy access gap, promote sustainable development, and foster social equity However, it has not been entirely clear whether they actually deliver on these promises (Bhattacharyya & Palit, 2016; Gill-Wiehl et al., 2022; Joshi & Yenneti, 2020; Sharma, 2020). Mini-grid projects are diverse in terms of their technological choices, ownership models, management structures, and financing mechanisms. This diversity can lead to different outcomes, with some projects achieving inclusiveness while others may not. As a result, it is challenging to generalize the inclusiveness of mini-grids as a whole. To better understand and harness the inclusive potential of mini-grids, it is crucial to address these challenges through targeted research.

This paper applies a justice-based framework for inclusive innovation in a indepth literature review to assess the social sustainability of minigrids in the Global South. We analyse whether and how minigrids, as presented in empirical studies in our review, attain different levels of inclusiveness, and interrogate the underlying implications on social justice.

2.0 INCLUSIVE INNOVATION: AN ANALYTICAL FRAMEWORK

In recent years, the paradigm of 'inclusive innovation' has sparked interest in the academic, policymaking, and developmental communities (Cozzens & Sutz, 2014; Heeks et al., 2014; IDRC, 2011; Kaplinsky, 2011; Paunov, 2013; UNCTAD, 2014). Initially, the term denoted specific products, services, or business models, but it has since evolved to encompass comprehensive initiatives and policies designed to mitigate social exclusion and inequality (Levidow & Papaioannou, 2017). Advocates suggest that the existing, resource-intensive model of innovation, predominant in developed societies, may be ill-suited to lower-income environments grappling with socio-environmental issues (Chataway et al., 2014; Cozzens & Kaplinsky, 2009; Paunov, 2013). Thus, a different approach might serve to bridge the gap for communities affected by social exclusion.

Inclusive innovation is a strategy designed to address social exclusion by ensuring that marginalized and poor communities are not only beneficiaries of innovation but are also active participants in innovation processes (Hoffecker, 2021). The ultimate aim of inclusive innovation is to foster social inclusion by creating opportunities for these marginalized groups to partake in, and benefit from, innovative activities that improve their quality of life. The concept can be seen as multidimensional, with different authors emphasizing different aspects, such as the intention of the innovation, inclusivity in the process, the structural environment, and the outcomes or impacts of the innovation (e.g., Bortz & Thomas, 2017; Malley et al., 2017; Altenburg, 2008; Ciarli et al., 2018; Onsongo & Schot, 2017).

Informed by Sen's (2000) conceptualization of poverty as a deprivation of capabilities, social exclusion, in the context of inclusive innovation, frequently aligns with financial poverty (Cozzens & Sutz, 2014; Joseph, 2014) (Cozzens & Sutz, 2014; Joseph, 2014a). Yet, as Sen emphasizes, poverty and social exclusion are multidimensional, comprising economic, social, political, individual, spatial, and group elements. They can be both the root and the result of each other, which Joseph (2014) further elucidates within the domain of inclusive innovation.

There are two main stances within scholarly circles exploring alternative models of innovation suitable for lower-income contexts: the market-oriented liberal-individualist stance and the equity-centered social-collectivist stance (Levidow & Papaioannou, 2017). The former, supported by base of the pyramid (BOP) literature (Prahalad & Hammond, 2002), encourages affordable products and services via substantial corporate investments. Critics, however, contend that this approach often neglects the cultural and political factors engendering social exclusion (Arora & Romijn, 2012). Conversely, the social-collectivist stance stresses equitable participation and collective creativity, hallmarks of grassroots and informal setting innovation (Gupta et al., 2003; Pansera & Owen, 2015; Seyfang & Smith, 2007). Nevertheless, their scalability remains a challenge due to the localized nature and small-scale implementations (Smith et al., 2014). Despite differing perspectives on leveraging innovation for social justice, both stances underscore social inclusion, thereby paving the way for further exploration of the nexus between innovation and development (Pansera & Owen, 2017).

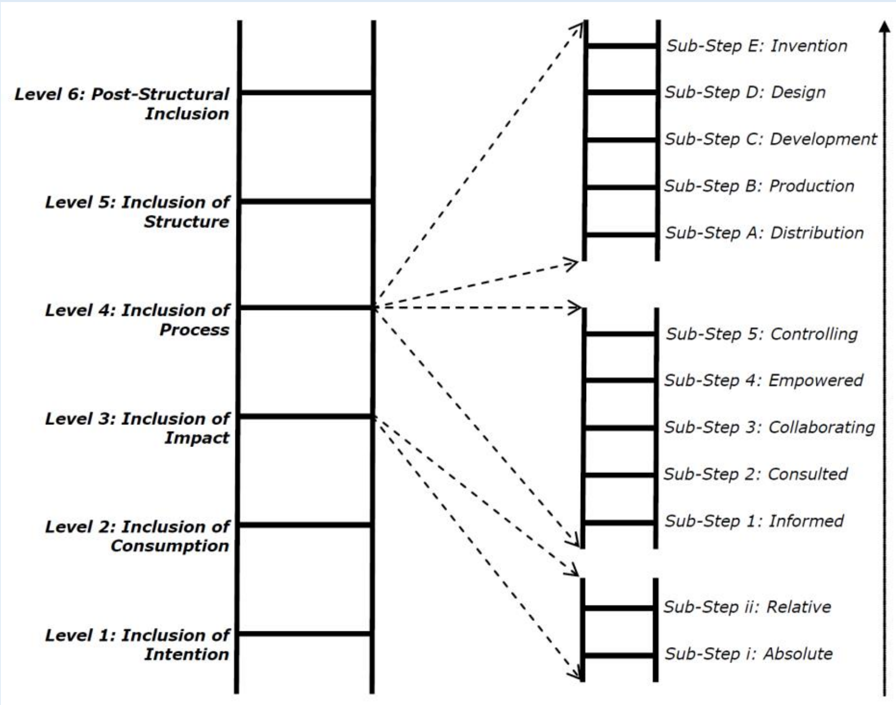

Figure 1. The ladder of inclusive innovation (LII) depicting different levels (or gradations) of inclusion. Source: Heeks et al. (2013).

The Ladder of Inclusive Innovation proposed by Heeks et al. (2013, 2014) provides a useful model to understand this linkage, outlining various degrees of inclusion based on the involvement of marginalized groups in the innovation process. The Ladder of Inclusive Innovation (see Figure 1) consists of six rungs, each signifying an increased level of participation by the excluded group in the innovation process. The lower rungs reflect a liberal-individualist stance, where the excluded group adopts an innovation created by others to address their needs (Levidow & Papaioannou, 2017). However, a more harmonized approach is feasible if the innovating entity is a community group or grassroots entrepreneur. Level 4, the mid-point of the ladder, hinges on the degree of ownership and control the excluded groups exert over the innovation process, with a shift towards a social-collectivist stance becoming evident if they dictate the process according to their norms and values. The pinnacle of the ladder—"Structure" and "Post-Structural" inclusion—demands systemic change and a significant transition of control to marginalized communities (Fressoli et al., 2014). These top rungs of inclusion might entail social justice organizations and activists dictating the terms for innovative processes and outcomes. This approach resonates with the concept of "empowered citizens" posited in Arnstein's model (Heeks et al., 2014).

2.1 Minigrids as inclusive innovation

Mini-grids, as localized energy systems, can potentially represent inclusive innovations by offering a decentralized, sustainable, and cost-effective solution for energy access, especially in underserved or isolated areas (Palit & Sarangi, 2016; Bhattacharyya & Palit, 2016). They can address multiple dimensions of social exclusion by providing affordable energy, extending productive hours, and enabling community involvement in energy planning and management (Bhattacharyya, 2013; Kirubi et al., 2009; Chaurey et al., 2012).

In the context of the inclusive innovation model, mini-grids can embody both the liberal-individualist and social-collectivist stances, depending on the degree of local participation and control (Levidow & Papaioannou, 2017). From a liberal-individualist perspective, mini-grids can be seen as market-driven solutions, with the private sector developing and selling energy services to low-income consumers. From a social-collectivist stance, they can be grassroots innovations, developed and managed collectively by communities based on local needs and resources. These issues reflect the spectrum of inclusion as described in the ladder of inclusive innovation by Heeks et al. (2013, 2014). At the lower levels of this ladder, external developers design and implement the mini-grid, and local communities adopt it. At higher levels, communities may own, control, and benefit from the mini-grid, indicating a significant shift in power and resource control.

Thus, simply labelling mini-grids as inclusive innovations may oversimplify the complex dynamics and challenges involved in their development and implementation. The extent of their inclusiveness can vary widely depending on various factors. In this paper, we conduct an in-depth analysis of the literature to establish whether and under what circumstances mini-grids can be truly considered as inclusive innovations. This analysis provides a more nuanced understanding of the role of mini-grids as inclusive innovations to guide the development of policies and strategies for their successful implementation.

3.0 METHODOLOGY

The approach of the study is to undertake a systematic review of literature. Systematic literature reviews are according to Tranfield, Denyer, & Smart (2003) important tools for developing an evidence database towards further developing the knowledge base around a research topic. This method is most preferred being that it will allow for the assessment of progress in research on inclusivity of mini grids and facilitate the formulation of recommendations for future areas of research (Fink, 2010).

The systemic literature review (SLR) structure proposed by Kitchenham (2004) and later adopted by (Bacca et al., 2014) along with other researchers divides the process into three broad parts. These include the planning stage, conducting the review, and reporting the results of the review (Figure 2).

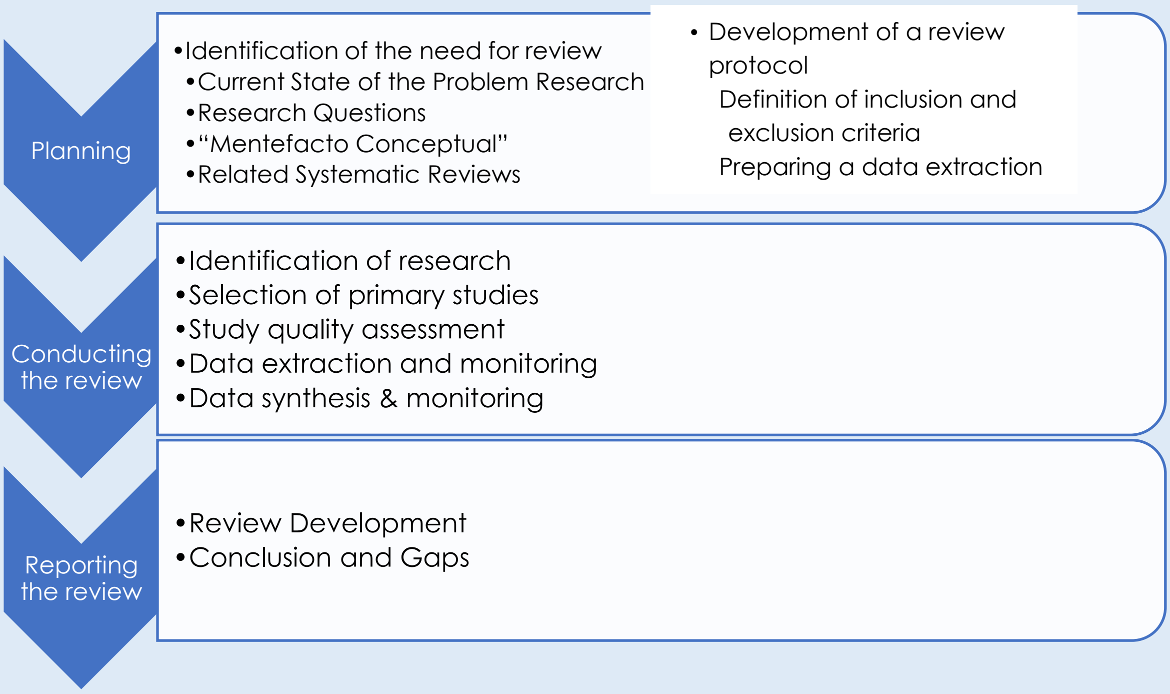

Figure 2: Three-Stage Systematic Literature Review

Further breaking down the three-stage procedure, Mayring (2010) offers an alternative structure to SLRs, which comprehensively covers the collection of the material to the analysis of the contents. This includes material collection, descriptive analysis, category section, and material evaluation. This method outlines specifics of the search, including the databases used, keywords, Timeframe considered, the units of analysis, filters applied, among others. Our methodology employs a combination of the methods proposed by (Kitchenham, 2004) and Mayring (2010) to come up with a comprehensive system and review (Figure 3).

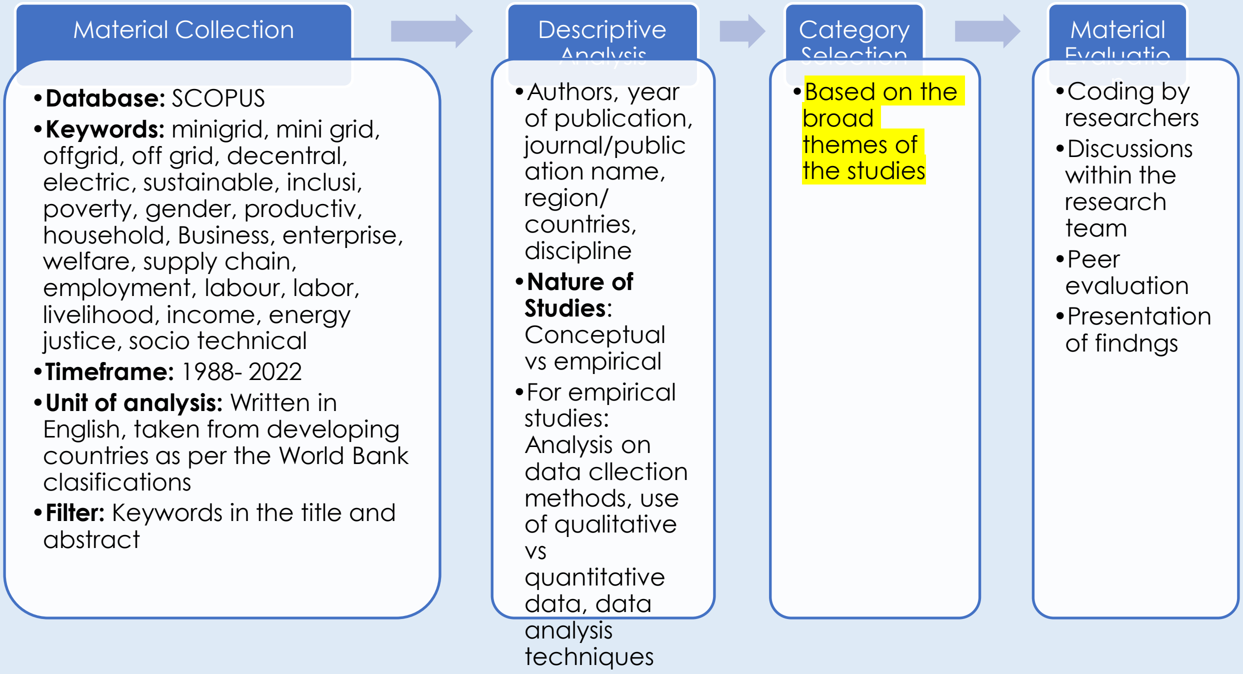

Figure 3: Methodology Adapted from Rosca et al. (2018)

The SCOPUS platform provided by Elsevier, with its extensive database of peer-reviewed journals in energy, social sciences, and humanities, was the primary source of documents. Other sources, such as development partner web platforms and grey literature, were also consulted. SCOPUS was searched for documents containing the keywords mini-grids or off-grid solutions, and measures of inclusivity such as poverty, gender, business, and welfare, among others, using the following broad search term: <"minigrid" OR "mini grid" OR "offgrid" OR "off grid" OR "decentral" AND "electric" AND "sustainable" OR "inclusiv" OR "poverty" OR "gender" OR "productiv" OR "household" OR "business" OR "enterprise" OR "welfare" OR "supply chain" OR "employment" OR "labour" OR "labor" OR "livelihood" OR "income" OR "energy justice" OR "socio technical">. These key words were selected based on a literature review and team discussions and quotation marks used to eliminate cases of grammatical coincidence within the results. This search yielded a total of 960 documents written between 1988 and 2021.

Other types of articles from the search include conference papers, book chapters, business articles, reviews, editorials and news reports, among others. A vast majority of papers were from 5 major fields including environmental science, energy, engineering, medicine and social sciences. Though occluding less frequently, there were papers from other fields including agricultural and biological sciences, economics, econometrics and finance, computer science, chemical engineering, and earth and planetary science, among others.

To obtain papers relevant to low- and middle-income countries, we used the World Bank's analytical classifications in the World Development Indicators (WDI) to filter results by geographic origin. The WDI Database includes 218 countries categorized into four income groups (Low, Lower Middle, Upper Middle, and High Income) between 1987 and 2018. We selected source countries that were classified as low or middle-income within the past decade, resulting in 123 selected countries. The filter was applied to each of the three databases, reducing the number of papers on SCOPUS to 324. The materials were organized on Mendeley, and we screened titles and abstracts to select relevant papers for the study. We were left with a total of 79 documents. The chart below gives a summary of the shortlisting process (Figure 4).

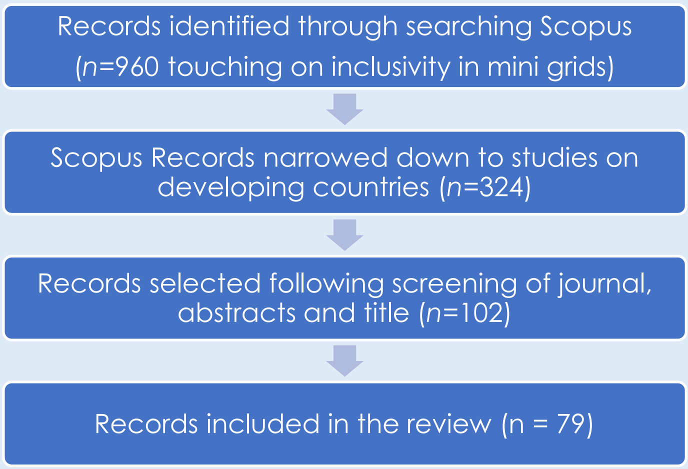

Figure 4: Summary of shortlisting process

4.0 CHARACTERISTICS OF SELECTED PAPERS

The years of publication of the selected articles, our review indicates that they were published between 2009 and 2021 with no paper published in 2013. However, there is a significant and drastic increase in number of published papers since 2018 peaking in 2020 (Figure 5). This clearly indicates that there is an increasing research interest in this field, a trend that is likely to grow in future.

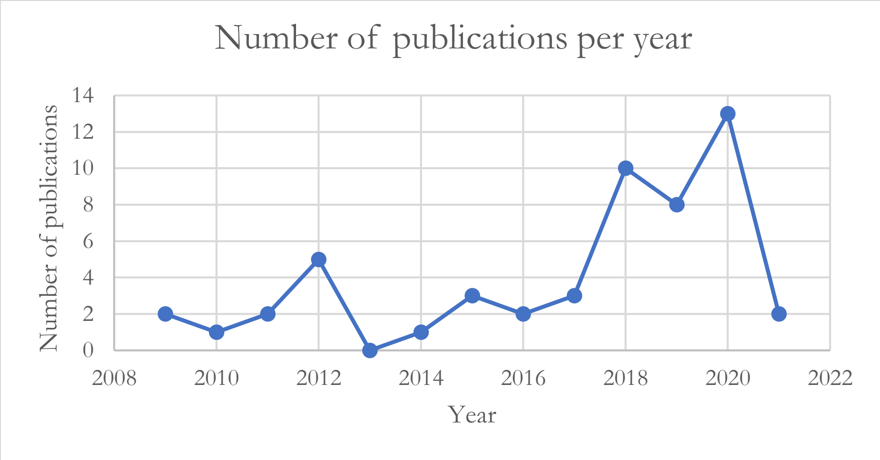

Fig.5: Year-wise distribution of papers published from 2008 to 2021

These articles on mini-grids were intentionally collected from the Global South, where there has been growing research interest in the subject. The studies mainly focus on developing economies in Sub-Saharan Africa, Latin America, and South Asia. India has the highest number of studies (26%), followed by Kenya (12%), Tanzania (7%), and several other countries accounting for smaller percentages (Figure 6). Only one paper covered developed countries such as the USA, UK, and Sweden. The concentration of studies in India can be attributed to the country's efforts to electrify its large rural population through mini-grid development projects.

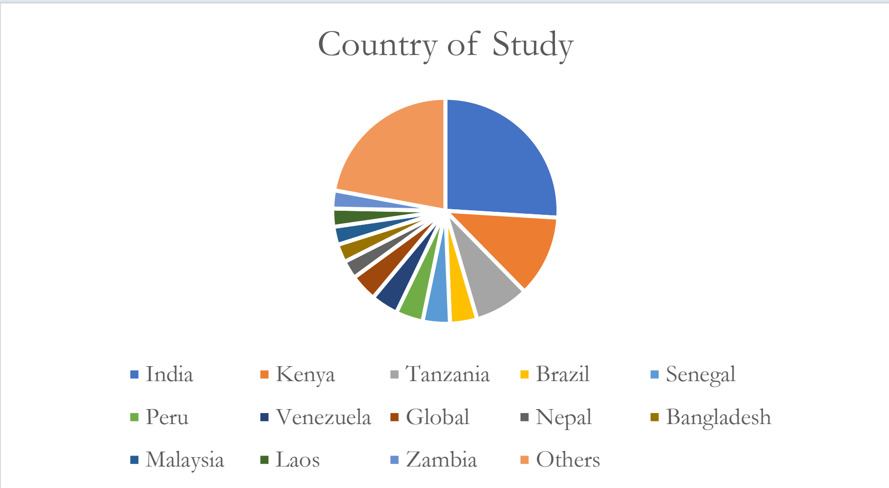

Fig. 6: Articles by Country of Study

The majority (94%) of the selected articles had an empirical component (qualitative or quantitative). The remaining (6%) were theoretical or conceptual. Among the empirical studies, 67% used mixed-method approaches, 24% used qualitative approaches, and 9% used quantitative approaches (see Fig. 7 to 10 for various data related to the papers reviewed). About half of the analyzed papers focused on one mini-grid, with the rest studying multiple mini-grids. Most of the studies (74%) were conducted in a single country, suggesting a lack of attention to cross-country comparisons in existing literature. Papers studying one mini-grid mainly evaluated the challenges and benefits of mini-grids, their sustainability, and their impact compared to pre-grid electrification. Some also compared the impact of mini-grids in electrified and unelectrified areas.

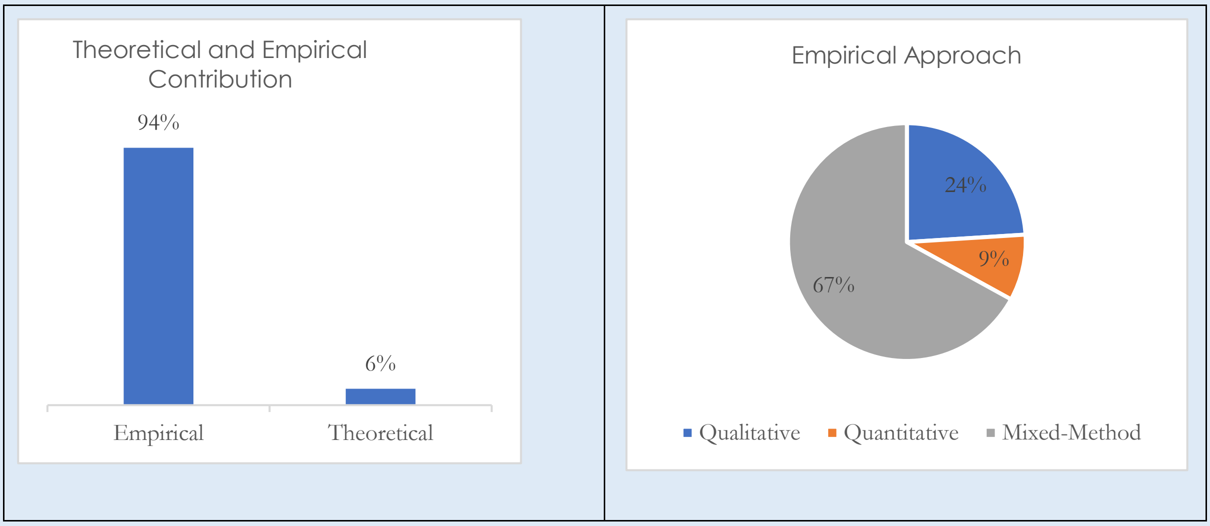

Figure 7: Type of papers reviewed

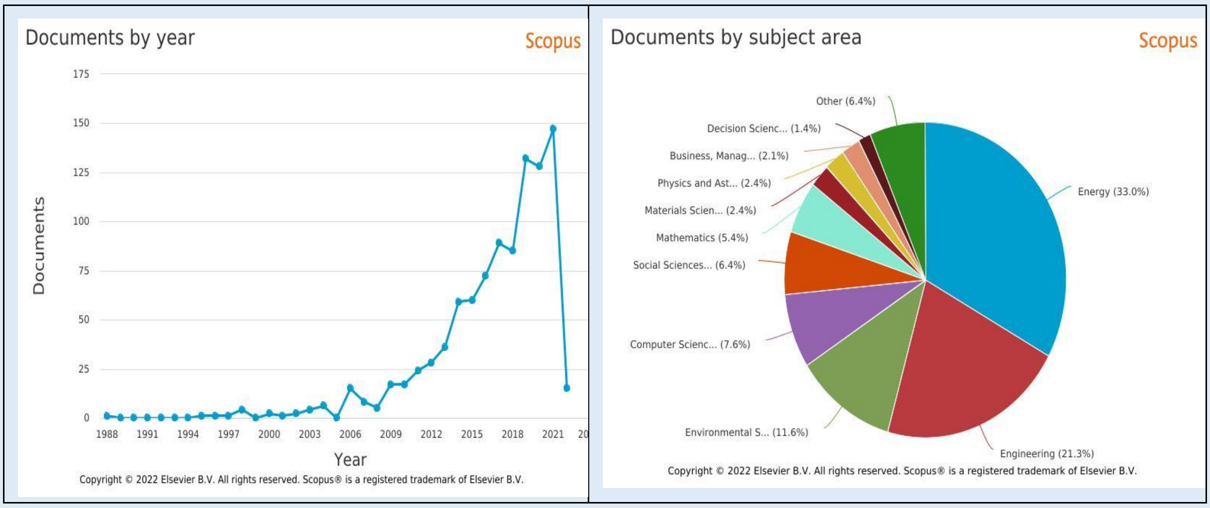

Figure 8: Year of publications overall publications vs publications with the exclusion criteria

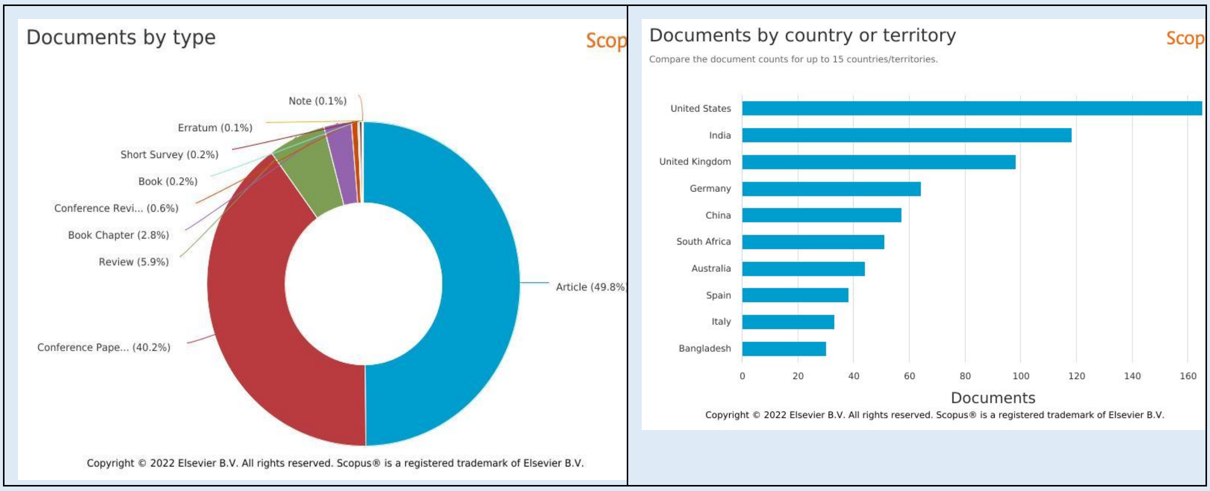

Figure 9: Documents reviewed by type and country

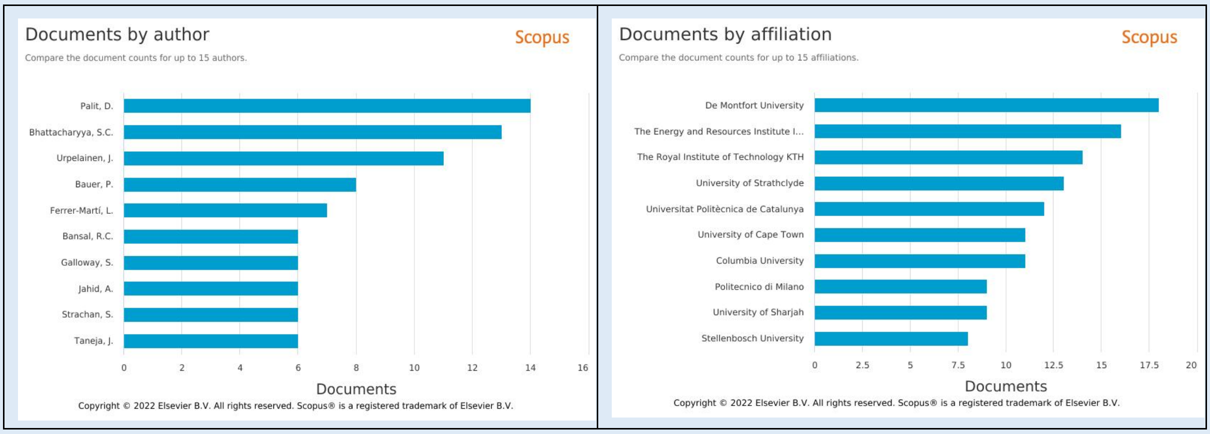

Figure 10: Document reviewed by author and affiliation

5.0 FINDINGS

5.1 Defining social inclusivity

Sustainable electricity services are typically assessed based on technical, economic, institutional, governance, environmental, and social and cultural considerations (Katre et al., 2019; Katre & Tozzi, 2018; Urmee & Md, 2016). Katre et al. (2019) also emphasize that the social sustainability of projects involves enhancing the lives of the community, including benefits to households, businesses, institutions, community connectedness, and operations. However, López-González et al. (2018) expand on this by including concepts of community empowerment, inclusion, and governance in assessing social sustainability. This involves considering issues such as community participation, improving health and education outcomes, promoting equity in energy access, and strengthening institutions (Wiese, 2020). The economic angle also plays a crucial role, encompassing energy equity, energy poverty, and productive growth. Energy equity refers to the ability to pay for quality electricity service and ensure sustainable access, while energy poverty can be measured using indicators such as the minimal standard (MIS), Low-income, High-cost (LIHC), and the Ten-Percent Rule (TPR) (Boardman, 1991, 2009; Hills, 2012; Moore, 2012). Productive growth pertains to the capacity to increase incomes through electricity use.

5.2 Inclusion of Intention: The case for minigrids

Minigrids have emerged as a popular solution to provide electricity access in remote and geographically isolated areas where extending the central grid is either technically or financially challenging (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). The development of minigrids is driven by a variety of reasons, including geographical barriers, high connection and operating costs, high renewable energy potential, household income levels, specific institutional needs, and policy restrictions.

Countries like the Philippines face significant geographical barriers due to their archipelagic nature, making grid extension difficult and expensive (Duran & Sahinyazan, 2021; IRENA, 2017). This has led to the increased adoption of minigrids powered by local renewable resources to provide electricity in remote areas (Almeshqab & Ustun, 2019). In countries like India and Brazil, extending the central grid to remote areas is similarly challenging due to wide rivers, creeks, and the vastness of the Amazon rainforest (Moharil & Kulkarni, 2007; Mazzone, 2019; Almeshqaba and Ustunb, 2019).

The high connection and operating costs associated with extending the central grid have prompted the installation of decentralized photovoltaic (PV) power plants with microgrids in remote villages in countries like India and Brazil (Moharil & Kulkarni, 2007; Aklin et al., 2017; Sharma, 2020; Duran & Sahinyazan, 2020; Lukuyu et al., 2021; Pedersen et al., 2020; Muchunku et al., 2018; Aklin et al., 2017; Kobayakawa & Kandpal, 2013; Bahaj et al., 2019; R.H. van Els et al., 2012; Yadoo & Cruickshank, 2012; Lukuyu et al., 2020). In some cases, households in these countries may find it more economical to pay for microgrid connection instead of using expensive alternatives like kerosene (Kobayakawa and Kandpal, 2014).

Regions with high renewable energy potential, such as areas with small waterfalls, wind, and solar energy, have also seen minigrid development (Lillo et al., 2015; Ngowi et al, 2019; Terrapon-Pfaff et al, 2014). Household income levels play a role in the type of connection, with higher-income households in countries like India being more able to afford electricity tariffs and initial connection charges (Kobayakawa and Kandpal, 2014; Schnitzer et al., 2014).

Energy demand plays a crucial role in driving the development of minigrids, as the presence of economic and agricultural activities in an area reduces the risk of non-payment, making minigrid projects more financially viable (Pedersen et al., 2020). By providing electricity access to small businesses and households with significant electricity demand, minigrids can promote economic growth and improve the quality of life in remote and rural communities (Pedersen et al., 2020; Kirubi et al., 2008).

Minigrids have been developed in some countries to specifically power institutions in remote areas that require electricity to function efficiently, such as hospitals, schools and vocational centers in Kenya and Tanzania (Leary et al., 2012; Ngowi et al, 2019; Klunne and Michael, 2010, Kirubi et al, 2008). Policy restrictions also play a role in minigrid development, with regulations in India, for example, prohibiting grid extension through reserve forests and leading to the establishment of minigrids in isolated regions with no future expectation of grid connection (Sharma & Palit, 2020).

5.3 Inclusion of consumption and impact

Our analysis of the literature shows that many grades are used by a wide variety of population groups in a community. However, the levels of consumption of energy differ among men, women and children, and even among different income groups and age groups. Consumption and impact are interrelated, such that population groups that utilize the minigrid energy more tend to experience higher positive and/or negative impacts. In the discussion below, we highlight consumption patterns and impacts of electrification on domestic lighting, drudgery reduction, communication and entertainment, health and education outcomes, security, water and sanitation and productive uses. Despite the many advantages, some challenges and disparities remain, emphasizing the importance of continued research and development in this field.

Domestic lighting: Access to lighting is a significant benefit for households, as highlighted in many reviewed papers (e.g. Aklin et al., 2017; Bhattacharyya & Palit, 2016; Ganguly et al., 2020; Groth, 2019; Johnson et al., 2019; Kirubi et al., 2009; Kobayakawa & Kandpal, 2014; Luukkanen et al., 2012; Pueyo & DeMartino, 2018; Terrapon-Pfaff et al., 2014, 2018; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020; Yadoo & Cruickshank, 2012). These studies report the social and emotional value that communities place on this new resource. A notable outcome that beneficiaries appreciate is the potential for improved futures for their children, who can "live in the light." This is a reasonable expectation, given the benefits such as increased study time and entertainment opportunities. Study time is a common metric used to measure household social welfare improvement. Many papers report that access to lighting allows children to study for longer hours after sunset. The additional study time ranges from just under an hour to 3.2 hours per day (Asuamah et al., 2021; Bhattacharyya & Palit, 2016; Ferrer-Martí et al., 2012; Kirubi et al., 2009; Millinger et al., 2012; Wiese, 2020; Yadoo, 2012; Yadoo & Cruickshank, 2012). Wiese (2020) suggests that longer study hours are more feasible due to the lower cost and reduced health risks of electric lighting. Further, improved learning outcomes have been linked to better illumination (Kirubi et al., 2009), which estimates a gain of approximately two years of educational achievement for children in electrified households compared to those without electricity. However, the authors also note that outcomes may vary depending on the size of the systems, as larger systems provide better lighting for study. Urmee & Md (2016) mention that families often base their choice of systems on their children's education. However, there are also gender disparities in extra study time, with boys generally having more time to study than girls (Wiese, 2020). The extra study time has been shown to improve children's performance, with instructors noting improved quality of education and homework for those with access to electricity at home (Yadoo & Cruickshank, 2012).

Domestic Drudgery: Numerous studies (Moharil and Kulkarni, 2009; Kirubi et al., 2009; Yadoo, 2012; Yadoo and Cruickshank, 2012; Terrapon-Pfaff et al., 2014; Muhoza and Johnson, 2018; Terrapon-Pfaff et al., 2018; Johnson et al., 2019; Katre et al., 2019; Ganguly et al., 2020; Wiese, 2020; Uamusse et al.,2020; Chandra et al,. 2020) have found a positive link between mini-grid electrification and easing household chores. For example, Kirubi et al. (2009) observed that power installations led to more women visiting local health clinics for prenatal care due to time savings and reduced manual labor. Yadoo (2012) and Yadoo and Cruickshank (2012) noted how traditional agro-processing techniques were modernized, easing tasks previously performed manually by women.

Wiese (2020) reported that electrified households saw improved efficiency in chores like cooking, while Muhoza and Johnson (2018) found that women could perform tasks more easily in well-lit houses and communal spaces. Millinger et al. (2012) observed later evening cooking times after electrification, and Terrapon-Pfaff et al. (2018) highlighted gendered impacts of sustainable energy, including reduced time for women gathering firewood. Ganguly et al. (2020) emphasized the importance of improved lighting for household productivity, and Katre et al. (2019) observed reduced drudgery for women in electrified households who now have more time to care for children.

However, Wiese (2020) and Muhoza and Johnson (2018) both found that despite electricity making chores easier, it did not significantly impact women's overall working time or substantially reduce the burden of their chores.

Entertainment and communication: Electricity access through mini-grids has significantly improved communication, connectivity, and information access for beneficiary communities (e.g. Kirubi et al., 2009; Millinger et al., 2012; Kobayakawa and Kandpal, 2014; Urmee and Md, 2016; Aklin et al., 2017; Ahlborg, 2018; Groth, 2019; Lopez-Gonzalez et al., 2018; Roche and Blanchard, 2018; Ngowi et al., 2019; Pueyo and DeMartino, 2018; Uamusse et al., 2020; Wiese, 2020; Chandra et al., 2020; Asuamah et al., 2021). Access to television has been shown to improve information access (Moharil and Kulkarni, 2009; Kobayakawa and Kandpal, 2014; Ngowi et al., 2019; Uamusse et al., 2020), and the proliferation of mobile phones has facilitated communication and connectivity due to easier and more affordable phone charging (Bhattacharyya and Palit, 2016; Urmee and Md, 2016; Ahlborg, 2018; Johnson et al., 2019, Luukkanen et al. (2012) and Kirubi et al. (2009). Katre et al. (2019) observed that communities with mini-grid electricity felt more connected to the outside world due to the availability of phones and televisions. Lopez-Gonzalez et al. (2018) found that electricity increased basic and secondary education rates, improving information access and telecommunication. Yadoo and Cruickshank (2012) reported improved communication and information access in a community with mini-grid electricity, with teachers noting that students seemed more informed due to increased television and radio access at home. Bhattacharyya and Palit (2016) highlighted better communication opportunities and higher profits for businesses providing communication services in electrified communities.

One of the major benefits of minigrid electrification highlighted in the literature is access to electronic entertainment and leisure activities such as watching and listening to televisions and radios, the use of internet and reading after sunset (Moharil and Kulkarni, 2009; Kirubi et al., 2009; Ferrer-Martı´ et al., 2012; Millinger et al., 2012; Yadoo,2012; Bhattacharyya and Palit ,2016; Urmee and Md, 2016; Ahlborg, 2018; Muhoza and Johnson ,2018; Ngowi et al., 2019; Johnson et al., 2019; Uamusse et al., 2020; Wiese, 2020). Ahlborg, (2018) found that electronic entertainment positively affected people's sense of well-being, as people "stopped having thoughts" or "thinking too much until you go mad". Luukkanen et al., (2012), reports a similar case where television watching among other benefits is said to be a relaxing entertainment activity as it is good for mental health and reduces loneliness after a hard day of work. Kirubi et al., (2009) found that electricity enables professionals working in rural settings access entertainment services enjoyed by their counterparts in the urban regions. This paper further emphasized the importance of television for women's education and access to health and family planning information. Groth (2019) suggested that electrified households with television access had higher levels of information and knowledge, which impacted their earnings and education. Various authors also showcase how rural minigrids enhanced socialization at the community level, by creating well-lit communal areas, allowing villagers to watch television or listen to the radio together, or have social gatherings while having a cold refrigerated drink (Muhoza and Johnson (2018), Johnson et al., (2019), Urmee and Md, (2016).

Health outcomes: Health outcomes in communities are influenced by multiple factors such as household activities, community involvement, and healthcare facilities. The relationship between these factors and access to electricity has been extensively discussed in the literature (Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Butchers et al., 2020; Ferrer-Martí et al., 2012; Johnson et al., 2019; Katre et al., 2019; Kirubi et al., 2009; López-González et al., 2018, 2020; Luukkanen et al., 2012; Moharil & Kulkarni, 2009; Muhoza & Johnson, 2018; Ngowi et al., 2019; Terrapon-Pfaff et al., 2014, 2018; Uamusse et al., 2020; Wiese, 2020; Yadoo, 2012; Yadoo & Cruickshank, 2012). Another way health outcomes have been improved is through access to educational content on TV and radio within households (Uamusse et al., 2020). Consuming educational content about diseases like HIV and malaria leads to a reduction in their prevalence, as viewers gain knowledge on prevention, management, and treatment (Kirubi et al., 2009; Uamusse et al., 2020). Awareness initiatives about family planning and hygiene are also beneficial (Wiese, 2020).

Mini-grid electrification has resulted in an overall improvement in community nutrition. Bahaj et al., (2019) reported a 30-55% increase in fruit consumption within two Kenyan communities following electrification, along with a significant increase in food supply due to higher incomes. Terrapon-Pfaff et al. (2014) also noted improved nutrition, with increased availability of cooked food and boiled water. Additionally, using refrigerators to store food can prevent infectious diseases by reducing contamination in items like bottles and infant food, which lowers infant mortality rates (López-González et al., 2018, 2020). Refrigeration also prevents the growth of pathogens, especially in indigenous communities in high-temperature areas with diets consisting mainly of meat and fish (López-González et al., 2018).

Access to electricity can directly reduce injuries and overall bodily harm caused by using other fuels. The use of kerosene and firewood for cooking has been linked to negative impacts on lung function and a higher incidence of ailments like asthma and tuberculosis. Reduced kerosene emissions from lighting in homes, schools, and other areas lead to a decrease in respiratory illnesses, eye infections, and cancer in both children and adults (López-González et al., 2018, 2020; Wiese, 2020). This is due to less indoor smoke from kerosene and candles (Ferrer-Martí et al., 2012; Terrapon-Pfaff et al., 2014). Terrapon-Pfaff et al. (2014) also reported improvements in space heating within electrified communities, which may contribute to better respiratory health outcomes. However, some studies have noted that the continued use of firewood for cooking after installing electricity can negate improvements in indoor air quality (Katre et al., 2019). Despite this, rural households that continue using firewood for cooking after gaining access to electricity experience a decrease in related accidents, as electric lighting simplifies cooking tasks (Wiese, 2020).

Minigrid electrification has also led to significant improvements in healthcare services within institutions and at the community level. Hospitals connected to electricity can provide a wider range of services, thanks to extended operating hours made possible by electrical lighting (Ferrer-Martí et al., 2012; Uamusse et al., 2020). Electrification of rural hospitals in Mozambique has facilitated better illumination across various departments, such as delivery rooms, consultation rooms, and administrative areas (Johnson et al., 2019). Reliable artificial lighting has allowed some hospitals to offer 24-hour services to their communities. It also makes medical examinations, such as those by ENT specialists, easier and improves the experience of nighttime deliveries (Yadoo, 2012; Yadoo & Cruickshank, 2012). In one case, a community mini-grid in Kenya enables night-time deliveries without the use of a torch or lantern (Bahaj et al., 2019). The availability of electricity also contributes to increased prenatal visits at local health clinics (Kirubi et al., 2009). Improved health services due to electricity have been linked to a reduction in maternal and infant mortality rates (Cecelski, 2004).

Electrification has also improved healthcare by powering diagnostic machines, sterilizers, and refrigerators for storing medications (Johnson et al., 2019; Muhoza & Johnson, 2018). Laboratory testing has improved, with one study reporting a rise in daily tests from 20 to 50 after electrification (Bahaj et al., 2019). Additionally, consistent refrigeration of medications and vaccines has made them more accessible to local communities, eliminating the need to travel long distances for these essentials (Bahaj et al., 2019). Furthermore, electrification can attract and retain healthcare professionals from other regions, as access to electricity is often a significant factor in their decision to work in a particular community (Bahaj et al., 2019).

Education outcomes: The literature highlights the connection between mini-grid electricity access and improved learning outcomes as a measure of social inclusivity (Aklin et al., 2017; Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Butchers et al., 2020; Ferrer-Martí et al., 2012; Ganguly et al., 2020; Groth, 2019; Johnson et al., 2019; Joshi & Yenneti, 2020; Katre et al., 2019; Kirubi et al., 2009; Kobayakawa & Kandpal, 2014; López-González et al., 2018, 2020; Luukkanen et al., 2012; Millinger et al., 2012; Moharil & Kulkarni, 2009; Muhoza & Johnson, 2018; Uamusse et al., 2020; Urmee & Md, 2016; Wiese, 2020; Yadoo & Cruickshank, 2012). Introducing electricity to a community can lead to the establishment of new learning institutions, the enhancement of existing ones, and other positive externalities such as increased migration and human resources. Access to electricity enables longer study sessions (Johnson et al., 2019) and attracts teachers to rural education facilities, ultimately improving the quality of education (Uamusse et al., 2020).

Electrification allows schools to utilize resources such as science laboratories and computer studies, exposing students to diverse opportunities (Ferrer-Martí et al., 2012; Kirubi et al., 2009; Yadoo & Cruickshank, 2012). Electricity-based resources like computers, projectors, and photocopy machines improve the efficiency of school administration and instruction (Kirubi et al., 2009; Yadoo & Cruickshank, 2012). Additionally, electrification supports innovative instructional materials, such as cassette players for language classes, DVD players and TVs for educational videos, and computers with electronic encyclopedias (Ferrer-Martí et al., 2012; Yadoo, 2012; Yadoo & Cruickshank, 2012).

Studies have reported higher educational achievement among children from electrified households compared to non-electrified ones (Kirubi et al., 2009). Factors contributing to this improvement include better access to water, improved hygiene, and reduced absenteeism (Bahaj et al., 2019; López-González et al., 2018). Schools with electricity access can also extend their school days, providing more time for learning (Bahaj et al., 2019). However, the extent of benefits for learning institutions and learners depends on available resources and the institution's capacity to implement new strategies. Some schools may not fully utilize electrification benefits due to financial constraints, lack of instructors, or insufficient demand for services like evening classes (Wiese, 2020).

Security: Several studies have highlighted the overall community benefits of street and outdoor lighting, which increases the sense of security for residents (Moharil & Kulkarni, 2009; Yadoo & Cruickshank, 2012; Luukkanen et al., 2012; Bhattacharyya & Palit, 2016; Ahlborg, 2018; Katre et al., 2019; Joshi & Yenneti, 2020). Johnson et al. (2019) suggested that improved lighting within communities facilitates social cohesion, as streetlights in public places make residents feel safe to move around and socialize at night, particularly benefiting women and children (Uamusse et al., 2020). Terrapon-Pfaff et al. (2014) noted that nighttime street lighting enhances the safety of women and girls, allowing them to attend school and participate in community events after dark. Yadoo and Cruickshank (2012) also emphasized that street lighting makes women feel more secure when visiting neighbors at night. Moreover, improved security through street lighting has contributed to better medical service provision, higher quality education, and the creation of new businesses (Muhoza & Johnson, 2018).

Water and sanitation: The importance of mini-grid electricity in providing access to clean, reliable water and sanitation for beneficiaries has been well documented in numerous studies (Moharil & Kulkarni, 2009; Kirubi et al., 2009; Yadoo, 2012; Sharma & Palit, 2014; Bhattacharyya & Palit, 2016; Chandra et al., 2020; Uamusse et al., 2020; Gyamff & Dagoumas, 2021). Moharil and Kulkarni (2009) describe an innovative approach that integrates water pumps into mini-grid systems, enabling communities to access clean and safe drinking water from deep underground sources. Uamusse et al. (2020) and Kirubi et al. (2009) report on developments involving the installation of water pumps that allow community members to access clean drinking water and sanitation facilities without having to travel long distances, significantly improving their lives. Gyamff and Dagoumas (2021) discuss the benefits of using mini-grid powered water pumping for agricultural purposes.

Productive uses: The importance of electricity in income generation has been extensively discussed in literature on inclusivity and social sustainability, emphasizing the advantages for households and SMEs (Ahlborg, 2018; Bahaj et al., 2019; Bhattacharyya & Palit, 2016; Ferrer-Martí et al., 2012; Ganguly et al., 2020; Kirubi et al., 2009; Lillo et al., 2015; López-González et al., 2020; Luukkanen et al., 2012; Muhoza & Johnson, 2018; Yadoo, 2012; Yadoo & Cruickshank, 2012). Productive electricity use benefits entrepreneurs and communities, creating value through cottage industries, particularly those that use electric appliances, tools and equipment, including barbershops and salons, phone charging services, welding, carpentry, and ice-block provision (Terrapon-Pfaff et al., 2018; Muhoza & Johnson, 2018b; Wiese, 2020; Yadoo, 2012; Ngowi et al., 2019; Kirubi et al., 2009b).

Increased income is attributed to direct and indirect uses of electricity, such as extending opening hours and supporting marketing techniques (Johnson et al., 2019) (Muhoza & Johnson, 2018b). Ferrer-Martí et al. (2012b) found that beneficiaries use energy to provide services to nearby unelectrified communities and expand or start small businesses. In the agricultural sector, farmers and SMEs benefit from electricity through improved storage for perishable goods, leading to better trade opportunities (Kirubi et al., 2009b; Yadoo, 2012; van Gevelt et al., 2020; López-González et al., 2020b). Cold storage facilities and electric tools enable local farmers to trade in larger volumes and create linkages between agriculture and SMEs (Kirubi et al., 2009b). Improved farming techniques, facilitated by better access to information and tools, also contribute to increased income (Yadoo, 2012). Indirect income generation effects are also highlighted in literature, such as the role of electricity access in improving education and household income (Kirubi et al., 2009b).

One notable outcome is increased competition within communities due to expanded electricity access (Pedersen et al., 2020). This can lead to both positive and negative effects, as well as conflicts of interest between entities promoting household connections to the mini-grid. Millinger et al. (2012) reported that, while women engaged in various small-scale activities after electrification, the impact on productivity was minimal.

It is worth noting that the inclusiveness of consumption increases when tariff subsidy programmes are implemented (Lukuyu et al., 2021), otherwise minigrid tariffs are generally vey high for low income households.

5.4 Inclusion of Process: Social inclusion in minigrid development processes

Effective and inclusive community participation and ownership can make low-carbon energy projects socially acceptable and enhance their long-term sustainability (Wiese, 2020). Numerous studies showcase how upfront involvement in the mini-grid design and implementation process empowers the community to become active stakeholders in the project (Katre et al., 2019; Palit & Chaurey, 2011; Pedersen et al., 2020; Uamusse et al., 2020). Community participation thought to increase sense of belonging and ownership structure as a key factor to success of power system (Urmee & Md, 2016). Further, community participation in the process is widely accepted as a pre-requisite to ensuring equity and sustainability of electrification efforts in rural areas(Palit & Chaurey, 2011), and enhances collective empowerment as it increased the community's confidence resulting to the seeking more minigrid projects (Lillo et al., 2015). Similarly, Uamusse et al., (2020) emphasises the importance of involving local stakeholders such as households and small-scale industry at an early stage.

In the sections below, we explore inclusivity in minigrid development processes, and the related dynamics.

5.4.1 Feasibility, site acquisition, approval

The initial step in mini-grid project development involves conducting a technical feasibility assessment of proposed sites (Wiese, 2020). The process differs in different countries, which affects the extent to which the process is inclusive. In India, for instance, state agencies secure funding for mini-grid projects and identify target areas (Ulsrud et al., 2011). Meetings are held with local leaders to discuss the project and outline community contributions. Surveys ascertain interest in electricity and village demand, while the tendering process for equipment, installation, and operators occurs later. In Peru, a non-governmental organization identifies electrification projects and communities through a quantitative-based socioeconomic and resource analysis (Lillo et al., 2015). Technical design, management models, and community-requested projects are prioritized to ensure high community motivation. Villagers receive training in efficient energy use, maintenance, and system operation. Community involvement is promoted to foster collective empowerment, leading to the pursuit of additional projects. Once operational and the community is deemed capable, the system is handed over for management and operation (Lillo et al., 2015). Similarly, Lopez-Gonzalez et al. (2018) describe a government-developed hybrid micro-grid program that began by estimating daily power consumption based on historical census data. Surveys in rural areas profiled houses and inhabitants, and socio-demographic evaluations determined the distribution of non-electrified rural households.

After site identification and approval, developers consult with community leaders to discuss various aspects of the project, including responsibilities, expectations, and ownership structures. Public village meetings inform the broader community about the project, e.g., issues around connection fees, bill payment methods, and connection procedures, and to create awareness of electricity's benefits (Ulsrud et al., 2011). Communal meetings allow for public participation, enabling community members to voice their opinions and ask questions, and this is seen as a way to prevent misinformation (Pedersen et al., 2020). Another strategy is door-to-door visits which addressed individual user issues and provided training, while open-air meetings served as a platform to share information about the company, However, the decision-making process is mainly focused on technical implementation, with limited community participation.

Several papers highlight cases of community and specific individuals being excluded from mini-grid development processes. Wiese (2020) reports that in some cases, only men were included in consultative meetings, and women were informed about the project at a later stage. Technical issues raised by villagers were sometimes ignored, leading to conflicts and disappointments. Van Gelvet et al. (2020) describe a Malaysian community that was completely excluded from a wind turbine project, unaware of its initiation, funding, or why it was never completed. In another solar-diesel hybrid mini-grid project, only male community leaders attended consultation meetings, leaving the rest of the community uninformed about the project and technology. Maintenance concerns were also raised since no one was designated to maintain the system.

The literature also highlights instances of social exclusion during feasibility and site acquisition processes. Wiese (2020) reports that some consultations only included men, with women being informed about the project at later stages.

5.4.2 Financing

Mini-grid projects require considerable capital for development, and the choice of funding instrument and financier depends on the project type and stage of development (Moharil & Kulkarni, 2007). Most mini-grid projects rely on subsidies and grants from various sources, such as governments, international development agencies, local governments, foundations, and private individuals (Moharil & Kulkarni, 2007; Pigaht and Van der Plas, 2009; Ulsrud et al., 2018; Pedersen et al., 2020). Funding also originates from venture capital investors, debt capital providers, Civil Society Organizations (CSOs), and self-help groups (Katre & Tozzi, 2018; Blum et al., 2015; IRENA, 2017; Joshi & Yenneti, 2020). The inclusiveness of the financing process depends on the extent of local community involvement, government engagement, and collaboration between stakeholders, such as the private sector and civil society organizations.

Debt and equity: Funding mechanisms often involve grants and subsidies for earlier, riskier stages of mini-grid development, while advanced and less risky projects rely on debt financing (Daniel Schnitzer, Deepa Shinde Lounsbury, Juan Pablo Carvallo et al., 2014; Pedersen et al., 2020; Pigaht & van der Plas, 2009). Pigaht and Van der Plas (2009) describe a project in Rwanda that sourced local equity and debt capital, combined with a subsidy of 30–50% for project costs, to develop micro-hydro projects with local distribution grids. The involvement of local investors fostered a sense of ownership and shared responsibility among stakeholders, which can promote greater community engagement and participation. This engagement can help ensure that the mini-grid project addresses the community's needs and expectations, fostering greater inclusiveness in the project. Chandra et al. (2020) propose a mini-grid development process in which external investors fund the setup costs and gradually recoup their investment through monthly instalments. The system would be owned by the financiers and leased to a community operating committee for utilization.

CSOs are pivotal in financing mini-grids in remote and unelectrified regions, engaging communities in the development and governance of these projects (Katre & Tozzi, 2018). For example, self-help groups, especially those led by local women in poverty-stricken regions, have been successful in owning and operating renewable energy systems (Joshi & Yenneti, 2020). This involvement has led to more inclusive institutional arrangements that can better adapt to local realities and respond to challenges (Katre & Tozzi, 2018). However, when Civil Society Organizations (CSOs) finance mini-grids, sometimes there are mixed project outcomes and high levels of failures (Katre et al., 2019; Katre & Tozzi, 2018). CSOs may have limited capacity and resources to adequately finance and support the development of mini-grids in remote and unelectrified regions. This can lead to underfunded projects and inadequate infrastructure, which may hamper the effectiveness of the mini-grid in providing reliable energy access to communities. In addition, CSOs may lack the long-term capacity to maintain and manage mini-grid systems, leading to sustainability issues in the future.

While benefiting communities may not be significantly involved in the direct financing of mini-grids, there are instances where they contribute in other ways, e.g. by contributing labour (Butchers et al., 2020; Wiese, 2020). Some minigrid cooperatives are structured so that users' initial labour and financial contributions grant them a share in project. This demonstrates that communities can participate and contribute to mini-grid projects through non-financial means, fostering a sense of ownership and engagement in the project's success.

Donor funding through grants, often provided by international development agencies, has been instrumental in financing mini-grids, especially in regions where private sector engagement is limited (Blum et al., 2015). Studies have found mixed outcomes in relation to inclusivity of donor-funded projects. On one hand, donor-funded projects offer flexibility to include community financial contributions to projects, e.g. in a mini-grid in Malaysia, whereby the developer alongside the local community, through their local leaders and the local leader’s daughter, sought funding from UNDP. The community further donated land and labour for the project (van Gevelt et al., 2020). There are also donor-funded projects with special purpose vehicles (SPVs) operating on a commercial basis, though with subsidies on investment and interest rates (Pedersen et al., 2020).

On the other hand, the process may not be very inclusive. For example, in Laos, donor-funded mini-grid pilots, which have been installed and supported by international development agencies, faced challenges due to an unfavourable national investment environment and high levels of corruption. These factors deterred international private investors from investing in rural Laos, limiting private sector engagement in mini-grid development (Blum et al., 2015). In Tanzania, a donor-funded NGO pilot project introduced an "Energy Service Platform" and micro-grid to supply electricity to villagers. However, the NGO failed to maintain service delivery, highlighting the challenges in ensuring the sustainability of donor-funded mini-grids (Ahlborg, 2018). Thus, to ensure a more inclusive process, donors should focus on actively involving communities, supporting capacity building, and promoting collaboration between different stakeholders, including the government, private sector, and civil society organizations.

Government subsidies are another significant source of financing for mini-grids (Millinger & Ahlgren, 2012; Blum et al., 2015; IRENA, 2017; Joshi & Yenneti, 2020). Governments can fully or partially finance mini-grid projects, either directly or by partnering with other financiers like NGOs and communities (Yadoo, 2012; Van Gevelt et al., 2020). In India, an established federal policy framework supports mini-grid co-financing with other actors, with local state governments providing up to 55% of financial costs (Ulsrud et al., 2018).

When governments finance mini-grids, several issues can arise, such as inconsistency in policy and technological preferences, lack of clear guidance, and limited coordination with other stakeholders. Governments can sometimes act opportunistically, accepting financial support for various electrification concepts from international donors, which can result in a lack of a clear technology strategy and discontinuity in the guidance of the search (Blum et al., 2015). Inclusiveness in the process depends on the level of coordination between governments, communities, and other stakeholders. Governments can facilitate inclusive processes by engaging communities in decision-making and ensuring that diverse regions and populations are represented in electrification plans. However, limited coordination and inconsistent guidance can negatively affect the inclusiveness of the process. In Peru, a 40kW micro-hydro mini-grid was installed in Tamborapa Pueblo, with capital costs covered by national and local government bodies (Yadoo, 2012). The community contributed unpaid labour, highlighting an example of exploitation in the process. Similarly, in Sarawak, Malaysia, the state and federal governments set an ambitious target to provide access to reliable and affordable electricity for all rural households by 2025 (Van Gevelt et al., 2020). However, the project was funded by the federal Ministry of Science, Technology and Innovation, rather than state funding, indicating potential coordination challenges. Overall, the inclusiveness of the process when governments finance mini-grids is contingent on effective coordination between different stakeholders, consistent policy guidance, and active community engagement.

Our analysis shows that many minigrid projects in fact adopt hybrid financing models, i.e. a combination of multiple financing sources and instruments to fund the development, implementation, and operation of mini-grid projects. Hybrid financing models enable project developers to leverage various funding sources, such as public, private, and donor financing, to improve project viability and sustainability.

5.4.3 Engineering, Procurement and Construction

A noticeable gap exists in the literature that specifically addresses the aspect of inclusiveness within the engineering and procurement stages. This lack is particularly evident when one considers the limited role of local communities within these crucial processes.

In the engineering phase, the interaction between the project developers and the local community is often confined to the collection of data for needs assessment or feasibility analysis. Although this information is vital, the role of the community is typically passive, providing the necessary details but not participating in the analytical process or the subsequent technical design of the minigrid. Van Gelvet et al. (2020) describe a Malaysian community that was entirely excluded from a wind turbine project's design and implementation. This approach may be attributed to the prevailing assumption that community members lack the requisite technical expertise. However, such an assumption could potentially overlook valuable local insights and knowledge, thereby undermining the inclusivity and possibly the effectiveness of the minigrid system.

Similarly, in the procurement stage, local communities frequently play a minimal role, if any. The process primarily revolves around the importation of equipment, an activity typically managed almost exclusively by the minigrid developer. This exclusion of community participation from procurement not only impedes the potential for capacity-building within the community but also limits opportunities for fostering a sense of ownership and investment in the minigrid project.

Although community members are often involved in the construction phase, their roles are largely confined to providing manual labour, with little involvement in decision-making or skill-building activities. Wiese (2020) highlights that community members provided raw materials such as sand and stones for project construction. Furthermore, they considered unpaid labor as a form of participation in the project implementation. Similarly, Butcher et al. (2020) mention that local beneficiaries were often expected to contribute labour for repairs when needed. Exclusion in the design process may lead to the deployment of minigrids that do not account for the local context and a lack of legitimacy. In a micro-hydropower grid in Ethiopia, villagers' complaints about technical issues during construction were not addressed, leading to conflicts and disappointment due to misinformation about the system's capacity and boundaries (Wiese, 2020). A Malaysian community was unaware of the project's origin, funding, and reasons for incompletion (van Gevelt et al., 2020). In another case involving a solar-diesel hybrid mini-grid, community engagement was insufficient, as only male kampong leaders attended consultation meetings. Other community members were uninformed about the project and technology used (van Gevelt et al., 2020).

5.4.4 Operation and maintenance

Mini-grid ownership and management models differ from project to project, with common models including private sector management, local community management, utility-based management, and hybrid ownership (Lillo et al., 2015). It has been observed that the majority of government and donor-funded projects are eventually transferred to the communities. These communities assume responsibility for the operation and maintenance of the project, either immediately upon installation or after a certain period, once the functionality has been ensured (Schnitzer et al., 2014; Lopez-Gonzalez et al., 2018; Joshi and Yenneti, 2020). Such management models are varied. For instance, an management model in Venezuela which was formed by the Ministry of Energy, which included the local community council among other stakeholders (López-González et al., 2018). Another management model in India involves the local community, civil society and the industry (Joshi & Yenneti, 2020; Pandey & Sharma, 2021). Joshi and Yenneti, (2020) highlight a solar module manufacturing unit owned and operated by local tribal women and supported by academics and philanthropic partners. Community-based management models empower locals and foster a sense of project ownership (Yadoo, 2012). In some cases, a mini-grid developer or any other entity with the technical know-how provides the technical assistance to the community to maintain the minigrid (Sharma and Palit, 2020).

Some communities form local micro-enterprises or cooperatives to operate, maintain, and administer the mini-grid systems, including revenue collection, minigrid extension, and tariff setting (Millinger and Ahlgren, 2012; Lopez-Gonzalez et al., 2018; Joshi & Yenneti, 2020). (Ferrer-Martı´ et al., 2012; Schnitzer et al., 2014; Moharil & Kulkarni, 2007; Ulsrud et al., 2011; Yadoo, 2012; Johnson et al., 2019; Bahaj et al., 2019; Butchers et al., 2020 Yadoo, 2012; Yadoo and Cruickshank, 2012). In some cases, mini-grids are managed by pre-existing cooperatives that are gender-balanced and democratically elected (Yadoo & Cruickshank, 2012). Wiese (2020) highlights that, in Ethiopia, women's inclusion in management committees was mandated by laws and achieved through an elective process. These committees were expected to remain independent from political and personal interests to ensure efficiency. Additionally, the revenues collected in some other cases is used to provide members with micro-loans repayable in a given period of time.

Successful mini-grid projects often involve training community and/or committee members to operate and maintain the systems (Van Gelvet et al., 2020). Technical issues beyond the capabilities of these technicians are handled at a secondary level, e.g. in a Kenyan case, through video conference call from the manager to the project team and if not resolved, an engineer on day call out fee is sent to the project from Nairobi (Bahaj et al., 2019). Klunne and Michael, (2010) points out that involvement of local technical skills in maintaining the mini-grid system enabled the community to solve technical problems by themselves bringing trust to the users over service delivery, a factor mentioned to be vital in willingness to pay for the services.

Institutional mini-grid projects, such as those installed for hospitals or schools, can be maintained and operated by the institutions themselves, or in collaboration with local community committees (Klunne & Michael, 2010; Ngowi et al., 2019). For instance, Ngowi et al. (2019) describe a hospital-owned mini-grid in Tanzania where the hospital management worked with local communities to manage and control power supply.

Overall, community inclusivity and involvement in the operation and maintenance of mini-grids can lead to more sustainable and successful projects. This can be achieved through various management models, such as local community management, cooperatives, and partnerships with institutions.

In sum, practically speaking, minigrid developers adopt different approaches to implement what they consider as an inclusive development process. For instance, two Kenyan private firms prioritized connecting nearly every household in the mini-grid's vicinity, considering both the commercial and social welfare logic. The firms believed that building good relationships with communities and gaining their acceptance are essential for success, thus implementing a 'connect all' strategy (Pedersen et al., 2020). Developers also take formal steps to increase community influence over projects by establishing project committees with balanced gender representation and setting up complaint procedures to enhance accountability and consumer rights (Pedersen et al., 2020). It is assumed that collective buy-in is crucial for accessing cost-effective options and ensuring that no one is left behind, as excluding community members could create opposition. Effective communication strategies, such as open-air meetings and door-to-door visits, are employed by private mini-grid developers in Kenya to reach customers, address individual user issues, and provide training (Pedersen et al., 2020). Communal meetings are used for participatory decision-making processes, fostering ownership, and addressing concerns like mini-grid system placement.

Nevertheless, mini-grid developers often face community resistance. Van Gelvet et al. (2020) mention a Malaysian solar project that faced opposition due to the community's belief that solar technology was unsuitable for their area, which received sunlight only 30% of the time. They also felt excluded from the decision-making process. Soshinskaya et al. (2014) document similar resistance due to past disappointments and vested interests. In some cases, community engagement levels vary, with some members showing little interest or ownership in the project, even when acknowledging its importance (Butchers et al., 2020). Non-participation is also seen as a way for communities to exercise their agency, especially when they do not accept predefined roles and identities as set by elite actors (Pandey & Sharma, 2021).

Economic situations affecting the ability to pay and reduced power from mini-hydro plants also contribute to reduced community interest (Butchers et al., 2020).

5.5 INCLUSION OF STRUCTURE

The discourse surrounding the inclusivity of mini grids, particularly within the context of energy systems in the Global South, reveals a complex landscape where the structural and inherent inclusivity of these systems is not a given but rather a goal that requires deliberate effort and design (Almeshqab & Ustun, 2019; Bhattacharyya & Palit, 2016; Kitenge & Siringi, 2019; López-González et al., 2019). Mini grids, heralded for their potential to democratize energy access and foster socio-economic development, face challenges in realizing truly inclusive innovation. The evidence presented in the literature indicates that while mini grids offer transformative potential for marginalized communities by providing access to electricity, the extent of their inclusivity, especially in the design, procurement, deployment, and governance stages, remains limited. The community involvement in these crucial stages is often minimal, focusing primarily on rubber-stamping participation, rather than meaningful participation in technical design or decision-making processes (Gill-Wiehl et al., 2022; Kitenge & Siringi, 2019; Pandey & Sharma, 2021). Moreover, the procurement and deployment activities are predominantly managed by developers, with community contributions largely confined to providing labour or local materials, rather than engaging in substantive decisions that shape the project's direction and outcomes.

The structural barriers to inclusivity within mini grid projects are further compounded by socio-economic disparities and gender dynamics (Aklin et al., 2017; Hills, 2012; Klunne & Michael, 2010; Van Els et al., 2012). Despite the potential benefits of mini grids in income generation and reducing domestic drudgery, the actual advantages tend to accrue to those already possessing technical know-how, financial resources, or decision-making power, typically middle- and upper-income males. Women and individuals from lower-income households frequently remain on the periphery, not because of a lack of interest or need but due to the absence of democratic structures of ownership, governance, and inclusive decision-making mechanisms that acknowledge and bridge these gaps (Johnson et al., 2019; Wiese, 2020). This scenario highlights a critical mismatch between the potential of mini grids to act as vehicles for inclusive innovation and the reality of their implementation, which often perpetuates existing inequalities rather than dismantling them. To move towards genuinely inclusive mini grid projects, there is a pressing need for policies and practices that prioritize community engagement, equitable participation, and the distribution of benefits across all segments of society, ensuring that the innovation process within energy systems becomes inherently inclusive.

5.6 POST-STRUCTURAL INCLUSION

The analysis of the literature reveals a critical gap between the potential of minigrids as vehicles for inclusive innovation and the reality of their development and implementation in the Global South. This gap exists primarily due to the predominant reliance on traditional engineering and economic paradigms, rather than embracing alternative, more democratic frameworks for energy infrastructure development.

The literature highlights instances where the design and deployment of minigrids are not fully democratized or inclusive of community inputs. For example, as already seen, community involvement is often limited to data collection for feasibility studies, without meaningful participation in the technical design or decision-making processes. This approach reflects a significant reliance on the expertise of engineers and economists, who prioritize technical efficiency and financial viability over the diverse needs and aspirations of the communities they aim to serve (Brix et al., 2020; Chaurey et al., 2004; Moore, 2012; Roche & Blanchard, 2018). The result is a system that may not fully align with the socio-cultural dynamics of the target communities, thereby limiting its inclusiveness and potential impact on energy poverty alleviation (Johnson et al., 2019; Urmee & Md, 2016).

Analysis of the literature underscores a significant oversight in considering alternative governance models of post-structural inclusion as argued by Smith et al, (2023), such as public ownership, co-operative governance, or conceptualizing energy infrastructure as a commons. These models have the potential to foster a more equitable distribution of energy resources and ensure that the interests of all stakeholders, especially marginalized communities, are taken into account (Korkovelos et al., 2020). However, the current approach to minigrid development often treats inclusiveness instrumentally, focusing on making the systems appealing to customers rather than integrating the systems sociologically around the community's inputs, knowledge, and aspirations.

5.7 THE DARK SIDE OF MINIGRIDS: EXCLUSIONS AND ENVIRONMENTAL EFFECTS

The introduction of minigrids and electricity in communities can provide numerous benefits, such as improved access to information, entertainment, and communication. However, these advancements can also lead to unintended negative consequences on social cohesion within communities. One such effect is the potential for reduced community engagement, as highlighted by van Gevelt et al. (2020). The availability of electricity may lead to a shift in social dynamics within the community. As people gain access to new forms of entertainment and communication, such as television, radio, and the internet, they may be less likely to engage in traditional community gatherings and events. This can result in a weakening of social ties and a decline in the sense of community that is often vital to the well-being and cohesion of rural populations.

Community participation is generally considered an essential component of successful minigrid development, as it helps to ensure that projects are tailored to the needs and preferences of local communities. However, if not managed appropriately, community participation can also have negative effects on the project, as mentioned by Gill-Wiehl et al. (2022). These negative effects can manifest in technical, economic, and social issues, which can hinder the overall success and sustainability of the minigrid. Negative end-user perceptions due to poorly implemented projects can have long-lasting consequences, leading to skepticism about the technology's appropriateness, economic cost, and suitability (van Gevelt et al., 2020). Further, inadequate training for community members responsible for the operation and maintenance of the minigrid can lead to improper handling, neglect, or misuse of equipment (Gill-Wiehl et al., 2022). This can result in reduced output, decreased reliability, and poor performance of the minigrid system. A lack of respect for all parties involved in the minigrid project can lead to social tensions and conflicts within the community. Disagreements over the planning, implementation, or operation of the project may arise if community members feel their opinions or concerns are not being taken into account. Moreover, miscommunication or lack of transparency can result in distrust and dissatisfaction among community members, which can negatively impact the overall social cohesion and acceptance of the project.

In a case in Cambodia, the minigrid was installed only along the road, resulting in houses situated more than 50 meters from the road being excluded from access to electricity (Luukkanen et al., 2012). Social segregation arising from such disparities can manifest in various ways. Firstly, households with access to electricity may enjoy improved living standards, increased productivity, and opportunities for economic development, while those without access remain at a disadvantage. This imbalance can create a sense of inequality and frustration among the unconnected households, as they might feel excluded from the benefits of the minigrid project. Unconnected households may struggle to participate in new economic opportunities, educational advancements, or social activities that require access to electricity. The division in access to electricity can exacerbate existing social or economic divides within the community, reinforcing existing power dynamics or widening gaps between different groups. This separation may lead to increased tensions and a breakdown in social cohesion, as community members perceive the uneven distribution of resources as unjust.

Gender disparities in minigrids are evident in various aspects, including access to education, work distribution, and the ability to benefit from electricity. Johnson et al. (2019) emphasize the triple role of women within the household and community, which encompasses reproductive, productive, and community work. These roles often result in women bearing a higher burden of responsibilities compared to men. Wiese (2020) highlights the differences between boys and girls in terms of studying time, with girls having less study time after dark due to their expected engagement in domestic work, unlike boys who are not obligated to perform similar activities. This disparity is evident in the fact that all the males in the study completed primary/basic school, while 5 out of 12 women were illiterate. Additionally, Wiese (2020) raises the possibility that the arrival of electricity could lead to higher dropout rates among boys as they may feel obligated to take up productive work to support their families financially.

Gender disparities are also observed in the way men and women spend their time post-electrification. Wiese (2020) points out that men, especially those in higher-income groups, can spend more time engaging in recreational activities, reading, or conducting business activities after dark. In contrast, women often find that electric lighting extends their working time as they continue to perform household chores such as cooking with less-than-efficient fuels, taking care of children, and feeding animals. Although minigrid electricity can make some chores easier, the overall reduction in the burden of domestic work for women may be limited (Wiese (2020) and Muhoza and Johnson (2018)). Many households may not be able to afford or choose not to invest in labour-saving appliances, such as washing machines, electric cookers, or refrigerators. In some societies, women may still be expected to perform a majority of domestic work, regardless of the availability of electricity or labour-saving appliances. In some cases, electricity may enable new income-generating activities for women. While this can have positive economic impacts, it may also result in additional responsibilities, maintaining or even increasing the overall workload of women, rather than reducing it.

Minigrids can have unintended negative consequences on the environment and the community at large. Rahmann et al. (2016) highlight two such effects: environmental problems arising from fossil-fueled backup generation and the impact on residents' quality of life due to noise and visual disturbances. Fossil-fueled generation units, which are sometimes used as backup power sources when renewable energies are not available, can contribute to greenhouse gas emissions and air pollution, and these emissions can have adverse effects on the health of community members. The visual impact of the minigrid infrastructure, including power lines, solar panels, and wind turbines, can alter the community's landscape and affect the aesthetic appeal of the area (Rahmann et al., 2016). In addition, the noise generated by certain components of the minigrid system, such as generators or inverters, can be disruptive to residents, particularly if they are located close to residential areas. The introduction of electronic devices and appliances can also lead to increased noise pollution within the community. As people play loud music on their stereos or watch television at high volumes, it can disrupt the peace and tranquility that was once prevalent in the community. This can be particularly concerning for older residents or those who value quiet and calm environments, and may lead to tensions and conflicts between neighbours.

6.0 DISCUSSION AND CONCLUSION

The aspiration behind minigrid development can be considered as promoting social inclusion, as it aims to provide electricity access to remote and geographically isolated areas where extending the central grid is challenging (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). By offering more economical alternatives to expensive energy sources, minigrids help households with different income levels gain access to electricity (Kobayakawa and Kandpal, 2014; Schnitzer et al., 2014). Furthermore, minigrids support economic growth, improve the quality of life in remote and rural communities (Pedersen et al., 2020; Kirubi et al., 2008), and power essential institutions such as hospitals, schools, and vocational centers (Leary et al., 2012; Ngowi et al, 2019; Klunne and Michael, 2010, Kirubi et al, 2008). Overall, minigrid development contributes to social inclusion by promoting economic development, enhancing living standards, and ensuring the efficient functioning of vital institutions in remote areas. The analysis of the literature on minigrids within the context of the Global South reveals nuanced insights into their role as inclusive innovations. By examining minigrids through the lens of the six levels of inclusiveness, we can discern their strengths, limitations, and the pathways needed to harness their full potential for marginalized communities.

When considering the first level, inclusion of intention, the aspiration behind minigrid development can be considered as promoting social inclusion, as minigrid projects often articulate a commitment to addressing energy poverty among marginalized groups, suggesting a recognition of the need to serve these populations (Ahlborg, 2018; Lukuyu et al., 2021; Muchunku et al., 2018; Uamusse et al., 2020; van Gevelt et al., 2020). By offering more economical alternatives to expensive energy sources, minigrids help households with different income levels gain access to electricity (Kobayakawa and Kandpal, 2014; Schnitzer et al., 2014). Furthermore, minigrids support economic growth, improve the quality of life in remote and rural communities (Pedersen et al., 2020; Kirubi et al., 2008), and power essential institutions such as hospitals, schools, and vocational centers (Leary et al., 2012; Ngowi et al, 2019; Klunne and Michael, 2010, Kirubi et al, 2008). Overall, minigrid development contributes to social inclusion by promoting economic development, enhancing living standards, and ensuring the efficient functioning of vital institutions in remote areas.

There is substantial evidence that there is inclusion of consumption, as minigrids adapt novel product-services with clear usage by marginalized groups in domestic and community lighting, alleviating drudgery, productive uses and even at institutional level (Asuamah et al., 2021; Bahaj et al., 2019; Chandra et al., 2020; Chaurey et al., 2004; Joshi & Yenneti, 2020; Mazzone, 2019; Roche & Blanchard, 2018). These services undoubtedly improve the quality of life, showcasing minigrids' ability to adapt to the consumption needs of marginalized communities. Inclusion of impact is similarly well-documented, with studies indicating that minigrids have a positive impact on the well-being of marginalized groups, which others showing some negative outcomes of minigrids in household and community dynamics (Gill-Wiehl et al., 2022; Rahmann et al., 2016; Wiese, 2020).

From the market-oriented liberal-individualist perspective captured by these first rungs of the ladder of inclusivity (Levidow & Papaioannou, 2017), these findings show that minigrids exemplify a promising avenue for providing affordable energy solutions to underserved populations. This stance, echoing the principles of base of the pyramid (BOP) strategies (Prahalad & Hammond, 2002), suggests that minigrids can be scaled through significant investments, potentially by large corporations, to extend electricity access to remote and marginalized communities efficiently. This approach views minigrids as market opportunities that, with the right business models, could attract substantial private investments to address energy poverty. However, as the findings on impact already show, this perspective may not fully account for the complex socio-political and cultural dimensions of energy access. There are clear disparities in how different populations groups access minigrid energy, and the extent of usage, with a clear disadvantage that affects women (Cecelski, 2004; Johnson et al., 2019; Pandey & Sharma, 2021; Sharma, 2020; Urmee & Md, 2016; Wiese, 2020). Like in the inclusiveness of consumption, the impact's distribution appears uneven, often favouring those within the community who already possess certain socio-economic advantages, such as higher income or technical know-how (Pandey & Sharma, 2021; Wiese, 2020). Thus, market-driven minigrid projects could prioritize profitability and operational efficiency over addressing deeper issues of social exclusion and equity, potentially neglecting the specific needs, preferences, and contributions of local communities.

Inclusion of process presents some nuances in the extent to which marginalised groups influence developments. While there are instances of community engagement in the development and deployment of minigrids, participation tends to be limited to initial consultations or providing labour, rather than deep, meaningful involvement in decision-making processes (Gill-Wiehl et al., 2022; Kitenge & Siringi, 2019; Pandey & Sharma, 2021). This indicates a moderate level of process inclusion but highlights the need for more robust mechanisms that allow for genuine influence by marginalized groups over project development.

Structural and post-structural inclusiveness remain elusive in the practice of minigrid development in the Global South. The structural inclusiveness of minigrid innovation remains limited, as evidenced by the absence of democratized ownership and governance models in many projects (Kitenge & Siringi, 2019; Pandey & Sharma, 2021). Although minigrids have the potential to be developed within frameworks that make it easy and desirable for excluded groups to become involved, the literature suggests that this potential is not fully realized, with traditional, top-down approaches still prevalent. Similarly, there is scant evidence to suggest that minigrids are developed within a post-structurally inclusive framework informed by the experience, knowledge, and discourse of marginalized groups who set the agenda and terms for development, deployment and operation. These observations suggest that for minigrids to become post-structurally inclusive, there needs to be a paradigm shift in how they are conceived, designed, and implemented. This shift should involve moving away from top-down, techno-economic approaches towards more participatory, sociologically oriented frameworks that prioritize community engagement, co-creation, and shared governance (Smith et al, 2023). By doing so, minigrids could better anticipate and explore the potential of inclusive energy systems, aligning user interests with system interests and fostering more sustainable, equitable energy access in the Global South.

The latter three rungs of the ladder of inclusivity exemplify the social-collectivist stance that emphasises the importance of equitable participation, community empowerment, and localized, grassroots innovations in minigrid development (Levidow & Papaioannou, 2017). From this perspective, minigrids designed and implemented with a focus on collective creativity and community governance can foster social inclusion and empowerment. Minigrid projects that align with this stance would involve communities in decision-making processes, from planning and design to operation and maintenance, ensuring that the energy systems are tailored to local contexts and needs (Smith et al, 2023; Pansera & Owen, 2015). This approach would not only addresses the immediate energy needs but also builds local capacity and supports socio-economic development through community ownership and governance structures (Fressoli et al., 2014). However, scalability and financial sustainability may pose significant challenges under this model, as projects may rely heavily on grants, subsidies, or community contributions, which may not always be readily available or sufficient for expansion.

In conclusion, the inclusiveness of minigrids can be better understood through the interplay between these two stances. A balanced approach that incorporates the market efficiency and scalability of the liberal-individualist perspective with the social equity and community empowerment focus of the social-collectivist stance may offer the most sustainable and inclusive pathway for minigrid development. Policies should aim to foster community ownership and governance of minigrid projects, ensure equitable access to the benefits of electrification, and support capacity building among marginalized groups to actively participate in and influence energy projects. Furthermore, policies should encourage the exploration of alternative, multistakeholder governance models and financing mechanisms that align with the principles of energy justice and inclusiveness (Korkovelos et al., 2020). By doing so, minigrids can move closer to realizing their potential as truly inclusive innovations that empower marginalized communities and contribute to sustainable development in the Global South.

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