JBLD, VOL 26, ISSUE NO. 2, 2026. (87 – 106)
@ ARDHI UNIVERSITY, DAR ES SALAAM, TANZANIA

Towards Productive Use of Solar Photovoltaic Water Pumping Systems in Rural Communities: A Review of Push and Pull Factors

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ABSTRACT

Governments, non-governmental organizations and international development agencies widely promote rural electrification to advance Sustainable Development Goal 7 and improve livelihoods. Despite widespread institutional promotion, expanded electricity access does not automatically translate into productive use, a gap that constrains the impact of solar photovoltaic investments in rural areas. This article presents a PRISMA-guided systematic review examining the push and pull factors shaping the productive use of solar photovoltaic water pumping systems in rural communities of developing countries. The review focuses on solar photovoltaic water pumping systems, a pathway linking electrification to productive use. Literature published between 2015 and 2025 was systematically sourced from Scopus and Web of Science. Following PRISMA screening procedures, thematic analysis conducted on 29 peer-reviewed studies. Findings show that institutional push is most evident through

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subsidy schemes, policy frameworks, implementation models, and public programmes promoting rural solar irrigation. Productive pull is shaped by local conditions, agricultural activities, affordability, land and water access, user capability, and livelihood relevance. A recurring mismatch is identified between top-down institutional promotion and the social, financial and contextual conditions necessary for sustained productive uptake. The review concludes that effective rural solar photovoltaic deployment requires alignment between institutional promotion and community-level conditions within an integrated water-agriculture-livelihoods framework.

Keywords: Solar irrigation, rural electrification, productive energy use, Photovoltaic, Livelihoods, Rural development

INTRODUCTION

Access to electricity is a precondition for rural development yet access alone does not ensure productive use. The International Energy Agency defines basic electricity access using minimum annual consumption thresholds of 250 kWh for rural households and 500 kWh for urban households (Cozzi et al., 2020). Access to electricity is essential but using it productively is vital for improving livelihoods and sustainable development in rural areas. However, approximately 685 million people worldwide were still denied access to electricity in 2022, and about 83% equivalent to approximately 568 million people living in Sub-Saharan Africa (IEA et al., 2024). Of these, around 451 million people reside in rural areas, where grid extension is not a viable option due to high transmission costs (ESMAP, 2025). Solar photovoltaic (SPV) systems have emerged as the primary off-grid response in rural areas, yet evidence on whether expanded SPV access translates into productive economic use in these settings remains contested.

The literature on the socioeconomic impact of SPV electrification in rural areas remains conflicting. Some studies report positive effects, including increased household income, extended working hours, growth in small enterprise activity, and improved access to information and communication technologies (Bos et al., 2018; Lenz et al., 2017), Conversely, other studies document negative or negligible outcomes, including displacement of existing livelihoods, elite capture of benefits, and widening intra-community inequalities (Aklin et al., 2017; Fingleton-Smith, 2020). Critically, this contradiction is not random; it reflects underlying contextual differences in institutional support, local economic conditions, and the degree to which electrification is aligned with existing productive activities. Where productive activity has been observed, gains often remain modest confined to a low-value activities and insufficient to generate sustained income improvements (Aklin et al., 2017). Key barrier to uptake includes the limited ability to pay (Boamah, 2020), inadequate technical knowledge (Groth, 2019), and limited markets for the goods produced (Peters et al., 2019). Furthermore, Boamah (2020) identifies a systemic gap that most SPV initiatives give insufficient attention to income-generating activities that would determine local electricity demand.

Within this contested landscape, solar photovoltaic water pumping systems (SPVWPS) offer a uniquely tractable entry point for studying productive use.

Unlike general SPV electrification which serves a diffuse range of consumptive purposes, SPVWPS is directly linked to agriculture, the dominant livelihood sector in most rural developing-country contexts. This specificity makes SPVWPS the most analytically appropriate application for examining whether and how institutional promotion translates into productive community-level outcomes. SPVWPS serves multiple functions: domestically, it provides reliable access to safe drinking water, supports household hygiene and sanitation, and reduces the water-collection burden on women and girls who typically bear the responsibility of water collection (Mweemba et al., 2025). In rural agriculture, it enable irrigation, extends cultivable periods beyond rain-fed seasons, and supports diversification of crops, improving agro-productivity and household food security across Bangladesh, Ethiopia, India, and sub-Saharan Africa (Bizimana et al., 2023; Negera et al., 2025). Beyond subsistence farming, SPVWPS supports livestock watering, and water sales generating additional rural income streams (Thapa et al., 2022). Trickle-down effects include reduced input costs, improved nutrition, and increased women's economic participation (Shrestha et al., 2023). Nonetheless, realising this potential depends on institutional support, local economic conditions, and alignment of system design with community needs, conditions that vary considerably across contexts.

This review examines the push and pull factors shaping the productive use of SPVWPS in rural areas of developing countries. Push refers to top-down institutional efforts by governments, NGOs, donors, and development agencies to promote rural electrification through SPV systems. Pull describes the extent to which rural communities adopt and integrate these systems into productive daily activities, particularly agriculture. The review is guided by three analytical objectives: (i) to map the institutional mechanisms through which SPVWPS is promoted in rural areas; (ii) to identify the community-level conditions that shape productive uptake; and (iii) to examine the alignment or mismatch between institutional push and community pull. The findings contribute empirical insights relevant to SPV developers, policy makers, and rural development practitioners engaged in current debates on the productive use of SPV electrification in rural areas (GIZ, 2016; Shaw, 2017).

METHODS

Study Context and Article Categorisation

The reviewed articles focus on rural contexts in developing countries, especially in South Asia and Sub-Saharan Africa (SSA), where evidence on SPVWPS is most concentrated. Recurring country contexts include India, Bangladesh, Pakistan, Ethiopia, Ghana, Nepal, Malawi, and the Philippines (Figure 1).

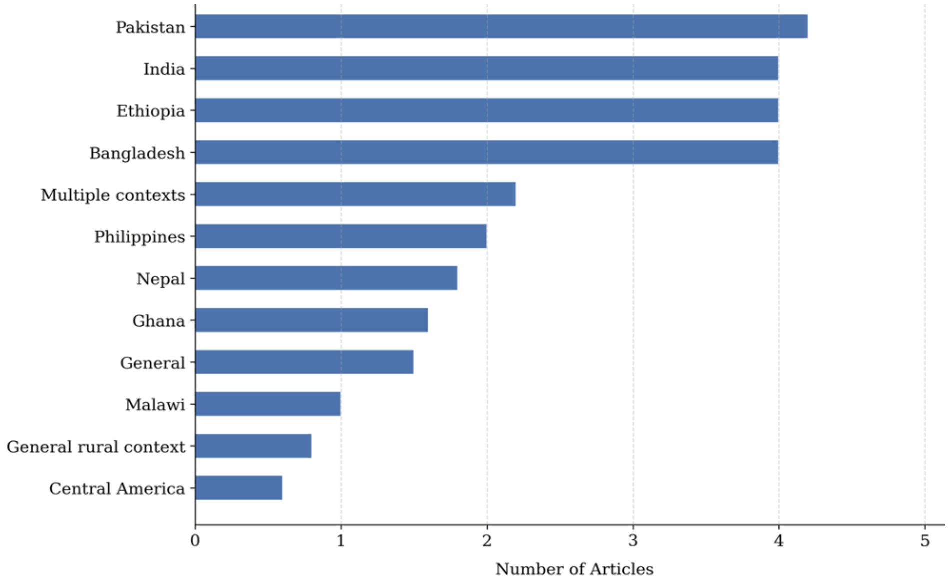

Figure 1: Distribution of reviewed articles across countries

This geographic concentration likely reflects the convergence of three conditions in these settings: high rural dependence on agriculture, persistent electrification gaps, and growing policy and research interest in solar irrigation and off-grid renewable energy. Most reviewed articles examined smallholder agricultural settings, where SPV is linked to irrigation, water pumping, crop production, farmer income, food security, and livelihood improvement. Methodologically, the articles are diverse, covering quantitative and qualitative approaches, including impact assessments, policy analyses, systematic reviews, and mixed-methods community-based case studies. Across literature, SPV is rarely treated as a stand-alone electricity technology; rather, it is situated within broader rural production systems shaped by water access, agricultural practices, policy support, local institutions, and livelihoods (Bizimana et al., 2023; Razzaq et al., 2025; Sunny, Fu, et al., 2022).

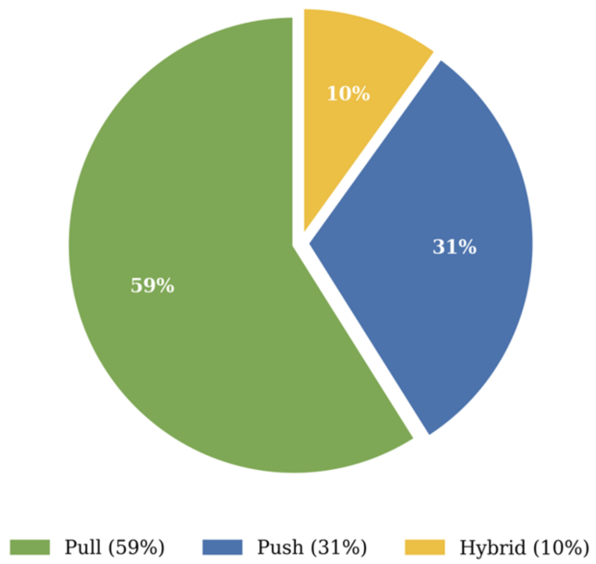

Figure 2: The distribution of articles by push and pull

Furthermore, the articles were categorised according to two principal orientations aligned with the review's conceptual framework. Push-oriented studies address institutional drivers such as policy support, financing mechanisms, and implementation programmes. Pull-oriented studies examine the productive uptake of SPV by rural communities. A small number of articles addressed both dimensions with comparable analytical weight and were classified as hybrid, analysed under both categories. Studies were categorised as push-oriented if their primary focus was on institutional mechanisms driving SPV deployment including government policy, subsidy schemes, donor programmes, financing models, and implementation strategies. Studies were categorised as pull-oriented if their primary focus was on community-level factors shaping SPV adoption and productive use including farmer income, livelihood needs, resource access, user perceptions, and socioeconomic outcomes. This categorisation was conducted by the lead researcher through a systematic reading of each study's objectives, analytical framework, and conclusions, and reviewed for consistency across the full sample. Overall, the reviewed literature is weighted more heavily towards pull factors than push factors, suggesting that research attention has focused more on how rural communities adopt and use SPV productively than on the institutional mechanisms driving rural electrification.

Search Strategy and Sampling

This review adopted a PRISMA-guided systematic approach to ensure transparency, consistency, and replicability in the identification, screening, and selection of relevant studies. PRISMA is widely used in evidence synthesis as it provides a structured procedure for reporting how articles are identified, screened, excluded, and retained for analysis (Liberati et al., 2009). The framework was further applied to document the stages of record identification, duplicate removal, title and abstract screening, full-text assessment, and final inclusion, as shown in Figure 3.

Studies were included if they: (i) focused on SPV water pumping systems in rural areas of developing countries; (ii) addressed push factors (i.e. institutional promotion, policy support, subsidies, or implementation models) and/or pull factors (community adoption, productive use, livelihood outcomes); (iii) were published in peer-reviewed journals or conference proceedings between 2015 and 2025; and (iv) were available as full-text English-language articles. Studies were excluded if they: (i) focused exclusively on technical performance of SPV systems without addressing socioeconomic or institutional dimensions; (ii) were produced by governments, NGOs, donors, or development agencies as institutional reports; (iii) were available only as preprints, working papers, or grey literature; or (iv) could not be retrieved as full texts due to access restrictions.

The literature search was using Scopus and Web of Science (WoS), as the two principal databases for the review. These databases were selected on the basis that they index a wide range of peer-reviewed literature across renewable energy studies, rural development, environmental studies, agriculture, and sustainability research. Also, combined use enhanced the breadth and interdisciplinary comparability of the review, capturing studies relevant to SPV, rural electrification, and productive use across multiple fields. Restricting the search to these two databases maintained methodological consistency whilst ensuring sufficient coverage of the topic.

The search strategy combined terms related to SPVWPS, productive use, rural context, productive use and livelihoods and adoption or enabling factors. The following search string guided the database query: *("solar water pumping" OR "solar irrigation" OR "solar-powered irrigation" OR "photovoltaic pumping" OR "solar pump*") AND "(productive use" OR livelihood* OR "income generation" OR "rural enterprise*" OR productiv*) AND ("rural OR "rural communit*" OR" village*" OR "smallholder*" OR "farmer*") AND ("driver*" OR "barrier*" OR "enabler*" OR "motivat*" OR "adoption" OR "uptake" OR "determinant*" OR challenge*").* The search was limited to English-language peer-reviewed journal articles and conference papers published between 2015 and 2025. This period was considered sufficient to capture recent developments in SPV technology alongside major technological, policy, and implementation changes. Restricting the review to this timeframe also improved the relevance of the evidence to current debates on off-grid electrification, productive use, and solar irrigation. Focusing on peer-reviewed sources further strengthened the quality and reliability of the evidence base by excluding less rigorous grey literature. Restricting the search to English-language publications is acknowledged as a limitation, as relevant studies published in other languages particularly those documenting SPV experiences in francophone West Africa, Latin America, and South and Southeast Asia may have been excluded. This language bias is a recognised constraint in systematic reviews and may limit the geographical representativeness of the findings. A total of 242 articles were initially identified, comprising 209 articles from Scopus, 25 articles from WoS, and 8 manually retrieved from related search strings. After merging, 9 duplicate articles were removed, leaving 233 records for screening. Title screening resulted in the removal of a further 125 articles leaving 108 records. Subsequent abstract screening against the review's inclusion criteria SPV for productive use and push and pull factors in rural electrification excluded a further 64 articles, leaving 44 studies for full-text assessment explicitly addressing push and/or pull factors in rural electrification with particular attention to productive use in rural areas. The final thematic synthesis, however, the review included 29 peer-reviewed full-text studies. Of these, 15 were subsequently excluded: 13 due to inaccessible full texts arising from unavailable institutional subscriptions or restricted publisher access, and 2 because they were available only as a research report and preprint, respectively. The exclusion of 13 studies may have introduced access bias. However, this was a predefined is acknowledged as a limitation in Section 6. Figure 3 presents the PRISMA-guided flowchart for article identification and selection.

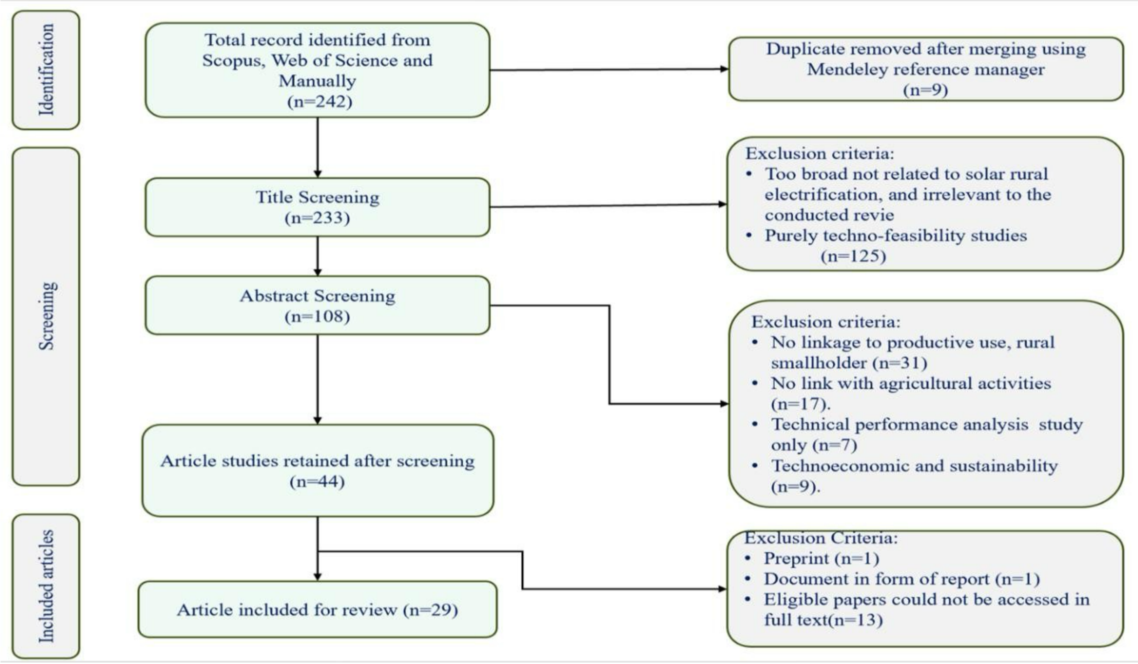

Figure 3: PRISMA guided flow chart for article identification Source: Adapted from Liberati et al. (Liberati et al., 2009)

Study Scope, Data Extraction and Synthesis Approach

Based on the conceptual framing of the review, the study focused on evidence from developing countries, where a approximately 84% of the world's unelectrified rural households are located (ESMAP, 2025) and where off-grid SPV interventions are most relevant to rural development. Reports produced by governments, non-governmental organisations, donors, and development agencies were excluded to reduce potential institutional bias, given that these actors are often involved in rural electrification and solarisation programmes. The review, therefore, relied on peer-reviewed academic literature to ensure greater analytical consistency and methodological transparency. Thematic synthesis was employed for qualitative evidence, whilst quantitative findings were summarised descriptively rather than statistically aggregated. No meta-analysis was undertaken, as the included studies did not provide sufficiently comparable outcome measures or methodological approaches to warrant such aggregation. Data extraction was organised around two main analytical dimensions. First, the productive uses of SPVWPS in rural economic activities, especially agricultural-related activities. The second is the extent to which rural communities align with, adopt and integrate SPVWPS into local productive practices. Throughout the extraction process, particular attention was paid to how institutional arrangements shape and mediate the productive use of SPVWPS in rural areas.

The methodological quality of the 29 included studies was assessed using a researcher-developed appraisal framework tailored to the review's thematic focus. Studies were evaluated based on: (i) clarity of research objectives, (ii) methodological appropriateness, (iii) rigour and transparency of data collection and analysis, and (iv) relevance to SPVWPS productive use in rural developing-country contexts. All studies met these criteria and were included in the thematic synthesis. Consistent with thematic synthesis methodology, studies were not excluded solely on quality grounds, as the review prioritised thematic breadth and contextual diversity over methodological uniformity (Thomas & Harden, 2008).

RESULTS

The results are presented to reflect both the diversity of the reviewed articles and the review's conceptual framing. The section begins with an overview of the case studies, highlighting their geographical spread and their clustering around the two dimensions of push and pull. The findings are then presented thematically, with push factors addressed first, followed by pull conditions, a comparative synthesis, and finally the specific role of SPVWPS in productive use.

The Push Factors and Institutional Support for SPV Electrification

The results identify three analytically distinct but mutually reinforcing push mechanisms: policy frameworks that define the enabling environment, implementation programmes that translate policy into operational delivery, and institutional coordination that aligns actors and sectors across levels. Further the results show that push factors are expressed through distinct institutional mechanisms, each contributing differently to rural livelihood transformation. First, the government subsidy scheme provides direct financial incentives for SPV adoption. In Punjab, Pakistan, a state cost-sharing scheme covered 80% of SPV irrigation system costs, resulting in over 2,000 installations serving approximately 20,000 acres and substantially reducing irrigation costs for smallholder farmers (Raza et al., 2021). Second, public installation programmes remove upfront capital barriers through direct state intervention. In the Philippines, government-installed solar-powered irrigation systems supported by extension services produced measurable rice yield increases between pre- and post-installation periods (Dalman et al., 2024). Third, policy frameworks and cross-sectoral coordination are documented as important enabling conditions for solar irrigation promotion, with evidence that effectiveness depends on funding, policy design, and institutional alignment. In Rajasthan, state policy addressed water scarcity through solar irrigation, though effectiveness was constrained by regional variation in farmer incentives and groundwater conditions (Jain et al., 2022). Beyond national contexts, the literature indicates that expansion requires policies that simultaneously coordinate energy, water, food security, and equity objectives (Lefore et al., 2021). Fourth, the institutional roles in pushing solarisation differ according to mandate and approach. Public agencies provide subsidies, mandates, and installed infrastructure. Development partners finance expansion and pilot innovative models. NGOs support community engagement and last-mile delivery. Community-based arrangements including cooperative and fee-for-service models shape local system management and long-term productive use (Khadka et al., 2023; Mitra et al., 2024b). Collectively, these findings show that push factors are best understood as a layered combination of state policy, donor support, financial incentives, and implementation structures. whose effectiveness depends not on any single actor, but on the degree of coordination across institutional types.

Pull Conditions Shaping Productive Use

Pull factors reflect the extent to which SPV users are able and willing to integrate solar water pumping productively into their agricultural and livelihood activities. It is important to note that pull conditions are analytically distinct from push factors: whilst push factors describe what institutions do to promote SPV, pull conditions describe what community-level realities determine whether that promotion results in productive use. The findings reveal several distinct pull conditions, each shaping productive use differently.

First, Livelihood needs and perceived benefits constitute a direct pull, reflecting the alignment between SPV capability and existing livelihood needs. In Bangladesh, adoption of solar irrigation is associated with improved agricultural outcomes and welfare effects with impacts most pronounced where farming systems are already constrained by water scarcity (Sunny et al., 2022). In Ethiopia, solar-powered irrigation similarly contributed to higher productivity, farmer income, and food security-related outcomes in specific smallholder contexts (Negera et al., 2025). Furthermore, in Ethiopia and Pakistan, solar-powered irrigation similarly contributed to higher productivity, farmer income, and food security-related outcomes (Negera et al., 2025). Second, farmer resources and investment capacity determine the degree to which adoption is feasible at the farm level. In Ghana, the effective demand for solar irrigation is shaped by differences in farm size, assets, and investment capacity, which determine whether farmers can engage with the technology at all (Gbodji et al., 2023). In rural Pakistan, perceived usefulness and ease of use further influence farmers' willingness to adopt solar water pumps (Zhou & Abdullah, 2017).

Third, access to land, water, and credit mediates productive pull through availability of key productive assets. Where land tenure is insecure, water sources are unreliable, or credit is unavailable, the incentive to invest in SPV is weakened, regardless of the technology's potential (Shrestha et al., 2023; Thomas et al., 2025). Fourth, local, social and institutional conditions shape whether productive use is sustained beyond initial adoption. Renewable energy interventions become meaningful only when grounded in bottom-up livelihood realities rather than imposed through top-down assumptions (Thomas et al., 2025). Evidence from India similarly suggests that where local business ecosystems and service environments are weak, productive use remains limited even when technology is available (Teferi et al., 2024). Across these four pull conditions, a common pattern emerges: productive uptake is not determined by technology availability alone but by the degree to which SPV aligns with existing livelihood systems, resource endowments, and local institutional environments. Collectively, pull factors are best understood not as isolated adoption decisions, but as the outcome of how well SPV aligns with local needs, user capability, social acceptance, and institutional conditions, all of which determine whether solar-powered pumping becomes productively embedded in rural livelihoods. (Mitra et al., 2024; Shrestha et al., 2023; Thomas et al., 2025).

Synthesis of Push and Pull Factors

This section brings push and pull factors together to identify convergences and divergences between the two, providing the analytical basis for summarised Table 1. The two sets of factors converge in several important aspects, both recognise that institutional conditions particularly policy design, financing, and coordination are necessary for productive SPV use. Also, they acknowledge that farmer-level economic capacity and livelihood relevance are central to whether systems are adopted and sustained. Furthermore, agricultural productivity and food security emerge in both push and pull oriented studies as shared objectives, suggesting that solarisation is most effective when institutional promotion aligns with farmer-level demand.

Notable divergences are also evident. Push factors are predominantly top-down, driven by state policy, donor financing, and programme design, and tend to prioritise system deployment and coverage. Pull factors, by contrast, are bottom-up, shaped by farmer perceptions, local resource access, social inclusion, and livelihood realities. Literature documents a recurring pattern in which push mechanisms proceed independently of pull conditions, resulting in systems that are installed but underutilised. Additionally, equity and gender inclusion feature more prominently in pull-oriented studies, whilst push-oriented literature focuses more heavily on technical and financial delivery mechanisms. Table 1, synthesizes these dimensions, combining closely related aspects into broader analytical categories across push and pull orientations. It shows that solar irrigation adoption is shaped by both enabling institutional conditions and farmer-level motivations and constraints. The convergences suggest opportunities for integrated approaches, whilst the divergences highlight the persistent mismatch between top-down promotion and bottom-up productive uptake.

Table 1. Synthesis of Push and Pull Aspects

Category	Included aspects	References
Push		
Policy and strategic frameworks	Rural electrification policy; solar irrigation policy; energytransition strategies; least-cost electrification planning; governance frameworks; tax exemptions and regulatory conditions; import procedures and administrative barriers; policy alignment with groundwater conditions	Jain et al. (2022); Lefore et al. (2021); Khadka et al. (2024); Durga et al. (2024); Razzaq et al. (2025); Ugwudike et al. (2025); Teferi (2024); Alam et al. (2025)
Financial support and incentives	Subsidy schemes; cost-sharing arrangements; public financing support; targeted incentives; financial support for deployment	Raza et al. (2021); Jain et al. (2022); Mitra et al. (2024); Agrawal and Jain (2019); Lefore et al. (2021)
Public programmes and implementation	Government programmes; public promotion and installation of solar irrigation, climate-smart agriculture initiatives; implementation models and pathways; programme design and deployment strategies	Dalman et al. (2024); Raza et al. (2021); Mitra et al. (2024); Lefore et al. (2021); Fenta and Berhanu (2025); Agrawal and Jain (2018); Jain et al. (2022)
Institutional coordination and delivery	Institutional support structures; public-private delivery arrangements; coordination agencies and development actors; coordination	Lefore et al. (2021); Teferi (2024); Mitra et al. (2024); Khadka et al. (2023); Thomas et al. (2025); Agrawal and Jain (2018)

	across water, energy, and food sectors; business environment for irrigation technologies	
Equity and inclusive design	Equitable access arrangements for smallholders; inclusive framework design	Lefore et al. (2021); Shrestha et al. (2023); Khadka et al. (2024)
Social inclusion and community dynamics	Gender relations; women's participation; smallholder realities; social inclusion and exclusion; cultural and participatory fit	Shrestha et al. (2023); Khadka et al. (2024); El-Mekaoui et al. (2024); Lefore et al. (2021); Fenta and Berhanu (2025); Thomas et al. (2025)
Pull		
Economic viability and financial capacity	Farmer income; affordability; investment capacity; return on investment; farm-level cost savings; income generation; willingness to invest; effective demand	Khan et al. (2024); Negera et al. (2025); Sunny et al. (2022); Gbodji et al. (2023); Zhou et al.(2017); Sunny et al. (2023); Raza et al. (2021); Gbodji et al. (2026)
Livelihood benefits and food security	Expected livelihood benefits; household welfare; food security; livelihood resilience; local livelihood systems; ability to sustain use over time.	Sunny et al. (2023); Thomas et al. (2025); Bizimana et al. (2023); Negera et al. (2025); Ejigu (2021); Fenta and Berhanu (2025); Lozano and Taboada (2021); Mitra et al. (2024)
Agricultural productivity and resource access	Access to land; access to water; groundwater availability; irrigation demand; water scarcity; crop production needs; farm productivity; technical efficiency in farming; dry-season cultivation potential	Sunny et al. (2022); Narayanmoorthy et al. (2025); Negera et al. (2025); Alam et al. (2025); Razzaq et al. (2025); Sunny et al. (2023); Gbodji et al. (2026); Jain et al. (2022); Khan et al. (2024); Bizimana et al. (2023); Ejigu (2021)
User perceptions and behavioural intentions	perceived usefulness; ease of use; willingness to adopt; farmer preferences; acceptance of solar pumps; perceived value of electricity use; information and awareness	Zhou and Abdullah (2017); Lozano and Taboada (2021); Ngonda et al. (2023); Gbodji et al. (2026); Shrestha et al. (2023)

The Push-Pull Mismatch

The review shows that policy support and technology availability does not automatically translate into productive use. Decentralised solar irrigation involves economic, social, and political trade-offs that produce uneven outcomes across rural communities (Durga et al., 2024). In Bangladesh, solar-powered irrigation was associated with 20-30% higher returns and 21–30% lower irrigation costs, yet several barriers constrained wider uptake, indicating that financial gains alone do not guarantee broad productive adoption (Sunny et al., 2022). In Ghana, effective demand was differentiated by farmers' resource positions, with wealthier farmers demonstrating greater investment capacity whilst smallholders faced persistent financial constraints (Gbodji et al., 2023). These findings are drawn from specific country contexts and should be interpreted with caution when applied to other rural settings.

Furthermore, the push-pull mismatch is grounded in the ways institutional intentions often fail to align with local realities. Weak maintenance systems, limited market information, business-environment barriers raise transaction costs and slow the adoption of solar-powered irrigation (Teferi et al., 2024). In Nepal, solar irrigation schemes introduced in the name of rural development failed to benefit women and smallholders equally, owing to entrenched social inequalities, limited decision-making power, and exclusionary access conditions (Shrestha et al., 2023). Similarly, in Bangladesh, the success of solar irrigation depends heavily on the institutional and financial model adopted, as high capital costs, weak demand generation, and sustainability concerns continue to constrain scaling (Mitra et al., 2024). Across the reviewed literature, the push-pull mismatch is not seen as a failure but as a recurring gap between the top-down institutional promotion and the social, financial, and institutional conditions required for productive uptake. This gap explains why certain SPV systems gain greater practical significance in rural areas than others. The most consistent point of convergence between institutional support and community-level productive use is found in SPVWPS directly linked to agriculture reinforcing its centrality to this review.

SPWPS for Productive Use in Rural Areas

The reviewed studies report that SPVWPS supports productive use through measurable gains in agricultural productivity, household income, and food security among smallholder farmers in specific developing-country contexts (Lefore et al., 2021; Razzaq et al., 2025; Thapa et al., 2022; Thomas et al., 2025). These findings indicate that the benefits of SPVWPS extend beyond energy access, delivering welfare improvements and enhanced farm performance particularly in water-scarce regions (Negera et al., 2025; Sunny et al., 2023). Simulation studies further support these findings by demonstrating that solar irrigation can improve household economic outcomes, strengthen livelihood resilience, and contribute to better nutrition through sustained productive agricultural use (Bizimana et al., 2023; Ejigu, 2021). Across the reviewed literature, SPVWPS is frequently positioned as the central element in conceptualisations of productive use in rural contexts. A systematic review of the socioeconomic and environmental impacts of solar irrigation identifies it as one of the most reliable pathways to socioeconomic progress, increased agricultural output, and environmental benefits (Thapa et al., 2022). In rural areas, energy acquires developmental significance when linked to tangible economic activities, and agriculture offers the most direct arena for such linkage (Thomas et al., 2025). Similarly, Lefore et al. (2021) position solar irrigation as valuable for smallholder farming, whilst Razzaq et al. (2025) illustrate how groundwater pumping and irrigation are deeply integrated into wider agricultural markets and policy frameworks, giving SPVWPS greater productive importance than most other rural electricity applications. Collectively, the evidence suggests that SPVWPS is not merely a prevalent rural but the most strategic form of productive use, directly connecting electricity to water access, crop production, and rural livelihoods creating a coherent pathway from electrification to increased yields, income generation, and enhanced rural wellbeing.

DISCUSSION

Findings indicate that government and institutional interventions play a significant role in promoting rural solar photovoltaic water pumping systems (SPVWPS) through subsidies, irrigation policies, implementation models, and public support mechanisms. For example, the cost-sharing subsidy programme in Punjab, Pakistan, has facilitated adoption by reducing fuel costs, improving irrigation efficiency, and expanding cultivable land (Raza et al., 2022). However, the effectiveness of such interventions depends on their ability to reflect local conditions. Evidence shows that solar irrigation interacts differently with groundwater availability, farmer incentives, local perceptions, and water markets across regions (Abbassi & Saidi, 2024; Jain & Palwalia, 2019). Consequently, successful promotion requires context-specific policies, implementation models, and support mechanisms rather than uniform top-down approaches. Institutional support is most effective when it is coordinated, inclusive, and responsive to local realities, particularly the needs of smallholder farmers (Khadka et al., 2023; Lefore et al., 2021; Mitra et al., 2024).

Despite these enabling conditions, expanding access does not necessarily guarantee productive use. In Ethiopia, for example, adoption is constrained by weak supply chains, limited market information, foreign exchange shortages, inconsistent tax incentives, and inadequate maintenance services (Teferi et al., 2024). Similarly, some implementation models face high capital and operational costs (Mitra et al., 2024). These challenges demonstrate that while institutional push can improve access to technology, productive outcomes depend on complementary demand-side conditions. The findings further show that productive adoption of SPVWPS depends on the extent to which rural communities can integrate the technology into their existing livelihood systems. Adoption is influenced by factors such as income, access to land and water, investment capacity, perceived usefulness, and expected economic benefits. Evidence from Bangladesh indicates that solar irrigation can reduce irrigation costs and increase agricultural returns, particularly in areas with high irrigation demand (Sunny et al., 2023). Likewise, acceptance of solar water pumps is influenced not only by perceived usefulness and ease of use but also by farmers’ resource base and capacity to invest (Gbodji et al., 2023; Zhou, 2017). These findings suggest that productive adoption occurs when the technology aligns with local economic activities, resource conditions, and livelihood priorities.

In this context, pull represents the mechanism through which rural households translate access to solar energy into improved irrigation, agricultural productivity, and livelihoods. Studies consistently show that renewable energy interventions are more effective when grounded in local needs and community realities rather than imposed through generic top-down approaches (Thomas et al., 2025). Participatory and adaptive implementation models further support this conclusion (El-Mekaoui et al., 2024; Sisto et al., 2018). Pull therefore encompasses local demand, social acceptance, community capability, and livelihood priorities, all of which influence whether SPVWPS generate meaningful and sustained benefits. Overall, the review identifies a persistent mismatch between top-down institutional promotion and local uptake. In many cases, the expansion of SPVWPS through policy and subsidy programmes progresses faster than communities' ability to adopt and utilize the technology productively. This reflects a disconnect between the supply-side logic of institutional push and the demand-side realities of rural pull. Figure 3 illustrates this push–pull relationship and highlights the need for stronger alignment between institutional support mechanisms and community-level conditions to achieve sustainable and productive rural energy outcomes

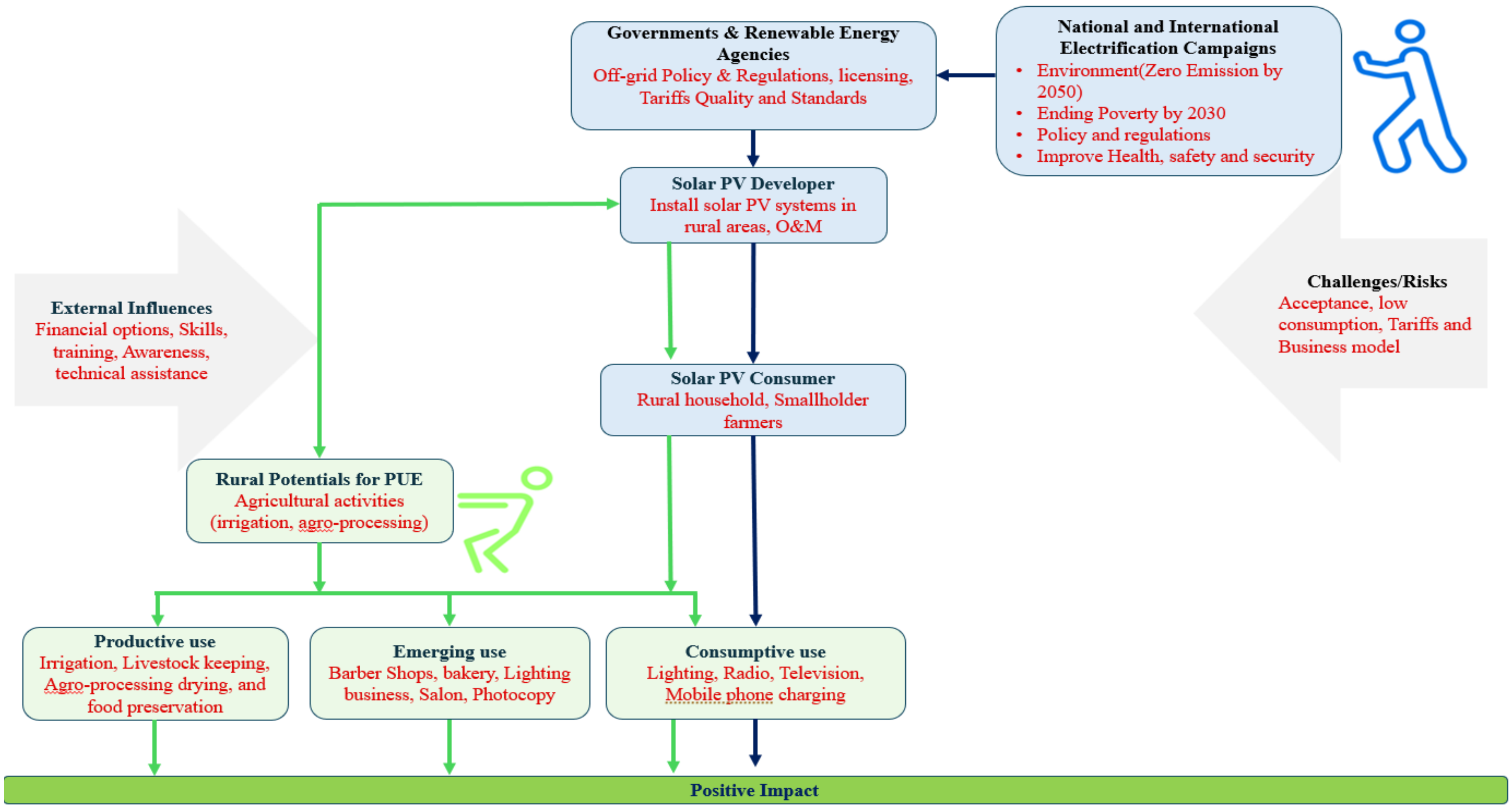

Figure 4: Conceptual framework of SPV for rural electricity access and its implications for productive use in rural areas. Blue indicates the push factors, while green indicates the pull factors

Figure 4 illustrates the conceptual relationship between push and pull factors in the solarisation of rural communities. Push factors create the enabling conditions for solar investment, whilst pull factors arise from rural communities' livelihood priorities and needs, particularly in agriculture. Where these factors are well integrated, electricity is more likely to be used productively, generating sustained benefits including higher incomes, local economic growth, improved health and safety, and poverty reduction. The figure also acknowledges that SPV can support other small-scale enterprises, such as barber shops, bakeries, salons, and lighting businesses, whilst also serving consumptive uses, including lighting, radio, television, and mobile charging.

CONCLUSION

This review examined the push and pull factors shaping the productive use of SPVWPS in rural areas of developing countries, guided by three analytical objectives: to map institutional promotion mechanisms, to identify community-level conditions shaping productive uptake, and to examine the alignment or mismatch between push and pull. With respect to the first objective the review finds that institutional promotion through subsidies, policies, and implementation models may expand access to SPV technologies, but uptake remains uneven, as policy support alone does not ensure productive use. Whilst access to electricity carries intrinsic developmental value improving health, safety, education, and quality of life the transition from access to productive use requires additional enabling conditions. These include ability to integrate SPV into everyday economic activities, particularly agriculture, irrigation, and water access. This integration is shaped by affordability, resource availability, user capabilities, gender dynamics, and continued service support.

With respect to the second objective, productive uptake depends on contextual conditions that enable farmers to convert solar energy into tangible economic and welfare gains (Lefore et al., 2021; Mitra et al., 2024; Sunny et al., 2022). Rural SPV programmes are therefore likely to be more effective when anchored in the dominant economic activities of specific communities. In most of the reviewed contexts, this means grounding SPV primarily in agriculture, since anchoring systems in irrigation and related productive uses increases the likelihood that electrification generates tangible livelihood benefits. This does not imply that electricity access alone is insufficient as a development objective, but rather that programmes designed to promote productive use should be explicitly aligned with local economic realities rather than treating productive outcomes as an automatic consequence of access expansion. With respect to the third objective, the review identifies a recurring structural mismatch between top-down institutional promotion and the social, financial, and contextual conditions required for productive uptake.

This mismatch helps explain why certain SPV systems gain greater practical significance in rural areas than others, and why SPVWPS directly linked to agriculture emerges as a particularly significant application in the reviewed literature though its significance is context-dependent and should not be generalised across all rural settings. Finally, this review calls for future research that moves beyond technology adoption and policy assessments towards a more systemic analysis of rural electrification. A systems thinking approach would enable examination of how energy access interacts with water availability, agricultural production, institutional support, local markets, and community priorities to shape productive use. This would provide a stronger foundation for designing rural SPV interventions that are technically viable, socially embedded, economically meaningful, and sustainable over time.

LIMITATION

This review is subject to three methodological limitations that should be considered when interpreting the findings. First, the search was restricted to English-language publications, which may have excluded relevant studies from francophone West Africa, Latin America, and South and Southeast Asia, limiting geographical representativeness. Second, the 2015–2025 timeframe, whilst appropriate for capturing recent SPV developments, excludes earlier foundational studies that may have offered relevant contextual insights. Third, the final synthesis draws on 29 of the 44 studies that reached full-text assessment, as 13 were inaccessible due to subscription restrictions and two were available only as a report and preprint respectively a constraint that may introduce access bias, though manual searches and the thematic diversity of the final sample partially mitigate this risk. Additionally, restricting the review to peer-reviewed sources introduces a degree of publication bias, as studies reporting positive or significant findings are more likely to be published. No meta-analysis was undertaken given the methodological diversity of the included studies, which limits the quantitative comparability of findings across contexts.

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