Energy Research & Social Science 89 (2022) 102673

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Review

Off-grid solar expansion and economic development in the global South: A critical review and research agenda

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ARTICLE INFO

Keywords:
Solar
Energy
Poverty
Development
Global South

ABSTRACT

In this paper, we seek to understand how the rapid expansion of off-grid solar energy across the global South since the turn of the century is influencing local and national processes of economic development. We do so through a systematic review of 125 papers published between 2001 and 2020 that provide much evidence and understanding on the topic. Ninety-six of the reviewed papers claim off-grid solar expansion has positively influenced economic development. However, among other issues, much of this positivity is based upon a narrow conceptualisation of economic development as increased income, often achieved by individuals and firms working longer. To what extent these income gains are likely to be sustained and strengthened over time remains unclear. Based on the findings, we call for future research in this area to adopt a more transformative conceptualisation of economic development, as well as a broader analytical framework that: pays greater attention to the role of the state; adopts a more critical position in relation to the foreign firm; and more fully embraces the contested, contingent, and uneven nature of the process of economic development under observation. We close the paper by identifying several fruitful avenues for future research. It is hoped that these suggested paths might help build on the rich insights generated to date, to further deepen and develop our understanding of to what extent, how, and where off-grid solar expansion is promoting (or undermining) transformative and emancipatory processes of economic development in the global South.

1. Introduction

In recent years, the provision of off-grid solar energy has expanded dramatically across the global South. Facilitated by the liberalisation of national energy sectors and responding to a dramatic fall in costs by roughly 80% since 2009 [1], much of this expansion has been driven by foreign direct investment. Global off-grid solar capacity expanded 10-fold in the last decade, with sub-Saharan Africa the recipient of around four-fifths of the $1.7 billion invested in private sector off-grid solar projects [2]. While off-grid solar technologies remain unaffordable for many, steep cost reductions appear to have instilled in governments, multilateral institutions, and development agencies a renewed belief that Sustainable Development Goal (SDG) 7 is now within reach: ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030. The International Energy Agency (IEA), for example, has stated that the majority of people living without access to electricity can be best served in the coming years by off-grid solar energy solutions [3]. In 2016, the African Development Bank (AfDB) launched its New Deal on Energy for Africa, with the goal of "scal[ing] up the off-grid energy revolution" to achieve universal energy access on the continent by 2025 [4].

Supporting these efforts is a vibrant literature investigating how to most efficiently and effectively expand access to off-grid solar in energy-poor regions across the global South [5–9]. This access literature is underpinned by the assumption that expanded access to off-grid solar will not only reduce energy poverty but can or will in turn reduce income poverty by driving local and national processes of economic development. This causal relationship is asserted most boldly by development agencies and multilateral institutions, with claims that expanded access "will drive economic growth and reduce poverty… particularly in the lowest-income communities" [10], and "will lift hundreds of millions of people out of poverty" [11]. While usually more reserved, the claim is nonetheless equally prevalent in the academic literature, where for example Comello et al. [12] note that "[off-grid solar] products and services can serve as the base for economic growth and development", and Smith and Urpelainen [13] observe that "solar home systems hold major promise for socioeconomic development".

Theoretically, this line of thinking can be traced to New Institutional

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https://doi.org/10.1016/j.erss.2022.102673
Received 9 December 2021; Received in revised form 17 May 2022; Accepted 18 May 2022
Available online 6 June 2022

Economics (NIE), where economic development is conceptualised as being held back by market barriers. Once these barriers are removed, individuals can "use their rational perceptions…to navigate transactions and make the most profitable decisions – aggregating to generate economic growth" [14]. For NIE proponents, liberation technologies – such as solar power – can "level the playing field" by allowing poor countries and households to participate more fully in the global economy [15]. Yet notably, techno-optimist claims about the economic development potential of off-grid solar in the global South are often either unsubstantiated or based on references to historic experiences of electrification in the global North. Yet while interlinked, the constraints to and challenges of contemporary development in the global South are distinct from those faced historically and today in the global North [16–20].

The purpose of the present paper, therefore, is to evaluate the extent to which the optimism found in this access literature is justified. It does so by undertaking a critical systematic review of the literature that provides empirical insight into the relationship between expanded access to off-grid solar and economic development in the global South. This would appear especially urgent at a time when, as outlined above, major efforts are underway to expand off-grid solar energy products into tens of millions of households across the global South before the end of the current decade, in pursuit of SDG 7. The paper builds on but is distinct from existing off-grid literature reviews in this and other energy journals [21–24] in: its inclusion of the most recent literature (in an area where, as will be shown, relevant publications have been most prolific in recent years); its conceptual focus on economic development; and its exclusive concern with the global South.

The work presented in the sections that follow is based on a review of 125 academic and grey literature publications between 2001 and 2020 that provide empirical insight into the relationship between expanded access to off-grid solar and economic development in the global South. Across the 125 publications, 96 claimed a positive relationship, 20 found mixed results, and only nine claimed a neutral or negative relationship (or 77%, 16%, and 7% respectively). At first glance, these findings appear to provide strong support to the belief held by the NIE-inspired, techno-optimist access literature, that off-grid solar expansion in the global South can reduce poverty and drive economic development.

However, as will be shown (among other issues), much of this positivity is based upon a narrow conceptualisation of economic development as increased income, often achieved by individuals and firms working longer. To what extent these income gains are likely to be sustained and strengthened over time remains unclear. Based on the findings, we call for future research in this area to adopt a more transformative conceptualisation of economic development, as well as a broader analytical framework that: pays greater attention to the role of the state; adopts a more critical position in relation to the foreign energy firm; and more fully embraces the contested, contingent, and uneven nature of the process of economic development under observation. We close by identifying several fruitful avenues for future research.

The next section develops the conceptual framework used to make a critical assessment of economic development in the reviewed literature. Section 3 foregrounds the methodology adopted for the review and presents an overview of the selected papers. Section 4 presents the findings and is divided into two subsections. Subsection 4.1 reviews the literature concerned with the economic impact on the individuals, households, and firms who gain access to off-grid solar energy (characterised as 'access outcomes'). Subsection 4.2 reviews the literature considering the contribution made to economic development by the expanding solar sector itself (characterised as 'sectoral outcomes'), drawing upon Hirschman's [25] linkages framework to structure the discussion. Section 5 discusses the findings, and Section 6 concludes by outlining a future research agenda.

2. Economic development in the global South: a conceptual framework

Economic development is understood here as a transformative process in which productive resources move from low productivity to higher productivity sectors and activities [26], measured by:

> …an increasing amount of value-added per person, achieved through increasing labour productivity (output per unit of labour time rather than simply people working more or more people working) and sustained by capital accumulation. Capital accumulation refers to the accumulation of produced means of production – for example, machines and also infrastructure – rather than simply an increase of inputs such as labour, land, natural assets, or money [27].

In this process of transformative economic development, driven by increasing output per unit of labour time and sustained by capital accumulation, attention has been drawn to the singular importance of an active and interventionist state through the design and implementation of strategic policy targeting land reform, agriculture, and key sectors and industries [28–34]. For Kay [35], for example, variation in "the ability of the state to design and implement strategies and policies conducive to development" was a crucial factor in explaining the divergent development performance of East Asia and Latin America during the latter half of the twentieth century.

One of the key insights to emerge from the literature investigating the state's role in guiding sustained gains in economic development in East Asia during the latter half of the twentieth century was the critical role played by domestic firms and capitalists. State-business alliances, "whereby the state implements a series of incentives and rewards to persuade domestic capitalists to undertake investments in targeted sectors in the economy" [36], were central to the transformational development trajectories undertaken during this period. A number of successful East Asian industrialisers, such as South Korea and Taiwan, were cautious of foreign investment and firms during early industrialisation, favouring instead the provision of supports and incentives to local business groups to develop targeted industries, including (during the initial stages) insulation from foreign competition [29].

In Latin America, by contrast, Sunkel [37,38] and Vaitsos [39] were among the first to highlight the contradictions and tensions of a model of development delivering high growth rates but predicated on the dominance of foreign firms in key industries:

> …industry was taken over to a large extent by foreign subsidiaries, with the result that much of the benefit expected from industrialisation has gone abroad in payment for capital equipment and in a transfer of profits, royalties, and other financial payments. This has effectively denationalised and eroded the local entrepreneurial class. Although the massive penetration of foreign firms has accelerated growth rates, especially industrial, it has also accentuated the uneven nature of development [37].

More recent scholarship has highlighted how these dynamics, documented by Sunkel and Vaitsos in 1960s and 1970s Latin America, have continued to haunt processes of late industrialisation and economic development across the global South in the opening decades of the twenty-first century [20,40–44].

Distributional concerns, therefore, are of central importance when studying and understanding local and national processes of economic development. At its crudest is the question of which groups are included and which are excluded or marginalised? Or, to use Bernstein's [45] four key questions of political economy: Who owns what? Who does what? Who gets what? What do they do with it? Such analysis points to economic development as a contested, contingent, and conflictual process that even in times of growth can breed polarisation, marginalisation, and exclusion.

Writing about economic development in Africa, Cramer et al. [46]

recently argued: "…capitalism is contradictory always and everywhere. Even where capitalist expansion brings about dramatic and, in many ways, progressive changes, it is contradictory, uneven, and brutal…. For capitalism is never linear and smooth, never friction-free in its expansion". In the case of off-grid solar expansion, pre-existing social stratification (such as along the dimensions of class, race, ethnicity, age, and gender) will likely influence which groups gain access to and benefit from off-grid solar, which domestic firms and capitalists are incorporated into the sector, and which groups gain employment in it (and at what levels). As the Brazilian economist Celso Furtado once wrote, "Development is … a process of reshaping social relations founded on accumulation" [18]. Of critical concern, then, is how social relations are being reshaped by processes of economic development and with what effects. While some groups will be included in these processes, others will be excluded from or marginalised within them, potentially accentuating pre-existing inequalities, grievances, and conflict (or generating new ones).

In sum, economic development is conceptualised here as a process driven by increasing output per unit of labour time and sustained by capital accumulation. The state has a central role to play in guiding this process, and the balance of power between domestic and foreign firms in key sectors and industries is of critical importance in determining where and to whom the benefits accrue. Yet while carrying emancipatory and socially transformative potential, the process of economic development is uneven and contradictory, from which certain groups tend to benefit at the expense of others.

3. Methodology

The aim of this review is to synthesise and critically interpret existing knowledge on the relationship between expanded access to off-grid solar and economic development in the global South. Here, off-grid solar is understood as any solar energy system operating outside of the national grid, ranging from pico-systems and lanterns to solar home systems and micro- or mini-grids (each discussed in more detail in Subsection 4.1 below). For this, a systematic review was undertaken in an attempt to produce "a comprehensive, unbiased, and replicable summary of the state of knowledge on a well-defined issue" [47]. The starting point for the review was the selection of a set of five keywords used in varying combinations – off-grid, solar, energy, economic, and development.

For the academic literature, the keywords were first applied to database searches of the International Bibliography of Social Sciences, SCOPUS, and Google Scholar. Following this, further literature was identified by applying the same keywords to search the online archives of 72 leading peer-reviewed journals in the areas of energy and environment, development studies (including geography and anthropology), economics (orthodox and heterodox), political economy, and African studies (see Appendix A). For the grey literature, the publication archives of 40 organisations were searched using the same keyword combinations, covering a range of development agencies, multilateral institutions, industry associations, and African institutions (see Appendix B). The targeting of African studies journals and African institutions stemmed from the observation in Section 1 that around four-fifths of private sector investment in off-grid solar projects over the last decade has been directed to the continent.

Four criteria determined whether identified literature was included in the review. First, the paper had to include a focus in part or in whole on a country or region from the global South. Second, the paper had to present primary data in support of any claim regarding the nature of the relationship between off-grid solar and economic development. Third, while no temporal starting point was assigned, any papers published later than December 2020 were excluded. Fourth, only papers published in English were selected.

Applying these criteria to the 1143 papers identified by the initial keyword search required reading all abstracts and, in many instances, full-text screening. Following this process, a total of 125 papers were selected for final inclusion in the review. From here, and based off the different topics and themes emerging from the selected papers, the literature was spilt into the two distinct analytical categories of 'access outcomes' and 'sectoral outcomes'. The 'access outcomes' category included papers with a focus on the economic impact for those who gained access to off-grid solar and was divided into the three subcategories of 'household income and savings', 'employment', and 'firm performance and productivity'. The 'sectoral outcomes' category included papers with a focus on the economic impact of the expanding off-grid solar sector itself and was divided into the two subcategories of 'employment' and 'firm performance and productivity'.

Of the 125 papers, 97 had an analytical focus on access outcomes and 34 on sectoral outcomes (with six papers including a consideration of both). From the five subcategories across both access and sectoral outcomes, 'household income and savings' was the most commonly found, with 81 of the 125 papers focused in whole or in part on this level of analysis. Seventy-one of the 125 studies were academic articles selected from across 30 journals, and 54 were grey literature reports selected from across 26 different organisations (see Appendices C and D for summarised overviews of the academic and grey literature respectively). With an earliest publication date of 2001, only eight of the papers were published between 2001 and 2006, while 83 of the papers were published between 2016 and 2020. A significant proportion of the selected academic papers (56 out of 71) were published in energy and environment journals. Most of the remaining papers came from development studies journals, with a noteworthy absence of papers from economics, political economy, and African studies. Lastly, and as mentioned in Section 1, of the 125 papers, 96 claimed a positive relationship between off-grid solar expansion and economic development, 20 presented mixed empirical results, and nine claimed a neutral or negative relationship.

Two limitations of the study must be noted. First, due to the linguistic bias of the review, non-English-speaking countries hold a marginal position in the reviewed literature. English-speaking countries predominate (India, Bangladesh, Kenya, Tanzania, South Africa, and Ghana all feature heavily) and there are only four papers with an exclusive focus on countries from Latin America, compared to 57 with an Africa focus and 32 focused on Asia. Second, country-level research to identify literature produced by national journals and organisations was not undertaken, due to the limitations of time and resources. Consequently, relevant publications by these outlets have regrettably been missed.

The following two sections now turn towards a description and critical discussion of the overall findings, structured in accordance with the analytical categorisation between access and sectoral outcomes described above, and beginning with the access outcomes literature.

4. Findings

4.1. Access outcomes

Energy access is widely considered as a necessary precondition of economic development, offering individuals and households the opportunity to increase their income, and firms and industries the opportunity to increase productivity, profitability, and output [21,23,48–50]. Most of the 125 papers included in this review address access outcomes, with 97 focusing at least in some part on this aspect. In these studies, a significant determinant of the economic impact of expanded access to off-grid solar was the generation capacity of the energy system to which individuals, households, or firms gained access.

Forty-six of the 97 papers were concentrated on either pico-systems or solar home systems (SHSs). Pico-systems consist of a single panel of up to 20 watts of power used to power solar lanterns and to charge small electronic devices, such as mobile phones. SHSs consist of one or more panels, usually installed on household roofs, that can produce up to 300 watts of power, or 900 kW-hours annually [51]. This is sufficient to power laptops, televisions, and LED lights, as well as, in certain models, efficient refrigerators and cooking systems. Only 14 access outcome

studies took the mini- or micro-grid – often used interchangeably in the literature – as the solar unit of analysis. These have a much larger generation capacity of up to 500 kW (up to 1500 times more wattage than the most powerful SHS) and are capable of powering entire rural communities or urban suburbs, and a far larger range of activities that extend beyond the household and into productive and industrial use. The remaining 37 papers included data from both mini-grids and pico-systems or SHSs.

In the three subsections that follow, the first considers the impact of expanded access to off-grid solar energy on individual or household income and savings, the second addresses the impact on job creation, and the third considers the impact on domestic firm performance and productivity.

4.1.1. Household income and savings

Gaining access to off-grid solar energy can increase household income by strengthening existing areas of economic activity or by allowing for new activities to be undertaken. If the provision of off-grid solar is less costly than the form of energy previously being used, it can also increase household savings. Investigating whether and to what extent access to off-grid solar increases household income and/or savings was by far the most popular analytical focus in the reviewed literature, with 81 of the 125 papers addressing this issue either in whole or in part. This included papers with a focus on rural micro-enterprises, or very small businesses that employ less than six people [52]. Of these 81 studies, 47 were peer-reviewed academic studies and 34 were from the grey literature. Forty-one of the papers were regionally focused on Africa, 24 on Asia, two on Latin America, one on Oceania, and 13 were global level studies. Sixty-two of the 80 studies observed a positive impact of off-grid solar expansion on household income and savings, while the remaining 19 papers were more reserved or cautious in their assessment.

Despite their extremely low wattage, pico-systems have been associated with increased levels of household income, including in the Philippines [53] and Ghana [52,54]. Generally, the documented increase is in the region of US$20 to US$40, such as a 66-year-old entrepreneur in Tanzania who recorded an increased monthly income of US $22–44 after she gained access to a single solar panel [55]. There is also widespread evidence that pico-systems increase household savings due to the greater affordability of solar energy compared to kerosene-fuelled lighting [56]. In Kenya, for example, households were found to have increased their monthly savings by 15% due to lower lighting costs once they had transitioned to off-grid solar [57]. Similarly, a case study in Malawi found net savings for households one year after purchasing solar-powered LED lamps to replace the use of kerosene [58]. In Ghana, the estimated savings of switching from kerosene lanterns to solar was US$1–5 per month [52]. The findings on savings were similar for households that had gained access to SHSs and solar mini-grids.

For SHS users, many studies demonstrated that this level of solar energy generation both enhanced existing forms of household income and generated new ones. In the Ivory Coast, Diallo and Moussa [59] found the use of a SHS to lead to a 42% increase in household consumption per capita. In Nepal, SHSs were found to generate additional income for rural women from knitting and sewing [60]. In Bangladesh, access to SHSs was found to increase women's income by US$2 per day [61] and to lead to a small increase in household expenditure [62] and income generation [63]. Similar findings were reported in Rwanda [64] and Kenya [65]. While only several studies focused on the impact of access to off-grid solar mini-grids, the findings here converged with those for pico-systems and SHSs, such as a study from India which found small rural microbusinesses connected to solar mini-grids reporting 12% to 15% increases in their monthly revenue [66].

There were two principal explanations for the positive impact of SHSs or mini-grids on household income. First and most commonly, that they allowed people running small kiosks and micro-enterprises in local areas to extend their working hours using evening lighting [52,55,64,67–72]. According to a fruit and vegetable seller at a local Kenyan market, for example, “I have been able to add two more hours of trading each day thanks to the small LED lighting system that costs just US$20” [72]. Second, that they allowed people to begin offering mobile phone charging services, or to expand their existing charging operations [70,73–76]. A shop owner in Rwanda, for example, was able to increase the overall capacity of his mobile phone charging business after accessing a SHS, generating increased income as a result [77].

While around three quarters of the papers in this subcategory found expanded access to off-grid solar to have a positive economic impact on household income or savings, the remainder caution that such an impact is by no means pre-determined. A survey in Fiji found 91% of respondents reporting that the use of SHSs had not led to any increase in household income [78]. A study of off-grid solar energy in rural communities in India and Nepal concluded “no discernible differences in income levels were found between households with and without electricity access” [79]. Similarly, studies on the impact of expanded access to solar mini-grids in India [50] and Kenya [80] found no systematic evidence for changes in savings, spending, or time spent working.

A recent ethnographic study of Malawi's off-grid solar sector by Samarakoon [81] goes one step further, arguing that the shift in responsibility for electricity provisioning to individual households underlying the market-based approach to SHS expansion hinders economic development and reproduces rather than overcomes pre-existing socio-economic inequities. Part of the problem here, as noted by other studies [63,82,83], is that the financial costs of maintaining and repairing off-grid solar systems are not always guaranteed by the supplying firm, and can surpass what poor rural households can afford. In addition, and especially with pico-systems and SHSs, some studies have noted the output of off-grid solar systems to be limited and unreliable, greatly constraining their potential to drive economic development [84,85].

4.1.2. Employment

Expanded access to off-grid solar can either increase the number of existing employment opportunities in an already established industry or sector, or it can result in new industries or sectors being established in a particular setting. For example, the purchase of a new solar-powered milling plant would generate new employment at the mill. At the close of the 2010s, however, Power for All [86] observed that “to date there is little literature available on the relationship between energy access and job creation in low energy access countries”. Fourteen papers addressing this relationship for off-grid solar were nonetheless identified, of which five were peer-reviewed academic studies [23,53,60,73,76] and nine were from the grey literature [71,74,75,86–91]. Of the six papers focused on pico-systems or SHSs, all six found off-grid solar expansion to have a positive impact on job creation [53,60,71,73,75,90]. Of the eight papers focused on mini-grids or a mix of different solar units and capacities, seven claimed a positive impact [23,74,76,86,88,89,91] while one was more cautious [87].

Defining employment generated by access to off-grid renewable energy as ‘productive use jobs’, Power for All [86] estimated that in 2017–18 there were 470,000 productive use jobs in India, 65,000 in Kenya, and 15,000 in Nigeria. Focusing more specifically on solar, Power for All [74] estimated that globally “pico solar systems support livelihoods of 1.6 million, either through direct employment or through use of pico-systems in business activities”. Both Power for All [74,86] reports note, however, the dearth of quantitative or qualitative studies into the nature of this relationship, noting “given the potential scale of productive use jobs, this is clearly an area for further research” [86].

Indeed, in four of the sixteen papers – a study of SHSs in Nepal [60], a case study of Bangladesh [73], a regional report on Africa [87], and a global study on the relationship between job creation and off-grid lighting [53] – the positive nature of the relationship between expanded access to off-grid solar and job creation is largely or exclusively based on projected outcomes and potential. The most speculative link is made by Mills [53], who forecasts that the displacement of kerosene by off-grid solar expansion in oil-importing countries will

improve countries' balance of payments position, from which the resulting savings can be used to increase employment opportunities.

Some survey data does exist, however, provided by GOGLA, the industry association for off-grid solar energy. In South Asia, 12% of surveyed businesses using SHSs reported having hired new employees since gaining access to solar energy [90]. In West Africa, 24% of surveyed businesses reported taking on additional employees since they began using a SHS [71]. For every 100 SHSs sold, GOGLA [75] claims that an additional four jobs are created in East Africa and an additional 21 jobs are created in West Africa, with most of the new employment concentrated in rural areas and undertaken by women.

These survey findings are supported by the insights generated from local-level case studies in several African countries. In Kenya, the introduction of SHSs was found to have generated new jobs offering mobile phone charging services, and in one rural community the use of a hybrid solar and diesel mini-grid system was found to have created 125 new jobs locally [76]. DFID [89] claimed its off-grid solar funding scheme to support businesses in nine African countries had generated 171 new jobs. In Zambia, USAID [91] claimed the Beyond Grid Fund for Zambia to have generated 1500 new jobs. In Zimbabwe, a beneficiary of a rural irrigation scheme powered by off-grid solar energy noted that the project had enabled some job creation locally [88].

A UNDP [87] paper sounds the only more cautious note among these papers, observing through several African case studies only a limited short-term impact of expanded access to off-grid solar on employment. It does forecast, however, that the process should usher in stronger long-term positive effects in job creation, while noting a wider sample and longer-term study is required to confirm these effects.

4.1.3. Firm performance and productivity

Here, firms are differentiated from the rural micro-enterprises discussed in Subsection 4.1.1 as businesses employing more than six people. While this was usually evident from the context this was not always the case, and on these occasions author judgement was required to delineate between micro-enterprises and firms. Firms across the global South, and especially in Africa, consistently report lack of access to electricity and unreliable quality of supply as one of the most important barriers to productive performance [92]. Consequently, expanded access to off-grid solar energy carries the potential to overcome these obstacles and drive increased productivity and profitability.

Of the 29 papers focused either in whole or in part on this issue, 20 were peer-reviewed academic studies and nine were from the grey literature. Sixteen of the papers had a regional focus on Africa, seven on Asia, two on Latin America, and four took a global perspective. Twenty-two of the 29 studies concluded that expanded access to off-grid solar had a positive impact on firm productivity [23,51,63,69,89,91,93–108] with only seven papers noting more neutral or less unambiguously positive effects [50,65,82,109–112].

Perhaps unsurprisingly given their significantly greater energy generation capacity compared to pico-systems and SHSs, the strongest and most commonplace evidence of the positive impact of off-grid solar on firm income and productivity was through connection to mini-grids. In Zimbabwe [101], Senegal [111], Rwanda [109], Zambia [104] and Bangladesh [93], off-grid solar mini-grids have been reported to increase yields and local agricultural firm productivity. While this has most commonly been achieved by powering water pumps for irrigation, mini-grids have also been observed to have increased firm productivity by facilitating new agro-processing activities such as milling.

Beyond agriculture, off-grid solar mini-grids have been documented to increase firm revenue and productivity in other economic sectors. In a case study of India, mini-grids were found to have enabled firms to engage in higher value-added activities, such as the grinding of spices and the packaging of products [95]. In Peru, Lillo et al. [94] document the increased productivity of a cheese production factory after it gained access to a solar mini-grid. In Africa, Kirubi et al. [107] describe how solar mini-grids in Kenya have enabled Kenyan firms to produce more technologically sophisticated items, resulting in gross revenue increases of up to 70% for tailoring and carpentry firms. Solar Plaza [101] note the introduction of a mini-grid in Entasopia, Kenya to have had a positive impact on firm revenue and productivity locally, including a petrol station, a cinema, an electrical repair shop, and a nightclub. In Tsumkwe, Namibia, a hybrid diesel-solar mini-grid spawned new businesses (especially bars) and led to the expansion of existing ones, such as one firm adding a fuel station and an ATM machine to its existing operations [110].

The evidence base for the positive impact of pico-systems or SHSs on firm productivity is less robust. Gray et al. [102] found solar lanterns in Tanzania to have increased income for several local firms, and a Global Status Report by REN21 [104] found SHSs to have increased firm revenue by allowing, for example, restaurants and shops to install refrigerators. However, in the case of Sri Lanka, Laufer and Schafer [82] found "access to electricity via SHS has not necessarily led to better productivity in agriculture or other productive sectors" due to their limited capacity and frequent functionality issues. This finding was echoed in a global study by 60 Decibels [112], which in addition to the limited capacity of SHSs and technical faults with SHS products also noted the financial burden of repaying the credit used to access a SHS as a further obstacle to its positive impact on firm productivity and growth. Overall, the low capacity of pico-systems and SHSs greatly limits their ability to be deployed for productive use [69].

Yet even when assessing the impact of off-grid solar mini-grids on firm productivity and profitability, Peters and Sievert [109] sound a note of caution in the African context. In the cases of Benin, Burkina Faso, Rwanda, Senegal, and Uganda, they found either very little or modest evidence for positive effects on firm creation and firm development. The reason for this, they argue, is that in rural and remote areas where most non-electrified African households are located, lack of market access is a far greater constraint on increasing non-agricultural firm productivity than access to electricity.

4.2. Sectoral outcomes

This subsection considers the economic impact of the expanding solar sector itself. Hirschman [25] proposed three major types of economic linkages from the commodities sector, which can be usefully transposed here to energy and off-grid solar: fiscal linkages in the form of corporate and other taxes accruing to the state; consumption linkages created by the demand for the output of other sectors stimulated by the expenditure of incomes earned; and production linkages, both backwards through producing inputs and forwards via processing [113]. Hirschman considered production linkages to hold the most economically transformative potential. This in turn contributed to the spawning of a now vast global value chain (GVC)/global production network (GPN) literature, concerned primarily with exploring the institutional and regulatory contexts in which domestic firms in the global South can integrate into and 'upgrade' within GVCs/GPNs to higher value-added activities [114].

The sectoral outcomes of off-grid solar's contribution to economic development remain relatively understudied, with only 34 of the 125 papers reviewed focusing at least in some part on this aspect. Of these 34 studies, only seven were concentrated on either pico-systems or SHSs, while just one had the mini-grid as the solar unit of analysis. The remaining 26 papers included data from across different levels of generation capacity. No studies investigating the strength or otherwise of the fiscal linkages created by the sector were identified. As such, in the two subsections that follow, the first focuses on the direct employment impact (or consumption linkages) while the second looks at the integration of domestic firms within the value chain and the resultant effects on performance and productivity (or production linkages).

4.2.1. Employment

The direct employment potential of off-grid solar lies at five different

points of the value chain: research and development; acquisition, manufacturing, and assembly; sales and distribution; installation and technical maintenance (including removal and recycling); and customer support [115]. Strikingly, of the 16 papers that address the issue of the direct employment generated in domestic Southern economies by expanding off-grid solar sectors, only three are peer-reviewed academic studies [53,116,117]. Of the remaining 13 from the grey literature, most are global level reports (including four by IRENA) and only three provide detailed case study material on African countries (Egypt, Tunisia, Kenya and Nigeria).[1] Taken together, 13 of the 16 papers noted the positive impact off-grid solar expansion is already having and will continue to have on employment in the global South [53,74,86,101,115,116,118–124]. Only three of the 16 papers took a more reserved or critical stance [117,125,126].

A seemingly uncontested finding from this literature is that the shift from fuel-based (kerosene) lighting to off-grid solar is forecast to have a significant net positive impact on direct job creation. Mills [53] estimates the potential creation of two million new jobs globally in the solar-LED lighting market alone, more than offsetting job losses among the estimated 150,000 employed in fuel-based lighting. Focusing on the Economic Community of West African States (ECOWAS), the United Nations Environment Programme [122] similarly projects that increased market penetration of solar lanterns "could create approximately 30 times more jobs…than fuel-based lighting", amounting to an estimated 500,000 new lighting-related jobs across the region.

Turning to the total employment potential of the sector, GOGLA [115] has forecast that by 2022, off-grid solar will have generated "510,000 medium and highly skilled jobs and 800,000 lower skilled roles" globally. Looking further ahead, IRENA [118,124] has estimated that by 2050 the solar industry could support between nine and 19 million jobs globally, with most of these clustered in the off-grid sector. In terms of distribution, IRENA [118] notes that of the 3.6 million people employed by the solar industry worldwide in 2018, nearly three million were in Asia (mostly China), and only 140,400 (or 3.9%) in Africa.

Employment in African off-grid solar is, however, projected to have significant scope for future growth, as might be expected given the sector's rapid expansion across the continent. In 2017–18, Power for All [74] documented 10,000 and 4000 direct formal jobs in Kenya and Nigeria's off-grid solar sectors respectively, and forecast that by 2022–23 these figures will have grown to 17,000 in Kenya and 52,000 in Nigeria. Similarly, while meetMED [120] found relatively modest direct employment in Tunisia and Egypt's solar sectors of 580 jobs in 2017 and 796 jobs in 2018 respectively (with approximately 90% of these concentrated in off-grid), they forecast that in the case of Tunisia this would increase more than 24-fold to 14,200 jobs by 2025 (no forecast for Egypt was provided). Solar Plaza [101] drew on case studies from Uganda, Kenya, and the Democratic Republic of the Congo (DRC) to document the energy jobs created by off-grid solar projects, including a forecasted 10,000 local energy jobs to be created through the British firm Bboxx's operations in the DRC alone.

The above papers underline the positive economic impact of the expanding off-grid solar sector on current and projected job creation in the global South. Yet as with the employment subcategory from the access outcomes literature, they have little to say beyond counting or projecting the number of generated jobs. Picking up on this research gap, World Resources Institute [125] looked more closely at the quality of jobs in India's renewable energy sector, finding the majority offer neither benefits nor job stability, and that the absence of wage data makes it difficult to establish whether and to what extent renewable energy jobs in India are contributing to poverty reduction. In a similar vein, Stock [117] has recently argued that beneath the formal economy of solar lies a hidden economy of marginalised workers whose labour is "defined by its informality, flexibility, precarity, and disposability". These two papers raise concerns, then, as to whether off-grid solar employment in the global South will provide sufficient stability, remuneration, and benefits to stimulate broader based processes of economic development via consumption linkages.

4.2.2. *Firm performance and productivity*

Another major contribution off-grid solar can make to economic development is through the opportunities the sector offers for domestic firms to integrate into and develop technological and productive capabilities within the solar value chain. Developing national capacity in the design, assembly, or manufacture of solar components, for example, will ensure greater domestic capture of the economic value generated by the sector that would otherwise accrue elsewhere (including the associated volume of skilled labour), and potentially create production linkages with and support the emergence of other sectors and industries.

Among the 24 papers addressing this topic, 10 were focused on Africa, five on Asia, and nine took a global perspective. Of the ten Africa-focused papers, eight found either some evidence of African firms already engaged in productive activity in off-grid solar, or cause for optimism based on the potential for future growth in this direction [76,97,123,127–131]. The remaining two were more circumspect, pointing to some successes but noting related challenges and limitations [132,133]. From the 14 global or Asia-focused papers, 11 papers either forecast or empirically demonstrated positive effects [53,118,119,124,134–139] while three papers were more cautious in their interpretation of progress or the potential for progress [126,140,141].

Most evidence on the successful development of a domestically embedded and led off-grid solar sector comes from East Asia [136], in particular China, which today accounts for around two-thirds of worldwide solar module production. China was a late entrant to this market, where the early industrialisers had been the US, Europe, and Japan [141]. Several papers highlight the central role played by the Chinese state in nurturing the late development of its domestic solar sector through the provision of large subsidies and other benefits to Chinese manufacturing firms, initially prioritising increased export capacity ahead of provision to the domestic market [135,136,139,141].

Similarly, in the case of Bangladesh, Heinemann et al. [137] note how beginning in 2003, the Bangladeshi state drew on a wide range of industrial policy measures to develop value-added productive capacity in what was at the time a non-existent domestic SHS industry. By 2015, 31,750 jobs had been created in the country's solar manufacturing sector, spread across nine assembly plants and around 150 domestic firms. Over the last two decades, Bangladesh has distributed more than four million SHSs in-country. Joshi et al. [138] document a comparable story in India, albeit on a much smaller scale, of a state-led rural livelihood development programme in Rajasthan that supported women self-help groups to move from the assembly of solar lamps to owning and operating a solar panel manufacturing firm and factory which, as of March 2018, had produced and distributed 25,000 panels.

Country case studies such as these demonstrate the potential for state intervention via strategic and targeted industrial policy to, in the words of Behuria [141], "wrest control of manufacturing capabilities in the renewable sector away from early industrializers". Yet they are focused on now established Asian latecomers, which raises the question to what extent is this pathway still open and replicable for today's late latecomers, seeking to compete with established solar sectors not only in the global North but also now in many Asian economies?

Three recent reports by IRENA [118,119,124] address this question and conclude with some optimism, arguing that even for late latecomers, there remain opportunities for domestic value creation "at each segment of the value chain" [124]. Exploring this issue more specifically in the African context, in 2016 the United Nations Economic Commission for Africa (UNECA) published two reports that provide case study evidence from Uganda and South Africa detailing how the respective

[1] While IRENA publishes an annual *Renewable Energy and Jobs* report, only the 2018 report is included here to avoid repetition.

governments made strategic use of selective and targeted industrial policies to successfully promote domestic private sector involvement in the solar sector [97,129]. One particularly notable finding was that many African firms active in the energy sector started out as local construction companies, and consequently UNECA [129] recommend strengthening African firms' ability to compete for and implement construction projects as "one of the most important ways in which local firms can be helped to play more substantial roles in the energy sector".

Commenting on the scale of solar productive capacity in Africa, Mills [53] notes that approximately 10% of global solar-LED lantern firms manufacture their products on the continent and documents local-level examples of domestic lantern manufacture in Liberia and Kenya. Two papers delve deeper into the successful emergence of Kenya's solar industry – with a particular focus on SHSs – documenting the extensive presence of domestic firms active across many different segments of the solar value chain, although with differing perspectives as to how this was achieved. While Ondraczek [128] contends the process was driven by consumer demand and emerged "largely without government intervention", Byrne et al. [131] characterize the Kenyan state as developmentalist, or interventionist, in its interaction with and guidance of its solar sector. Looking outside of Kenya, UNIDO [133] concludes that in Chad, The Gambia, Guinea-Bissau, the Ivory Coast, and Zambia, 'sufficient' or 'good' progress has been made in the development of domestic capacity in the design, manufacture, assembly, operation, and maintenance of off-grid solar projects.

Some of the papers strike a more sombre tone on the potential for late latecomers to usher in vibrant domestically anchored off-grid solar sectors. An OECD [140] report has argued that if not carefully designed and tailored to local context, local solar content requirements "can have mixed or negative impacts on local job creation, value added and technology transfer", by raising the costs of inputs for downstream businesses. Bond et al. [134] and Sovacool and d'Agostino [135] likewise draw attention to the failures that can follow if policy is not effectively tailored and designed to suit specific local and national contexts, using the cases of East Timor and Papua New Guinea respectively to illustrate their arguments.

Taking this one step further, Baker and Sovacool [132] note the difficulty of developing domestic technological and manufacturing capabilities in South Africa's wind and solar photovoltaic sectors given the strength of global competition and the strategies adopted by foreign firms to circumvent and undermine local content policy, designed to improve the local procurement of goods, inputs, and services. These findings converge with Behuria's [141] analysis of the challenges to designing and implementing effective state policy to develop manufacturing capacity in India's solar sector, with both papers also pointing to the tension between seeking to deliver low-cost energy access while simultaneously wanting to develop local technological and manufacturing capacity which, initially at least, comes at a cost. Lastly, van der Vleuten et al. [127] draw on examples from Morocco, Kenya, and Zimbabwe to argue that in the absence of an emphasis on and engagement with how to support and promote indigenous local entrepreneurs already active in off-grid solar, donor models for expanding access risk stifling and marginalising this group in favour of the arrival of a foreign managerial class. Taken together, these papers sound an important cautionary note against a belief that state policy or donor models will always and everywhere deliver positive outcomes.

5. Discussion

5.1. Access outcomes

As mentioned in Section 3, most of the literature assessing the economic effects of expanded access to off-grid solar in the global South is focused on how this expansion interacts with household income and savings. Most of these studies, in turn, have found the relationship to be positive, leading to increased household income and savings. Similarly, at the level of the firm, most studies have linked access to off-grid solar with increased firm activity, productivity, and income, especially when firms gain access to a mini-grid system.

Yet the tendency of the literature to conceptualise economic development as increased income or productivity achieved by people working longer casts doubt over whether and to what extent these documented increases will be sustained or strengthened over time. This conceptualisation was present, for example, in both the household literature [55,64,67,68,70–72,116,142–145] and the less populous firm-level literature [69,94]. Most usually in these studies, the claim of increased income or productivity was based on local stalls, kiosks, and firms staying open and operating beyond nightfall.

While celebrated in the literature as a marker of progress and a newfound source of freedom, it could also be argued this development represents the more ambiguous outcome of workers' heightened capacity for self-exploitation. Putting this to one side, these observed increases represent one-off gains that cannot be repeated, given the physical limit to how many hours people can work in a single day. For this impact to be sustained and strengthened over time, and to return to the conceptualisation of economic development foregrounded in Section 2, it would need to form part of a broader process achieved via increasing output per unit of labour time and sustained by the accumulation of capital. The cases documented might have involved either or both of these elements, but existing studies have tended not to focus on these dimensions, leaving the economically transformative nature of the observed impact unclear.

Moreover, rather than ascribing positive, negative, or neutral outcomes solely to expanded energy access, as commonly seen in the literature, the extent to which these effects are the result of the broader institutional political economy within which expanded access is embedded is deserving of greater attention. Is increased rural household income, for example, due solely to access to off-grid solar energy, or that expanded energy access was conjoined with government policy supporting small-scale agriculture through the provision of subsidies and inputs such as fertiliser? Existing studies generally fail to consider such dynamics, prescribing the observed outcome to the act of energy provision or expansion alone.

Lastly, two related issues carry the potential to undermine any income gains achieved in the short-term. First, several access outcomes studies noted that energy firms do not always assume the maintenance of off-grid solar systems and the cost of this maintenance can often surpass what rural households or communities can afford. This speaks to a tension within the market-led delivery model driving expanded access to off-grid solar. As energy provision shifts away from a centralised, state-led public good to a decentralized and privatised for-profit model, who will assume the financial burden of maintenance and repair, and at what cost?

Several grey literature reports from the techno-optimist access literature, discussed in Section 1, celebrate this shift as a welcome transition from a costly and inefficient state-led system to an affordable and efficient privatised alternative. Power for All [146], for example, argue this will enable "individuals to control their own power supply and cost. Essentially, democratized energy". Similarly, IRENA's [147] Africa 2030 roadmap report argues "The fact that renewable-energy technologies can be widely distributed is a source of autonomy for local areas and villages. They can increasingly plan for and meet their energy needs on their own, as localisation gives isolated communities a chance to participate in the process". Yet might the supposed and celebrated 'source of autonomy' not just as easily become a source of financial burden that undermines both the energy efficiency and generation capacity of the system as well as its economic effects? Most of the studies covered in this review focused on the short-term impact of expanded access to off-grid solar on income, savings, and productivity, usually within one or two years of a household or firm gaining access. Yet short-term income gains might be undone over the medium- or longer-term if a household or community is unable to adequately

maintain the system over time. This issue remains underexplored in the existing literature.

Second, several access outcomes studies noted the recent development of the pay-as-you-go (PAYG) model to deliver solar energy products to income-poor rural households unable to afford the full upfront cost [64,77,148,149], generally welcoming and celebrating this development as a "crucial engine" for economic development [77]. A study by the Consultative Group to Assist the Poor (CGAP) found that 30% to 50% of PAYG solar customers were new to mobile money and had opened a mobile account to purchase an off-grid solar energy product [150]. This indicates that the PAYG delivery of off-grid solar looks set to simultaneously incorporate tens of millions of households in the coming decades into the process of what the World Bank and other mainstream development agencies label 'financial inclusion'. Indeed, GSMA [151] has already documented how PAYG solar firms are increasingly marketing a range of other products and assets to their clients, while ODI [148] has noted the potential for PAYG solar firms to generate profits by selling their energy data to electronics firms.

For many orthodox economists and institutions, financial technology (or fin-tech) such as PAYG is seen as a key tool to facilitate poverty reduction and stimulate economic development. Critical heterodox and political economy studies from the global South have countered, however, that fin-tech is associated with rising over-indebtedness and other issues that constrain rather than liberate fin-tech users, while serving to enrich fin-tech firms and shareholders. As Bateman et al. [152] concluded, based on a detailed case study of M-Pesa in Kenya:

> fin-tech is very clearly designed to hoover up value and deposit it into the hands of a narrow global digital-financial elite that are the main forces behind the fin-tech revolution. Of course, this enormous wealth could be redirected towards Kenya's poor population and reinvested locally, for example through community-owned financial institutions and financial cooperatives, but there would appear to be little time, sympathy, or political support for building such pro-poor institutions when so much wealth can be appropriated by so few so quickly in another way.

Through the development of a PAYG delivery model to increase the market for its products, the off-grid solar sector has now become a part of this fin-tech industry. The implications of this recent development for individuals and households seeking pathways out of poverty, and the fin-tech policies needed to ensure these efforts are supported, are yet to be fully explored.

Lastly, in the realm of employment, there is to date very little research investigating this issue beyond either projected potential or a quantitative documentation of the number of new jobs generated by expanded access in a particular localised context. A central question of concern for understanding the transformative impact of any new jobs generated by off-grid solar expansion would be how does remuneration compare with available employment opportunities in the surrounding economy? On this and other issues relating to the conditions under which any newly generated labour functions, remarkably little is known.

Here, the concept of 'labour regimes' from agrarian political economy might be usefully applied:

> …labour regime analysis is a useful tool for analysing agrarian structures and comparing them across space and time, and identifying points and processes of contestation, conflict, and negotiation. Henry Bernstein's definition – 'specific methods of mobilizing labour and organizing it in production, and their particular social, economic, and political conditions' (Bernstein 1988, 31–2) – emphasizes that the emergence of specific labour regimes is not inevitable but the product of politics [153].

The analytical attention to the social, economic, and political conditions underlying the mobilisation and organisation of labour emphasizes the emergence of labour regimes as a product of the institutional structures that surround them, but also the conflict and contradiction that defines them, and the agency and power of workers to resist and transform their conditions. Such insight would greatly sharpen our understanding of the labour regimes emerging around off-grid solar across the global South today, and the intersection between these emergent regimes and economic development.

5.2. Sectoral outcomes

Reflecting on the existing state of knowledge concerning the impact of the expanding off-grid solar sector itself on economic development in the global South, or the 'sectoral outcomes' papers, perhaps the most striking observation is how relatively little we know beyond a select handful of countries. The potential impact is well established, through both the projected global growth in off-grid solar employment in the coming decade and beyond [115,124], as well as through detailed reports analysing where and how domestic technological capabilities and productive capacity can be leveraged across the different components and stages of the solar value chain [118]. Yet the realisation of this potential in the global South remains understudied, outside of East Asia.

In relation to employment, the critiques of World Resources Institute [125] and Stock [117] converge with a broader body of scholarship drawing attention to the 'adverse incorporation' of global South workers labouring at the bottom of global value chains, including issues of expanded labour informality and low wages [154–156]. This latter issue of low wages is of particular relevance as, relating back to Hirschman's consumption linkages, for employment to support sustained gains in economic development, it must be sufficiently remunerated to the extent that wage expenditure drives demand for output in other sectors. Which groups of solar labour capture what levels of income, how large are these groups, and what do they do with the wages accruing to them? These questions are critical to an understanding of the economic significance of any generated employment, yet on which we appear to know little. Again, as with the access outcomes literature, the concept of labour regimes from agrarian political economy might be usefully deployed here.

On firm productivity, a common theme emerging from this literature is the central role played by the state in nurturing the emergence and development of domestic solar sectors in late or late market entrants. Yet the literature is also clear that state interventions – such as the use of tariffs, subsidies, and production targets – involve trade-offs and a certain degree of risk, and thus it is critical that each industrial strategy and policy is carefully designed and tailored to suit and respond to local and national context.

While there is some empirical evidence to suggest off-grid solar production linkages with domestic economies are being forged by late latecomers, in particular from Kenya and South Africa, this evidence raises two associated questions. First, much existing evidence in this direction is clustered around the lower value-added segments of the solar value chain, and in particular productive activity related to the manufacture and distribution of solar lanterns or certain SHS components. The extent to which this is serving as a springboard for domestic firms and entrepreneurs to move into higher value-added activities within or outside of the chain is little documented, although Baker and Sovacool's (2017) study of solar in South Africa highlights the challenges of moving in this direction, casting some doubt on whether other late latecomers can successfully position themselves to do so.

Second, available findings focus heavily on the assembly or manufacture of solar panels and cells but speak less to the production linkages between off-grid solar and other domestic sectors and industries. By way of example, IRENA [118] notes glass (produced using, among other commodities, limestone, and sand) and concrete (made using cement) as two of the three largest material inputs required in the production of a 1 MW solar photovoltaic plant (the third being steel), comprising 33% and 22% of the total material tonnage respectively. Yet to what extent these material inputs are being procured domestically or regionally in the

global South is largely unexplored by the existing literature.

On the whole, the literature on domestic firms tends to assume and present the foreign firm as a benevolent presence. Yet as discussed in Section 2, the dominance of foreign firms in key sectors and industries can lead to the marginalisation of domestic firms and capitalists, the erosion of the local entrepreneurial class, and the overseas capture of the anticipated economic benefits. The generally uncritical presentation of foreign firm arrival in rapidly growing off-grid solar energy sectors fails to account, then, for the multiple ways in which the ongoing shift from state-led to foreign corporate-led energy sectors in the global South might undermine or disrupt local and national processes of economic development, rather than promote them.

In closing, it is worth revisiting the absence of any in-depth study into the fiscal linkages between off-grid solar and global South governments. Late industrialisation is by its nature a heavily import-dependent and capital-intensive process [157], placing severe pressure on low- and middle-income country balance of payments positions and revenue. Given this, understanding whether and to what extent off-grid solar is making a net contribution to government revenue – via for example corporate and income tax – or whether it is imposing a net drain – via for example the receipt of subsidies, tax holidays, and exonerations – is of critical importance to a holistic appreciation of the sector's contribution to economic development. Currently, little is known on this issue.

6. Conclusion

This review has sought to understand how the expansion of off-grid solar energy in the global South is influencing local and national processes of economic development. At first glance, the literature would appear to provide strong support to a belief in off-grid solar's economic potential, with only 7% of the studies claiming a neutral or negative relationship between off-grid solar expansion and economic development. In the literature, off-grid solar expansion is repeatedly shown to have increased household income and savings, generated new employment, and improved firm productivity. Based on these findings, the techno-optimist access literature helping to facilitate the rapid expansion of off-grid solar would appear well justified in its oft-asserted claim that this process will reduce poverty and drive economic development.

Many of the households and firms that have gained access to off-grid solar report increased income. For households, this is aided by savings from the greater affordability of solar energy compared to kerosene-fuelled lighting. For both households and firms, a significant driver of increased income was the ability to work longer. Indeed, given that 81 of the 125 papers, around two-thirds, were focused on the impact on household income and savings, the one-off gain of people working longer formed the empirical foundation for much of the literature claiming a positive relationship. Whether or not this outcome is taking place alongside a more dynamic measurement of labour productivity as output per unit of labour and sustained by capital accumulation was rarely addressed. The extent to which this one-off gain is sustained and strengthened over time, then, provides a fruitful avenue for future research.

The review identified two further under-researched areas of relevance to understanding how expanded access to off-grid solar in the global South interacts with local processes of economic development. First, several studies noted that energy firms do not always assume responsibility for the maintenance and repair of the off-grid solar systems they distribute. Who assumes the maintenance and repair of off-grid solar systems – between firms, governments, and end-users – and with what effects, merits further attention. Second, several studies have documented – and for the most part celebrated – the development of the PAYG fin-tech model to expand the market for off-grid solar energy products to low-income households. How this recent development will evolve and what policies are required to ensure fin-tech supports rather than undermines economic development provides another valuable and currently unexploited direction for future research.

In the sphere of employment, both survey and case-study evidence indicate that expanded access to off-grid solar stimulates the creation of new jobs, with most of these concentrated in rural areas. For those working in the solar industry itself, the few existing studies are heavily based on quantitative appraisals and projections. Additional empirical detail, such as on wage levels and expenditure patterns, would help better understand how any documented employment increase interacts with and influences sustained processes of economic development. The two sectoral outcomes studies to consider these broader dynamics both contend solar labour in the global South to be characterised by informality, flexibility, and precarity [117,125]. This highlights the critical need for future research to go beyond job-counting exercises, useful and informative as these are, to qualitatively interrogate the underlying labour conditions and better understand the differentiated lived experiences of workers.

Concerning the position of domestic firms and entrepreneurs in off-grid solar value chains, several studies have documented the successful development of domestically embedded off-grid solar sectors in latecomer East Asian countries, most notably China and Bangladesh. In addition, further studies have demonstrated that late latecomers outside of the global North and East Asia have more recently enjoyed some early success in integrating domestic actors into the low value-added end of the chain, such as in installation and the manufacture of solar lanterns and SHS components. Looking forward, there is scope for future research to investigate whether and how late latecomer countries and regions are using this entry point to support economic diversification and the development of technological and high-value productive capabilities domestically.

Related to this last point, there is little to no research on the production linkages between off-grid solar and other domestic sectors and industries. Future research focused on to what extent the material inputs required to manufacture off-grid solar systems are being procured domestically or regionally would provide fresh insights into the economically transformative effects of expanding off-grid solar sectors. To draw once again on a concept from the commodities literature, whether and to what extent off-grid solar functions as an enclaved economy – "one which has little articulation with local and national economies, and [in which] the benefits accrue largely to the foreign countries and transnational corporations providing the industrial technology and capital" [41] – remains an open question seemingly ripe for future lines of investigation. Similarly, no studies examining the fiscal impact of this expansion were identified, highlighting a final valuable direction for future research in this area.

More generally, future research would benefit from a deeper appreciation that any observed economic impact is likely to result as much from the institutional political economy within which expanded access takes place, as from the process of expanded access itself. Here, particular attention ought to be given to the role played by governments and state bureaucracies in supporting and nurturing (or not) local and national processes of economic development. Comparative country case studies might prove useful, in ascertaining what level and range of targeted interventions and policies are most effective in harnessing off-grid solar expansion as a tool for driving sustained processes of economic development.

Future research would also be enriched by adopting a more critical position in relation to the foreign energy firm, and in particular the ways in which its en masse arrival might undermine or disrupt local and national processes of economic development, as much as it might serve to promote them. At present, the image of the benevolent foreign firm stands at odds with what we know about its often-deleterious effects, which alongside the potential benefits such as employment and technology transfer, can also lead to the marginalisation or exclusion of domestic firms and capitalists – critical groups in the process of late industrialisation – while syphoning much of the value generated overseas.

Lastly, greater attention to the contested, contingent, and uneven nature of economic development would enhance future research in this area, by providing a more rounded and realist appraisal of any observed impact. Very often, the off-grid solar literature on the global South presents a linear, smooth, and friction-free assessment. Household savings and income are increasing, rural micro-enterprises are expanding, new jobs are being created (or could be), and firms are developing manufacturing capabilities (or could do). Left out of these assessments is a consideration of the uneven and contradictory nature of the observed process. While the existing literature is adept at identifying households and firms who appear to have benefited from access to off-grid solar through increased income, savings, or productivity, it is less well attuned to the processes of polarisation, marginalisation, and exclusion likely to be associated with this growth. If, to return to Furtado, development is a process of reshaping social relations founded on accumulation, how social relations are being reshaped by off-grid solar expansion, and with what effects, is deserving of more attention.

Governments, multilateral institutions, and development finance are increasingly aligning behind a market-led model of expanding access to off-grid solar, underpinned by a belief that this expansion will not only reduce energy poverty but can also reduce income poverty and drive economic development in some of the world's poorest regions and communities. There is, in turn, a growing literature interrogating the nature of the relationship between expanded off-grid solar access and economic development in the global South, which to date has provided much evidence and understanding on the topic. It is hoped that the suggested paths for future research outlined here might help build on the rich insights generated to date, to further deepen and develop our understanding of to what extent, how, and where off-grid solar expansion is promoting (or undermining) transformative and emancipatory processes of economic development in the global South.

Declaration of competing interest

There is no potential conflict of interest to report.

Acknowledgements

The authors would like to thank the three anonymous peer reviewers as well as ER&SS Editor-in-Chief Benjamin Sovacool for their helpful comments and additions to this manuscript. Research for this article was funded by the Research Infrastructure and Investment Funds (RIIF) of the London School of Economics and Political Science, Department of International Development (LSE ID). The authors gratefully acknowledge LSE ID's support. An earlier version of the paper was presented at the Sussex Energy Group seminar series, in March 2021. Thank you to everyone who attended the seminar and provided thoughtful comments.

Funding details

Research for this article was funded by the Research Infrastructure and Investment Funds (RIIF) of the London School of Economics and Political Science, Department of International Development (LSE ID).

Appendix A. Reviewed academic journals

Energy & Environment (24): Applied Energy; Economics of Energy & Environmental Policy; Energy & Environment; Energy Journal; Energy Policy; Energy Procedia; Energy Research and Social Sciences; Energy for Sustainable Development; Environmental Progress & Sustainable Energy; Energy, Sustainability and Society; Environment, Development and Sustainability; Renewable Energy; Environment and Planning A; Global Environmental Change; Green Energy & Environment; International Journal of Energy Sector Management; Journal of Cleaner Production; Journal of Environment & Development; Renewable and Sustainable Energy Reviews; Resource and Energy Economics; Sustainable Cities and Society; Sustainable Production and Consumption; Sustainability; Sustainability Science.

Development Studies (19): Antipode; Canadian Journal of Development Studies; Development; Development and Change; Development in Practice; Development Policy Review; Geoforum; European Journal of Development Research; Journal of Agrarian Change; Journal of Development Studies; Journal of Economic Geography; Journal of International Development; Journal of Peasant Studies; Journal of Rural Studies; Oxford Development Studies; Progress in Development Studies; Progress in Human Geography; Third World Quarterly; World Development.

African Studies (12): Africa; African Affairs; Africa Development; African Review of Economics and Finance; African Studies Quarterly; African Studies Review; Journal of African Economies; Journal of Contemporary African Studies; Journal of Eastern African Studies; Journal of Modern African Studies; Journal of Southern African Studies; Review of African Political Economy.

Heterodox Economics and Political Economy (10): Cambridge Journal of Economics; Competition & Change; Global Production Networks; International Review of Applied Economics; New Left Review; New Political Economy; Review of Black Political Economy; Review of International Political Economy; Review of Political Economy; Review of Radical Political Economics.

Orthodox Economics (7): Econometrica; Journal of Economic Growth; Journal of Economic Literature; Journal of Financial Economics; Journal of Political Economy; The American Economic Review; The Quarterly Journal of Economics.

Appendix B. Reviewed grey literature

Development Agencies (20): 60 Decibels; Center for Global Development; CDC Group; Climate Action Network; Efficiency for Access; German Agency for International Cooperation (GIZ); Green Growth Knowledge Platform; Global Green Growth Institute; Overseas Development Institute; Oxfam; Power for All; Practical Action Consulting; REN21; Rockefeller Foundation; Solar Plaza; Sustainable Energy for All; World Resources Institute; UK Foreign, Commonwealth and Development Office (formerly UK Department for International Development); United States Agency for International Development; World Resources Institute.

Multilateral Institutions (11): International Energy Agency; International Labour Organisation; International Renewable Energy Agency; Mitigation Enabling Energy Transition in the Mediterranean region (meetMED); Organisation for Economic Co-operation and Development; Regional Center for Renewable Energy and Energy Efficiency (RCREEE); United Nations Conference on Trade and Development; United Nations Development Program; United Nations Environment Programme; United Nations Industrial Development Organization; World Bank.

Industry Associations (5): Africa Solar Industry Association, GOGLA (Global Association for the Off-grid Solar Energy Industry); Groupe Speciale Mobile Association (GSMA); Renewable Energy Solutions for Africa Foundation; Solar Energy Industries Association.

African Institutions (4): African Development Bank; African Union Infrastructure and Energy Commission; The Economic Community of West African States Centre for Renewable Energy and Energy Efficiency; United Nations Economic Commission for Africa.

Appendix C. Description of peer-reviewed papers

Reference article	Year	Journal	Academic Area	Analytical Focus	Solar Unit	Geographic Focus	Positive Impact?
Adkins et al.	2010	Energy Policy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Malawi)	Yes
Adwek et al.	2020	Environment, Development and Sustainability	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Kenya)	Yes
Agostini et al.	2016	Journal of Environment and Development	Energy & Env.	Access (income & savings)	Mix	Latin America (Chile)	Yes
Aklin et al.	2017	Science Advances	Economics	Access (income & savings, firms)	Mini−/Micro-	Asia (India)	No
Amadou et al.	2019	Journal of African Economies	Africa/Economics	Access (income & savings)	Pico/SHS	Africa	Yes
Azimoh et al.	2015	Applied Energy	Energy & Env.	Access (income & savings, firms)	Pico/SHS	Africa (South Africa)	Yes
Azimoh et al.	2016	Energy Conversion and Management	Energy & Env.	Access (income & savings)	Mix	Africa (South Africa)	Yes
Azimoh et al.	2017	Renewable Energy	Energy & Env.	Access (firms)	Mini−/Micro-	Africa (Namibia)	Mixed
Baker and Sovacool	2017	Political Geography	Development	Sectoral (firms)	Mix	Africa (South Africa)	Mixed
Baurzhan and Jenkins	2016	Renewable and Sustainable Energy Reviews	Energy & Env.	Access (income & savings)	Pico/SHS	Africa	Mixed
Behuria	2020	World Development	Development	Sectoral (firms)	Mix	Asia (India)	No
Bhattacharyya and Palit	2016	Energy Policy	Energy & Env.	Access (firms)	Mini−/Micro-	Global	Yes
Bisaga et al.	2017	Energy Policy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Kenya, Rwanda)	Yes
Bisaga et al.	2020	Energy Policy	Energy & Env.	Access (income & savings)	Mix	Africa (Rwanda)	Yes
Boliko and Ialnazov	2019	Energy Policy	Energy & Env.	Access (income & savings, jobs)	Mix	Africa (Kenya)	Yes
Bond et al.	2007	Energy Policy	Energy & Env.	Sectoral (firms)	Pico/SHS	Asia (East Timor)	Yes
Brunet et al.	2018	Renewable and Sustainable Energy Reviews	Energy & Env.	Access (income & savings, jobs, firms)	Mix	Africa	Yes
Byrne et al.	2018	Energy Research and Social Science	Energy & Env.	Sectoral (firms)	Mix	Africa (Kenya)	Yes
Chakrabarty and Islam	2011	Energy	Energy & Env.	Access (income & savings, jobs)	Pico/SHS	Asia (Bangladesh)	Yes
Charles et al.	2019	Energy	Energy & Env.	Sectoral (firms)	Pico/SHS	Africa (South Africa)	Yes
Dauenhauer et al.	2020	Energy, Sustainability and Society	Energy & Env.	Access (income & savings)	Mix	Africa (Malawi)	Yes
Diallo and Moussa	2020	Energy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Ivory Coast)	Yes
Ellegård et al.	2004	Renewable Energy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Zambia)	Yes
Feron et al.	2016	Energy, Sustainability and Society	Energy & Env.	Access (firms)	Mix	Latin America (Chile)	Yes
Geall et al.	2018	Energy Research and Social Science	Energy & Env.	Access (income & savings)	Mix	Asia (China)	Mixed
Gollwitzer et al.	2018	Energy Research and Social Science	Energy & Env.	Access (firms)	Mini−/Micro-	Africa (Kenya)	Yes
Gray et al.	2019	Development in Practice	Development	Access (income & savings, firms)	Pico/SHS	Africa (Tanzania)	Yes
Hayashi	2020	Energy Research and Social Science	Energy & Env.	Sectoral (firms)	Mix	Asia (China)	Yes
Heinemann et al.	2019	WIT Transactions on Ecology and the Environment	Energy & Env.	Sectoral (firms)	Pico/SHS	Asia (Bangladesh)	Yes
Ibrik	2019	Cogent Engineering	Energy & Env.	Access (income & savings)	Mini−/Micro-	Asia (Palestine)	Yes
Jacobson	2007	World Development	Development	Access (income & savings, firms)	Mix	Africa (Kenya)	Mixed
Joshi et al.	2019	World Development	Development	Sectoral (firms)	Mix	Asia (India)	Yes
Karekezi and Kithyoma	2002	Energy Policy	Energy & Env.	Access (firms)	Mix	Africa	Yes
Katre et al.	2019	Energy, Sustainability and Society	Energy & Env.	Access (income & savings, firms)	Mini−/Micro-	Asia (India)	Yes
Kattumuri and Kruse	2017	Climate and Development	Energy & Env.	Access (income & savings), Sectoral (jobs)	Mix	Asia (India)	Yes
Kirubi et al.	2009	World Development	Development	Access (income & savings, firms)	Mini−/Micro-	Africa (Kenya)	Yes
Laufer and Schafer	2011	Energy for Sustainable Development	Energy & Env.	Access (income & savings, firms)	Pico/SHS	Asia (Sri Lanka)	No
Lemaire	2011	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (South Africa)	Mixed
Lemaire	2018	Energy and Environment	Energy & Env.	Access (income & savings)	Pico/SHS	Global	Yes
Lillo et al.	2015	Energy for Sustainable Development	Energy & Env.	Access (firms)	Mix	Latin America (Peru)	Yes
Mandelli et al.	2016	Renewable and Sustainable Energy Reviews	Energy & Env.	Access (income & savings)	Mix	Global	Yes
Mills	2016	Energy for Sustainable Development	Energy & Env.	Access (jobs), Sectoral (jobs, firms)	Pico/SHS	Global	Yes
Mishra and Behera	2016	Renewable and Sustainable Energy Reviews	Energy & Env.	Access (income & savings)	Pico/SHS	Asia (India)	Yes
Mondal and Klein	2011	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Pico/SHS	Asia (Bangladesh)	Yes
Monyei et al.	2018	Energy Research and Social Science	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (South Africa)	No
Narula and Bhattacharyya	2017	Journal of Cleaner Production	Energy & Env.	Access (firms)	Mini−/Micro-	Asia (India)	Yes

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Reference article	Year	Journal	Academic Area	Analytical Focus	Solar Unit	Geographic Focus	Positive Impact?
Niethammer and Alstone	2012	Gender and Development	Development	Access (firms)	Pico/SHS	Africa (Ethiopia, Ghana, Kenya)	Yes
Obeng and Evers	2010	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Ghana)	Yes
Obeng et al.	2008	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Mix	Africa (Ghana)	Yes
Ondraczek	2013	Energy Policy	Energy & Env.	Sectoral (firms)	Mix	Africa (Tanzania, Kenya)	Yes
Peters and Sievert	2015	Revue d'économie du développement	Development	Access (income & savings, firms)	Mix	Africa	Mixed
Pueyo and DeMartino	2018	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Mini−/Micro-	Africa (Kenya)	No
Radulovic	2005	Energy Policy	Energy & Env.	Access (firms)	Mini−/Micro-	Asia (India)	Yes
Rahman and Ahmad	2013	Energy Policy	Energy & Env.	Access (income & savings)	Pico/SHS	Asia (Bangladesh)	No
Rai	2004	Energy for Sustainable Development	Energy & Env.	Access (income & savings, jobs)	Pico/SHS	Asia (Nepal)	Yes
Rastogi	2018	South Asian Journal of Business	Economics	Access (income & savings)	Pico/SHS	Africa (Kenya)	Yes
Roche and Blanchard	2018	Renewable Energy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Kenya)	Yes
Saing	2018	Oxford Development Studies	Development	Access (income & savings)	Mix	Asia (Cambodia)	Yes
Samarakoon	2020	Energy Research and Social Science	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Malawi)	No
Sarker et al.	2020	Energies	Energy & Env.	Access (income & savings, firms)	Pico/SHS	Asia (Bangladesh)	Yes
Scott	2017	Renewable and Sustainable Energy Reviews	Energy & Env.	Sectoral (firms)	Mix	Global	Yes
Sovacool and D'Agostino	2012	Progress in Development Studies	Development	Sectoral (firms)	Pico/SHS	Asia & Oceania	Yes
Stock	2020	Antipode	Development	Sectoral (jobs)	Mix	Global	No
Tong et al.	2015	Perspectives on Global Development and Technology	Development	Access (income & savings)	Pico/SHS	Africa (Kenya)	Yes
Turner	2019	Energy Research and Social Science	Energy & Env.	Access (income & savings)	Pico/SHS	Asia (Sri Lanka)	Mixed
Urmee and Harries	2012	Renewable Energy	Energy & Env.	Access (income & savings)	Pico/SHS	Oceania (Fiji)	Mixed
Urpelainen and Yoon	2016	Clean Technologies and Environmental Policy	Environment	Access (firms)	Pico/SHS	Asia (India)	Yes
van der Vleuten et al.	2007	Energy Policy	Energy & Env.	Sectoral (firms)	Pico/SHS	Africa	Yes
Wamukonya	2007	Energy	Energy & Env.	Access (income & savings)	Pico/SHS	Africa	Yes
Wamukonya and Davis	2001	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Pico/SHS	Africa (Namibia)	No
Wijayatunga and Attalage	2005	Energy for Sustainable Development	Energy & Env.	Access (income & savings)	Pico/SHS	Asia (Sri Lanka)	Yes

Appendix D. Description of non-peer-reviewed papers

Organisation	Year	Analytical Focus	Solar Unit	Geographic Focus	Positive Impact?
60 Decibels	2020	Access (income & savings, firms)	Pico/SHS	Global	Mixed
CDC	2020	Access (income & savings)	Pico/SHS	Africa (Nigeria)	Yes
Climate Action Network	2015	Access (income & savings, firms)	Mix	Global	Yes
DFID	2018	Access (jobs, firms)	Mix	Africa	Yes
GIZ	2017	Sectoral (jobs, firms)	Mix	Africa (Egypt)	Yes
GOGLA	2018	Sectoral (jobs)	Mix	Global	Yes
GOGLA	2019	Access (income & savings, jobs)	Pico/SHS	Global	Yes
GOGLA	2020	Access (income & savings, jobs)	Pico/SHS	Global	Yes
GOGLA	2020	Access (income & savings, jobs)	Pico/SHS	Asia	Yes
GSMA	2016	Access (income & savings)	Pico/SHS	Africa (Rwanda)	Yes
GSMA	2020	Access (income & savings)	Pico/SHS	Africa	Yes
IEA	2014	Sectoral (firms)	Mix	Global	Yes
IRENA	2017	Sectoral (jobs, firms)	Mix	Global	Yes
IRENA	2018	Sectoral (jobs, firms)	Mix	Global	Mixed
IRENA	2019	Sectoral (jobs, firms)	Mix	Global	Yes
IRENA	2019	Sectoral (jobs, firms)	Mix	Global	Yes
meetMED	2020	Sectoral (jobs)	Mix	Africa & Asia (Egypt, Tunisia, Lebanon)	Yes
ODI	2015	Access (income & savings)	Mix	Africa	Mixed
ODI	2016	Access (income & savings)	Pico or SHS	Africa	Yes
ODI	2018	Access (income & savings)	Mix	Global	Yes
OECD	2015	Sectoral (jobs, firms)	Mix	Global	Mixed
Oxfam	2015	Access (income & savings, jobs)	Mini−/Micro-	Africa (Zimbabwe)	Yes
Power for All	2017	Access (income & savings)	Mix	Global	Yes
Power for All	2017	Access (income & savings)	Mini−/Micro-	Africa & Asia (India, Tanzania)	Yes
Power for All	2018	Access (income & savings, jobs), Sectoral (jobs)	Mix	Global	Yes
Power for All	2019	Access (jobs), Sectoral (jobs)	Mix	Global	Yes
Practical Action Consulting	2015	Access (income & savings)	Pico/SHS	Africa & Asia (India, Kenya)	Mixed
REN21	2019	Access (income & savings, firms)	Mix	Global	Yes
Res4Africa Foundation	2017	Access (income & savings, firms)	Mix	Africa	Yes

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Organisation	Year	Analytical Focus	Solar Unit	Geographic Focus	Positive Impact?
Res4Africa Foundation	2018	Access (income & savings)	Mix	Africa	Yes
Rockefeller Foundation	2017	Access (income & savings)	Mini−/Micro-	Asia (India)	Yes
Solar Plaza	2018	Access (income & savings, firms), Sectoral (jobs)	Mix	Africa	Yes
UNDP	2004	Access (income & savings)	Pico/SHS	Asia (Bangladesh)	Yes
UNDP	2005	Access (income & savings)	Mix	Africa (Mali)	Yes
UNDP	2007	Access (income & savings)	Mix	Global	Yes
UNDP	2011	Sectoral (jobs)	Pico/SHS	Asia (India)	Yes
UNDP	2012	Access (jobs)	Mix	Global	Mixed
UNECA	2016	Sectoral (firms)	Mix	Africa (Ghana, South Africa)	Yes
UNECA	2016	Access (firms), Sectoral (firms)	Mix	Africa	Yes
UNECA	2016	Sectoral (firms)	Mix	Africa	Yes
UNEP	2014	Sectoral (jobs)	Mix	Global	Yes
UNIDO	2017	Sectoral (firms)	Mini−/Micro-	Africa & Asia	Mixed
USAID	2019	Access (income & savings, jobs, firms)	Mix	Africa	Yes
World Bank	2008	Access (income & savings)	Mix	Global	Mixed
World Bank	2013	Access (income & savings)	Pico/SHS	Asia (Bangladesh)	Yes
World Bank	2015	Access (income & savings)	Pico/SHS	Global	Yes
World Bank	2016	Access (income & savings)	Pico/SHS	Africa (Ghana)	Yes
World Bank	2018	Access (income & savings)	Mix	Africa (Kenya)	Yes
World Bank	2018	Access (income & savings)	Mini−/Micro-	Asia (Sri Lanka)	Yes
World Bank	2019	Access (income & savings)	Pico/SHS	Latin America (Peru)	Yes
World Bank	2019	Access (firms)	Mix	Africa	Mixed
World Bank	2020	Access (income & savings)	Mix	Asia (Myanmar)	Yes
World Resources Institute	2016	Access (income & savings)	Mix	Asia (India, Nepal)	Mixed
World Resources Institute	2017	Sectoral (jobs)	Mix	Asia (India)	Mixed

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