International Water Management Institute

215

Working Paper

Understanding Early Adoption of Solar Irrigation in Lao PDR: Benefits, Challenges and Policy Gaps

Paul Pavelic, Oulavanh Keovilignavong, Phonevilay Sinavong, Mathieu Viossanges, Santi Keonouchanh, Poupey Keovongdy, Saetmany Phompackdee, Daosavanh Bounphanousay and Jonathan Lautze

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Summary

Solar-powered irrigation pumps (SIPs) offer a promising climate-resilient option for farmers, enabling a shift from rainfed to year-round agriculture that can enhance food security and livelihoods. In Laos, SIPs are beginning to be adopted, but the impacts and broader implications of this early uptake remain unclear. This study examines 10 off-grid, smallholder-operated SIPs in the lowlands of Laos to provide evidence for optimal scaling. Interviews were conducted with system operators and complemented by the on-site collection of technical data. Despite high upfront investment costs, most users report strong satisfaction with SIPs. The systems provide reliable irrigation for home consumption, with occasional surpluses sold in markets, and typically achieve payback within five years. Adoption is mainly driven by reductions in fuel and electricity costs, with most systems privately financed. However, broader adoption remains constrained by operational limits under low solar radiation, a lack of government incentives and supportive policies, and limited awareness of potential aggregated impacts on groundwater resources. To support sustainable expansion and reduce investment risks, measures such as capacity building on pump operation, promotion of water-efficient practices, and improved groundwater monitoring are necessary.

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1. Introduction

Global experiences with solar-powered irrigation pumps (SIPs) highlight several key benefits, including improved food production and strengthened rural livelihoods. SIPs can also help ensure more reliable water access during erratic rainfall within the growing season, enabling dry-season cultivation, and supporting greater crop diversification. These improvements can lead to higher incomes and better household nutrition (Passarelli et al. 2018; Shinde and Wandre 2015; Burney and Naylor 2012), particularly in off-grid areas where conventional irrigation infrastructure is limited (Lefore et al. 2021).

While SIPs offer significant benefits, their adoption and effectiveness among smallholder farmers are often constrained by several challenges. One major barrier is the prohibitively high upfront capital costs, which remains out of reach for many farmers despite falling technology prices (Grant et al. 2022; Senol 2012, Figure 1). Access to affordable financing for both installation and ongoing maintenance is also limited (Durga et al. 2024). In addition, inadequate data on water resource availability and quality—especially groundwater—hampers effective planning and decision-making (Lefore et al. 2021). Finally, limited awareness and technical capacity related to SIP operation and maintenance increases the perceived risks for users (Hussain et al. 2023).

Lao PDR (hereafter referred to as Laos) has high potential for SIP use, and emerging evidence suggests that rural communities are starting to install SIPs, particularly in remote villages for community water supply, often with support from international development agencies. Nanthavong (2005) identified that solar pumps in Sangthong District, Vientiane Prefecture, may reduce the burden on women and children who previously collected water from a river. Thammavongsa (2019) identified that large-scale surface irrigation schemes are being converted from grid electricity to solar energy. Pavelic et al. (2024) carried out a rapid assessment of a community-managed SIP site in Southern Laos, highlighting system design and user capacity as critical to success. Nonetheless, the effectiveness and broader implications of initial SIP implementation efforts in Laos remain unclear. There is no peer-reviewed assessment of the practical benefits and post-implementation challenges.

To support effective implementation of future SIP interventions in Laos, it is important to understand the efficacy of initial efforts. This study therefore examines early experiences with SIPs in Laos in order to:

(1) Explore how early adopters of SIPs perceive its performance, benefits, and limitations.

(2) Understand the motivations and barriers for broader adoption.

(3) Provide recommendations for more sustainable and inclusive SIP adoption among smallholder farmers in Laos.

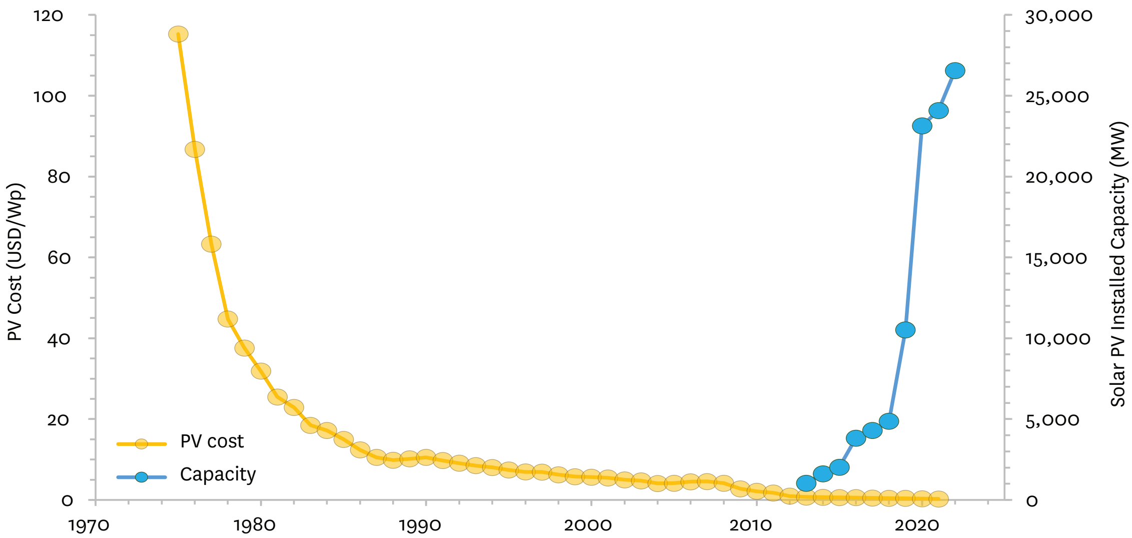

Figure 1. Global solar photovoltaic panel costs and cumulative installed solar PV capacity in the SEA region.
Source: IRENA 2023; Ritchie et al. 2023

2. Context and Methodology

2.1 Study Area

Laos, a developing country in Mainland Southeast Asia, has significant untapped potential for solar-powered irrigation. With abundant land, water, and solar energy resources, there are clear opportunities to harness SIPs for agricultural development. National water availability was 26,600 m³ per person in 2019, well above the global average of 5,600 m³ (FAO 2023). Solar irradiance ranges from 3.6 to 5.2 kWh/m²/day, with 2,000 to 2,600 hours of sunshine annually (ESMAP 2019). This is broadly in-line with the global daily average solar irradiance at the Earth's surface, which is about 6 kWh/m²/day under clear skies, and 4 kWh/m²/day under cloudy conditions (Trenberth et al. 2009). These values provide a useful benchmark for assessing solar pump performance under global average conditions.

The lowland areas of Laos – which is the focus for this study (see Figure 3) – stretches over a 1,000 km² corridor along the Mekong River and its tributaries, supporting approximately five million people (~70% of the total population). The region has a tropical monsoon climate, with a pronounced wet season from May to October and a dry season from November to April. Annual rainfall ranges between around 1,500 to 2,500 mm, mostly concentrated in the wet months. These lowlands are vital for national rice production, particularly for both rainfed and irrigated paddy systems. The flat terrain and fertile alluvial soils are well-suited to intensive agriculture. Agricultural productivity, however, is limited by water scarcity during the dry season, inadequate irrigation infrastructure, and vulnerability to climate extremes. Climate change is intensifying these risks through increased rainfall variability and more frequent extreme weather events. While surface water is abundant during the wet season, groundwater remains underutilized but offers significant potential for supporting dry-season irrigation and improving resilience.

2.2 Research Design

The research approach involved three distinct steps. First, over the period between June and September 2020 we identified prospective SIP survey sites through an online search of solar company websites and popular social media platforms. A total of 27 companies were found in Laos (mainly in the capital city, Vientiane) that import, supply, and install solar products from China and Thailand. We contacted each company directly by phone, explained the nature of our research, and then requested they provide relevant solar water pump sales information.

Of these, five companies shared information. Operators of the solar systems were contacted by phone to determine whether their solar water pumps were primarily used for agriculture, and if so, to gauge their willingness to participate in the study, while assuring them that all personal information would remain confidential. Here, we focused on agricultural areas in the lowlands of Laos as a potentially attractive region for SIP implementation.

Second, we collected data using a structured questionnaire administered to the SIP operators at each site (see Appendix). To aid understanding, Figure 2 presents a schematic representation of a typical SIP, showing the main components and their interconnections as captured in the survey tool. The tool draws on insights from comparable field studies in other regions (EED Advisory Ltd 2018; Shirsath et al. 2020) and was designed to provide site-specific information relevant to the study aims. It comprises five sections covering key technical, operational, and contextual aspects of solar-powered irrigation systems (Table 1). This includes basic site and respondent identification, details of the water source and infrastructure, technical specifications of the solar pumping system, water storage and distribution methods, irrigated cropping patterns, user experiences regarding system performance and maintenance, and investment and ownership information.

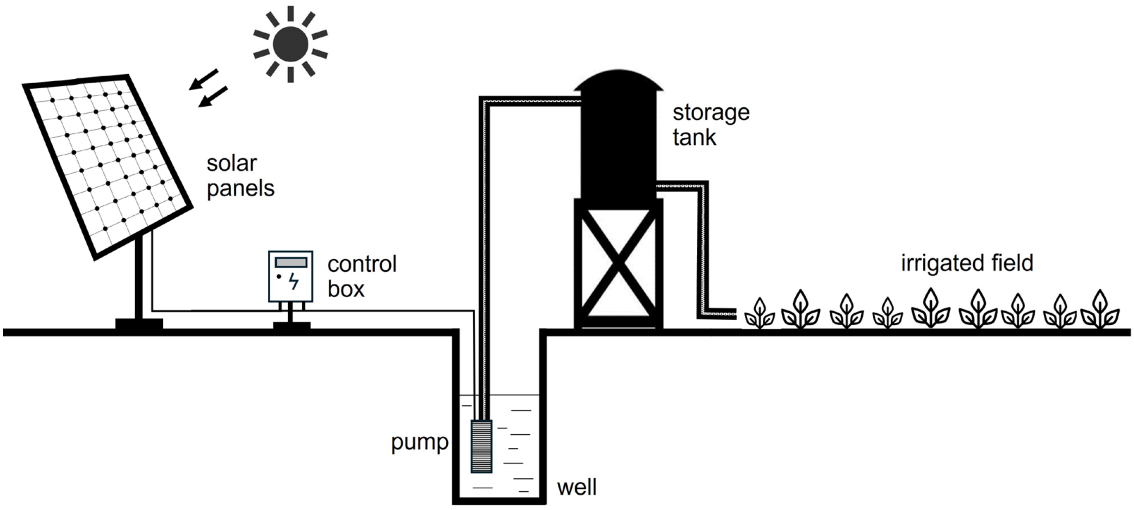

Figure 2. Generalized schematic of a solar irrigation pump system.

Table 1. Overview of the key aspects of the questionnaire used in this study.

Category	Indicators
1. *Site information*	• Date of visit • Name and contact details of SIP operator • Village name and geographic coordinates
2. *Technical and infrastructure characteristics*	• Type of water source (well/borehole) • Depth of well/borehole • Diameter of well/borehole • Depth of pump below ground • Measured discharge rate • Type of pump (surface/submersible) • Brand and model of pump (if available) • Age of pump • Number of solar panels • Rating of each solar panel • Total solar array power • Presence or absence of battery storage • Battery storage capacity (if present)
3. *Water distribution and agricultural use*	• Volume of storage tank • Elevation of tank above ground • Water flow method (direct/gravity/output pressure pump) • Irrigation methods used (furrow/sprinkler/hose etc.) • Cropping details (up to five irrigated crops): - crop type - irrigated area - cropping frequency per year
4. *User experiences and perceptions of performance, benefits, and limitations*	• Primary use of the system (agriculture/domestic) • Maintenance practices • User assessment of system performance • Perceived advantages of the solar pumping system • Expected payback period • Main problems experienced
5. *Investment and adoption pathways: motivations and barriers*	• Details of system owner • Date of system purchase • Supplier • Capital costs • Type of investment (self-funded/subsidy/loan etc.) • Previous energy system replaced (if any)

Third, we administered the questionnaires through field surveys of 10 existing SIPs in lowland areas between 2020 and 2024 (Figures 4 and 5). This included an extended interruption due to travel restrictions associated with COVID-19 and the lockdown policy. During the first period of fieldwork in 2020, six sites within a 100 km radius of the capital city, Vientiane, were selected due to their convenient access and high solar potential. In the subsequent period (2023-2024), four additional sites were selected within the Vientiane region and the Attapeu Province in Southern Laos (see Figure 3). Whilst the total number of sites is limited, they were deemed sufficient to provide a basic understanding of the overall situation, though not necessarily detailed enough to support broader generalizations.

Prior to field deployment, the tool was pretested to ensure clarity and appropriateness of the questions. All survey team members received training on both the technical principles and practical aspects of SIP, as well as interview protocols. Written or verbal consent was obtained from all respondents before the interviews were conducted. To strengthen the analysis, the information provided by respondents was supplemented with field observations and contextual insights from related research in the region. This multisource approach enabled triangulation and contributed to a richer understanding of the factors influencing SIP implementation and use.

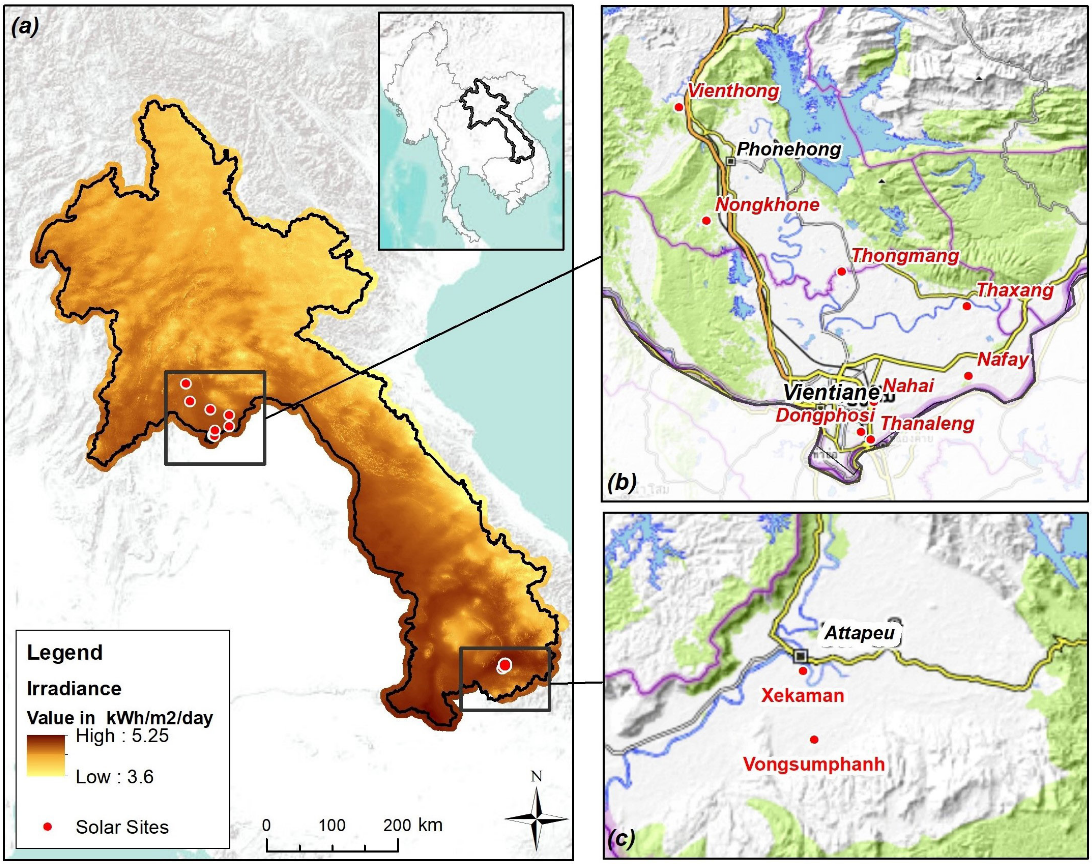

Figure 3. (a) Daily totals of horizontal irradiance for Lao PDR, Inset maps show the location of the 10 field sites on (b) the Vientiane Plain, and in (c) Attapeu.

Figure 4. Site 3 shows solar irrigation infrastructure and a citrus garden behind. (*photo*: Mathieu Viossanges/IWMI)

Figure 5. An SIP operator being interviewed in the field. (*photo*: Saetmany Phompackdee/NAFRI)

3. Results

3.1 System Characteristics and Uses

The configurations of the SIPs varied considerably across the 10 sites, reflecting variations in agricultural practices and livelihood strategies (Table 2, Figure 6). Solar panel capacity ranged from 0.3 to 4.6 kW, typically paired with pumps of 0.4 to 3.7 kW (where data were available). Measured pump discharge rates ranged from 0.5 to 2.5 L/s. All systems sourced groundwater from tubewells, with depths ranging from 8 to 70 m.

All sites supported crop production, and two were also used for animal husbandry and aquaculture. Irrigated areas typically ranged from 0.8 to 1.7 hectares (ha), except for one outlier (Site 2), where a commercial investor established a 50-ha jackfruit plantation. Most sites employed improved irrigation technologies, with drip irrigation used in five sites, alongside sprinkler, mini sprinkler, furrow, and hosepipe systems.

At seven sites, SIPs replaced diesel and electric pumps, while the remaining three were entirely new installations (Figure 6a). Half of the sites were used for commercial production (fruit trees, vegetables, and herbs), while four were for household consumption and one combined both uses (Figure 6d). One site involved a commercial investor from a neighboring country, suggesting that investor-led SIP development may be starting to occur (Figure 6e). All systems had been installed since 2018 (Figure 7), indicating a recent interest in adoption, likely driven by falling solar technology costs and improved accessibility. From the total pool of respondents, eight were male and only two were female, highlighting a clear gender imbalance in SIP adoption.

Table 2. Summary of the main characteristics and uses of the ten SIPs assessed.

No.	Name	TD (m)	PD (m)	SPC (kW)	PS (kW)	IFR [a] (L/s)	TC (m^3)	BC (Ah)	Crops	IA (ha)	IM	CC (Million LAK / USD)
1 [b]	Dongphosi Village, Hadxaifong District, Vientiane Prefecture	35	5	1.32	1.1	0.69	NA	NA	coconut, bamboo, wattle, banana	1.1	drip + hose	17.3 / 1922
2 [b]	Nongkhone Village, Phonhong District, Vientiane	70	60	4.6	-	1.25	80	NA	jackfruit	50	drip	75 / 8333
3 [b]	Vienthong Village, Phonhong District, Vientiane	52	24	0.99	0.75	0.47	10	NA	orange + cattle/buffalo	1.5	drip	17.5 / 1944
4 [b]	Thongmang Village, Xaythany District, Vientiane Prefecture	18	13	0.99	-	0.64	4	NA	vegetables and herbs (organic)	1	hose	-
5 [b]	Thaxang Village, Pak Ngum District, Vientiane Prefecture	30	15	0.32	-	0.09 e	0.7	24	mango, papaya, banana, sugar cane, jujube	1	drip	8.4 / 933
6 [b]	Nafay Village, Pak Ngum district, Vientiane Prefecture	42	32-36	1.4	-	0.67	6	NA	mango, jackfruit, banana, lychee, avocado, coconut	1	drip	10.7 / 1189
7 [c]	Thanaleng Village, Hadxaifong District, Vientiane Prefecture	13 and 13	9	1.08	0.4 and 0.75	0.14	1	NA	fruit trees (banana, avocado), flowers, home garden, decorative trees	0.8	fitted hose	16 / 941
8 [c]	Nahai village, Xaysetha District, Vientiane Prefecture	50	40	3.6	0.75-2.2	2.6	56 [f]	NA	rice, fruit trees (various types), home garden	1.6	mini sprinkler	72 / 4235
9 [c]	Vongsumphanh Village, Phouvong District, Attapeu	45	-	1.52	0.66	-	-	NA	fruit trees (various types), aquaculture, livestock, home garden, rice nursery	1.7	sprinkler + furrow	43.5 / 2559
10 [d]	Xekaman Village, Samakkhixay District, Attapeu	40	-	1.6	-	0.44	NA	NA	rice	0.5	furrow	29 / 1450

Notes: TD = total depth of well; PD = pump depth; SPC = solar panel capacity; PS = pump size; IFR = indicative flow rate as measured from discharge from well during the visit; TC = tank capacity; BC = battery capacity; IA = irrigated area; IM = irrigation method; CC = capital cost including installation in Lao Kip and US Dollars. Owing to significant changes in exchange rates over the study period a rate of 1 USD = 9,000 LAK is used for site visits in 2020; 1 USD = 17,000 LAK for site visits in 2023; and 1 USD = 20,000 LAK for site visits in 2024

[a] discharge rate was measured using the 'measuring bucket and stopwatch' method wherever possible;
[b] visited between August and October 2020;
[c] visited in March to April 2023;
[d] visited in March 2024;
[e] cloudy weather during site visit;
[f] concrete pond used for fertilization of crops; NA = not applicable.

3.2 Perceived Performance and Benefits

Most respondents expressed high levels of satisfaction with SIP performance. Out of the ten users, seven rated their SIP's performance as high, and the remaining three rated it as medium. Respondents expressed strong satisfaction, especially with regards to financial and labor savings compared to diesel or electric pumping systems. SIPs were generally considered reliable and cost-effective, helping to reduce input costs and increase flexibility in water use.

Labor savings were particularly valued at sites that used drip irrigation, where daily watering became less labor intensive. Users also reported improved independence and reduced impact from high fuel prices.

3.3 Adoption Patterns and Investment Decisions

Private financing played a dominant role in SIP adoption. From the ten systems, eight were self-funded by farmers or supported through informal borrowing (Figure 6e). One system was financed by donor programs and the other through government support.

Total capital costs—inclusive of well drilling—ranged from LAK (Lao kip) 8 million to 75 million (USD 900 to 8,300), with a median cost of USD 1,900 (Table 2). Systems used for commercial purposes generally incurred higher costs, largely because they had installed deeper wells.

Upfront investments were weighed against expectations of reasonably short payback periods. A total of six out of ten respondents indicated a payback time of less than five years. For instance, one farmer reported a five-year payback period if rice was grown alongside vegetables and fruits, but just three years if aquaculture and livestock were prioritized. However, two respondents were unable to estimate a payback period.

To verify these estimates, a farm-level profitability analysis was conducted at two representative sites with supporting field data (Table 3). Results showed that net profits aligned well with farmer estimates. Site 4 (vegetables) and Site 10 (rice) both had good financial returns. Profit was calculated as the difference between total production value and input costs, excluding household labor as an expense.

3.4 Barriers and Operational Challenges

Despite widespread satisfaction, several users identified limitations that could deter uptake among more risk-averse or resource-constrained farmers, especially those without access to technical support. The most frequently cited issues were reduced pumping capacity during periods of low sunlight and limited ability to adapt to the variable energy supply of solar pumps.

For example, at Site 2 the system failed to meet water demands for a 50-ha plantation, reflecting the limits of SIPs in large-scale operations, particularly in areas with modest well yields. Across sites, the dominant sandstone aquifer generally provides sufficient water to irrigate two to three ha. Irrigating larger areas would require either multiple wells or the adoption of more water-efficient crops and improved irrigation scheduling (Clément et al. 2018).

A three-day follow-up visit to Site 9 in Attapeu Province during the early dry season reinforced these challenges. Daily flow rates peaked around midday, with usable discharge (defined here as greater than one-third of the daily peak) lasting only 7 to 8 hours (Figure 8). Solar radiation levels during the follow-up were slightly below the annual average (Janjai 2006). Farmers accustomed to grid electricity or diesel-powered systems can irrigate at any time, but without battery storage, SIPs limit flexibility. While most sites had overhead storage tanks, capacity and pressure were often inadequate, leading to scheduling constraints for farmers who typically prefer to irrigate in the early morning or late afternoon.

Despite these challenges, most high performing SIP sites experienced only small, manageable issues. Medium performing sites faced greater adaptation difficulties. To fully realize the benefits of SIPs, users need to either adjust irrigation schedules or invest in improved water storage.

3.5 Perspectives on Groundwater Sustainability

All respondents expressed interest in continuing or enhancing their SIP use. Several were considering expanding SIPs elsewhere, encouraged by low operating costs and system autonomy. Interestingly, none raised concerns about the long-term availability of groundwater from their wells.

The lack of concern suggests insufficient awareness or attention to sustainability-related risks. As SIP adoption grows—especially if concentrated in discrete areas—the impacts of cumulative groundwater use could become significant. Although groundwater remains underutilized in virtually all locations, ensuring long-term resource sustainability would require stronger integration of groundwater management into SIP planning and support programs.

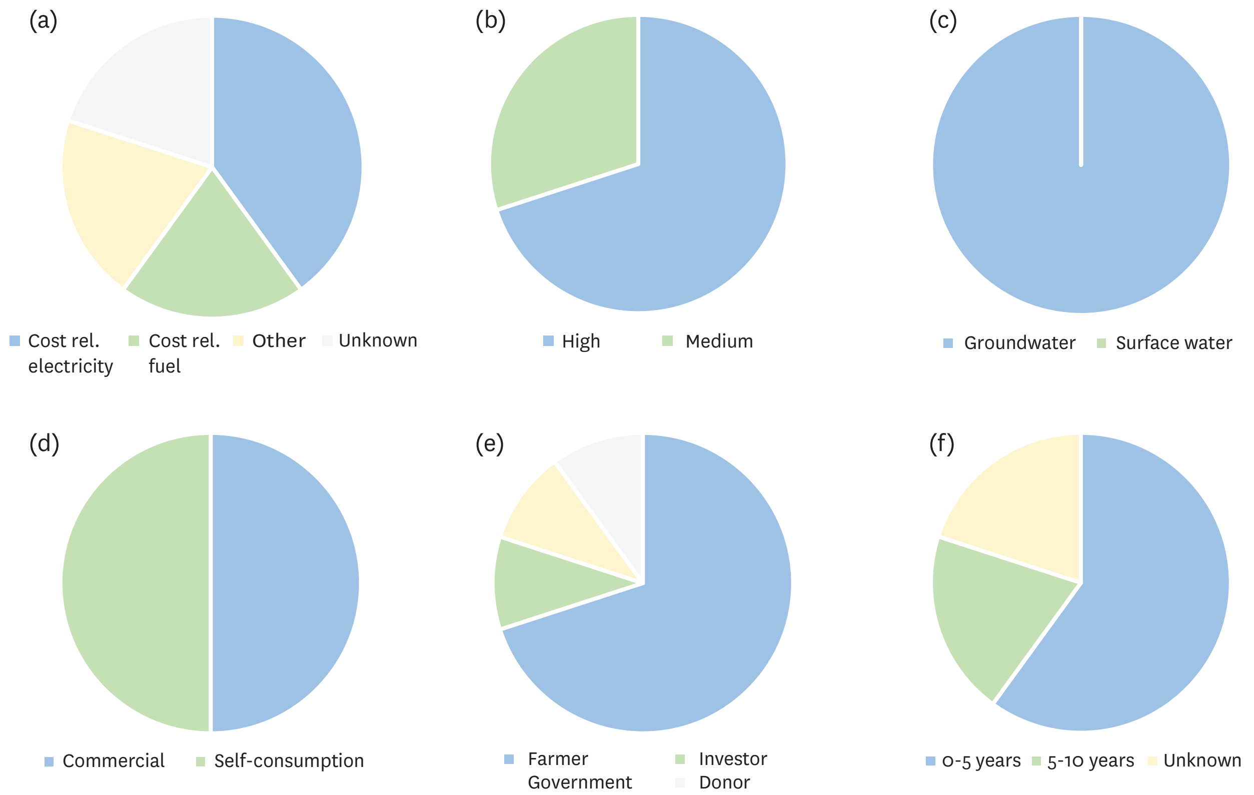

Figure 6. Pie charts showing breakdowns of: (a) reason for investing in the solar system, (b) perceived performance, (c) water source, (d) purpose for agricultural production, (e) source of financing, and (f) perceived payback time.

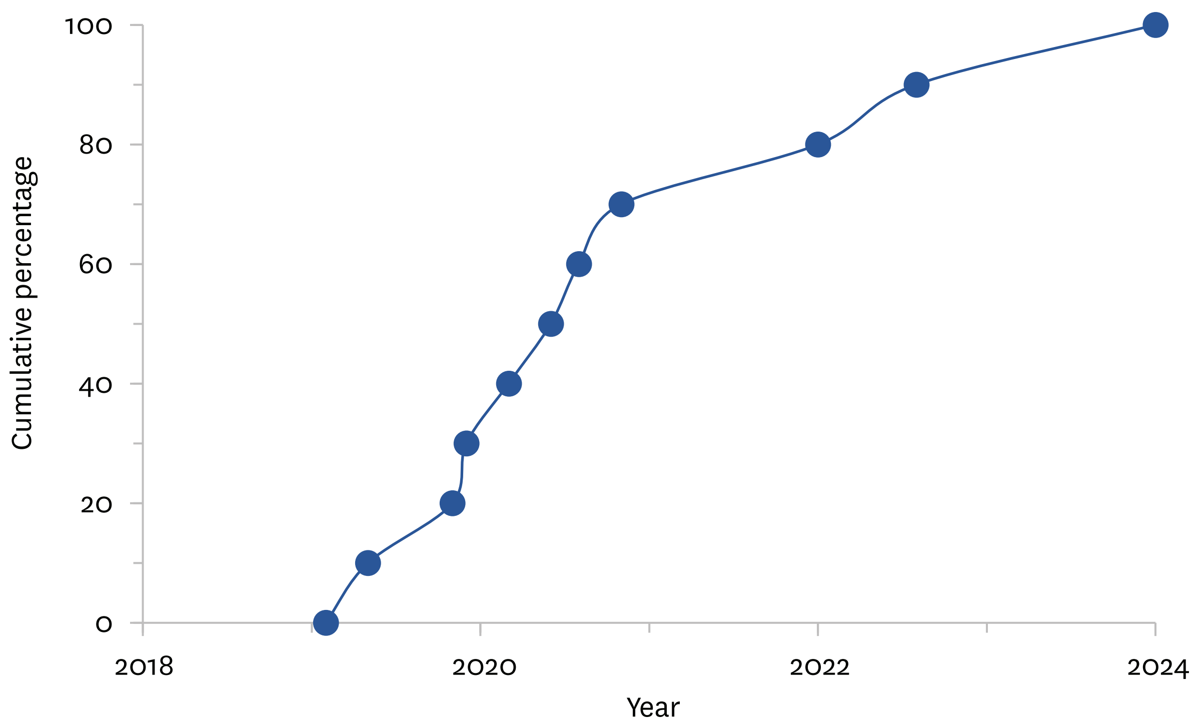

Figure 7. Adoption of solar irrigation over time.

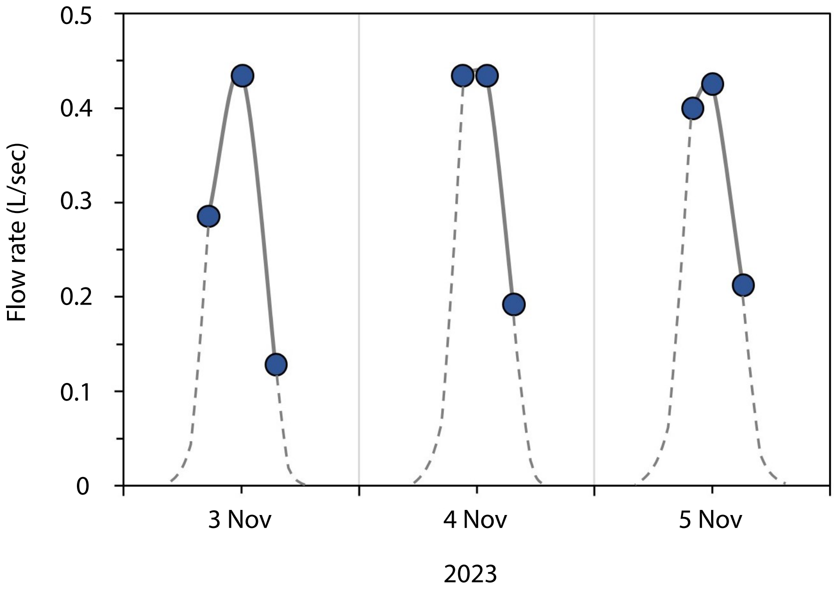

Figure 8. Measured pump discharge rates at Site 9 from November 3 to 5, 2023.

Table 3. Farm-level profitability analysis and calculated SIP payback time.

Items	Site 4	Site 10
Crop area (ha)	1.0	0.5
No. of crops grown during the dry season	2	1
Crop yield (t/ha)	8 1	2.5
Direct inputs costs (LAK)	720,000 [1]	500,000
Sale price for produce (LAK/kg)	7,000 [1]	4,000 [1]
Value of production (million LAK)	11.1	4.5
SIP capital cost (million LAK)	15	29
SIP operating cost to date (million LAK)	0	0
Calculated payback time (years)	1.4	6.4
Farmer-reported payback time (years)	1	5

Notes: [1] from Clément et al. (2018)

4. Discussion

Solar irrigation is increasingly recognized as a way to enhance water reliability and reduce agricultural production costs by eliminating diesel or electricity power expenses. In Laos, patterns of SIP adoption and their effectiveness were previously poorly understood. This study provides the first empirical assessment of SIP adoption in lowland smallholder farming systems of Laos, offering key insights for both policy and practice.

4.1 Adoption Patterns and Types of Applications

The study revealed that adoption in Laos is recent, with all SIPs installed since 2018 reflecting falling technology costs and improved accessibility. Configurations varied widely across sites, ranging from smallholder plots of less than 2 ha to a 50-ha commercial plantation, and supported diverse cropping patterns as well as aquaculture and livestock. Most SIPs replaced diesel or electric pumps, indicating that rising energy costs are a core driver of adoption. Previous studies of Lao farmers using electric pumps (Clément et al. 2018) and diesel pumps (Suhardiman et al. 2020) both highlight energy costs as a major constraint. The diversity of system sizes and uses observed in this study emphasizes the need to tailor technical and management support to the specific context.

4.2 Perceived Performance and Benefits

Across most sites, respondents reported high satisfaction with SIP performance where seven out of ten users rated their system as high performing, with the remaining three rating it as medium. Key benefits included financial savings, labor reduction (particularly with drip irrigation), and reduced impacts from fuel price fluctuations. These findings reinforce global evidence that SIPs can provide reliable and cost-effective irrigation, with studies showing major advantages over diesel. For example, over a 20-year period in India, solar pumping proved to be nearly five times cheaper compared to diesel (Kanna et al. 2020) and became economically viable within 8 to 10 years in Turkey (Senol 2012). In Pakistan and Vietnam, solar is increasingly replacing diesel due to its cost-effectiveness and the need for improved energy access (Hussain et al. 2023; Hien 2017).

4.3 Investment Decisions and Payback Periods

Investment in SIPs in Laos is predominantly led by farmers. From the 10 systems, 8 were privately financed, either through self-funding or informal borrowing, while donor or government support was limited. Median capital costs were approximately USD 1,900, and most users anticipated payback periods of less than five years which were confirmed through farm-level profitability analyses. This demonstrates that SIPs are financially viable for smallholders and comparable to international experiences, where payback periods have been reported to be as low as 1.5 years in Kenya (Lighting Global 2019) and 6.5 years in Indonesia (Aini et al. 2021).

4.4 Operational Challenges

Despite widespread satisfaction amongst respondents, operational constraints were also evident. Pumping capacity declined during periods of low solar radiation, and most systems lacked battery storage, limiting irrigation schedules to peak solar hours. Larger operations, such as the 50-ha commercial site, exceeded the capacity of a single SIP system, indicating that multiple wells or more efficient irrigation methods are needed to achieve scale. Medium performing sites faced more adaptation challenges than high performing ones. These findings highlight that farmer-focused technical support, improved water storage, and adaptive management are central to maximizing SIP performance and benefits.

4.5 Groundwater Sustainability Considerations

All SIPs relied on groundwater from tubewells, reflecting broader regional and global trends (Closas and Rap 2017). In Laos, about 50% of rural households rely on groundwater for domestic supply, rising to 90% in some provinces (Pavelic et al. 2014). While groundwater use is still modest, demand is growing, making sustainability a priority for continued development. Despite its strategic importance and the growing recognition of groundwater among policymakers (AWP 2021), respondents expressed little concern about long-term sustainability, highlighting a knowledge gap regarding the potential aggregated effects of expanded SIP adoption. While most individual systems only irrigate small areas of land (0.5 to 2 ha), the cumulative effects of expanded SIP adoption may become significant. Expansion carries risks due to limited knowledge of aquifer characteristics, groundwater recharge, and quality, combined with constrained monitoring and management capacity, which makes proper well-siting complex and uncertain (Coulon et al. 2021; Viossanges et al. 2018). Integrating groundwater monitoring, together with guidance on well-siting and sustainable abstraction practices will therefore be essential to ensure that SIP development is not undermined by poor well performance or unsustainable groundwater use.

4.6 Policy and the Enabling Environment

Only 27% of farming households in Laos have access to irrigation (LSB 2021). The Ministry of Agriculture and Forestry highlights the need for improved on-farm water access to boost productivity, reduce climate risks, and support market-oriented agriculture (MAF 2015). SIP adoption pathways strongly depend on coherent policy frameworks.

Although off-grid solar is expanding in upland areas to support rural electrification (ADB 2019), its integration into agricultural strategies remains minimal. The Renewable Energy Development Strategy (2011–2025) targets 30% of energy from renewables but overlooks solar irrigation (MEM 2011), and the 2016–2020 National Socio-Economic Development Plan mentions solar only in relation to the drying of agricultural produce (MPI 2016). Legislative frameworks—including the Electricity Law and Investment Promotion Law—provide little or no targeted support for SIPs, and coordination across water, energy, and agricultural sectors remains weak (GoL 2016).

Despite near-universal electrification, around a quarter of rural households remain energy poor, spending over 10–15% of their income on energy (Oum 2019). This underscores the need for cost-effective, off-grid solutions. Figure 9 shows that electricity prices for the irrigation sector have steadily risen from 4 to 7% annually due to restructuring of the state-owned utility (Phouthonesy 2021; Nanthavong 2015). High electricity prices may further incentivize SIP adoption. Scaling SIPs sustainably will therefore require policies that combine financial incentives, technical support, and integrated planning across sectors.

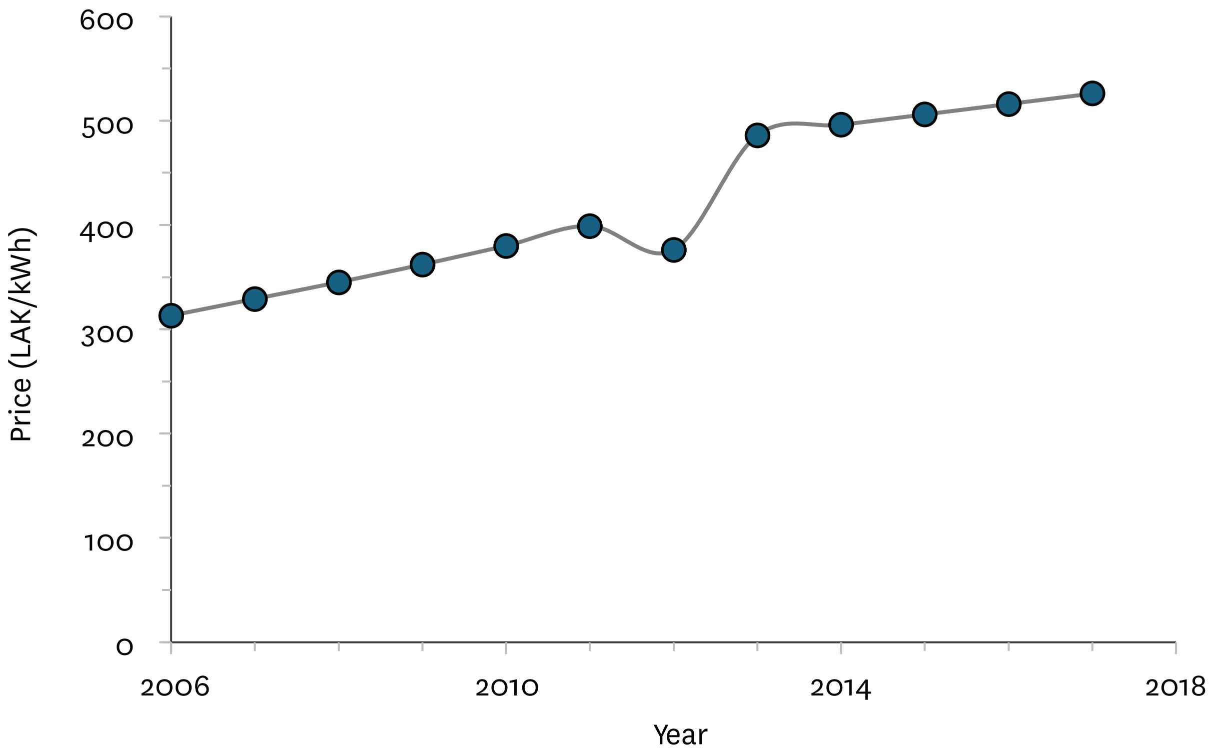

Figure 9. Changes in electricity prices in the irrigation sector.
Source: Nanthavong (2015)

4.7 Comparative Insights from Sub-Saharan Africa

Although this report concentrates on Laos' emerging solar irrigation experiences, comparative evidence from sub-Saharan Africa (SSA) provides valuable insight into how technical, financial, and institutional conditions shape adoption. Solar irrigation has been implemented in SSA over longer periods and across more diverse contexts, offering lessons on both opportunities and pitfalls (Efficiency for Access Coalition 2019). Drawing on a recent review of solar irrigation uptake in SSA (Durga et al. 2024) and supporting case studies, this section highlights cross-regional insights relevant to Laos.

Natural resources: In Laos, aquifers accessed by solar pumps can be up to 70 m deep and are relatively well-buffered from seasonal drawdowns. By contrast, in SSA shallow wells in Ethiopia and Mali frequently go dry, forcing farmers to rely on surface storage or limit irrigated areas (Birhanu et al. 2023; GIZ 2023). In South Africa, groundwater limitations in hard rock aquifers restrict solar irrigation potential (Durga et al. 2024). These experiences illustrate that resource conditions strongly affect the reliability of solar irrigation for farmers. In Laos, emphasis on sedimentary aquifers with higher yields reduces immediate risks, but SSA cases suggest that if seasonal shortages emerge, strategies such as drilling deeper wells or combining surface and groundwater use will be necessary to sustain production.

System design and performance: In Laos, technical performance is generally reliable and water-efficient technologies such as drip irrigation are commonly incorporated. Yet, the experience in SSA demonstrates how equipment quality and service networks determine farmer trust and long-term uptake. In Mali, the availability of low-quality pumps and panels shortened system lifespans and undermined confidence, limiting adoption. Conversely, in Ethiopia, coupling solar pumps with drip irrigation has enhanced reliability and reduced dry-season stress (Teferi et al. 2024). These cases highlight how weak supply chains and inadequate quality assurance can undermine adoption despite favorable resource conditions. For Laos, proactive measures such as certifying equipment quality, strengthening upstream service networks, and training local technicians will be critical to build on initial progress.

Financial aspects: High upfront costs relative to farmer incomes are a common barrier to both regions. In SSA, limited credit availability has constrained adoption, showing that financial innovation is as crucial as the technical aspects. Models such as leasing, sharing, and pay-as-you-go schemes have expanded access by aligning repayments with farmer cash flows (Lefore et al. 2021). However, many of these models struggle without external subsidies. For example, in Uganda, subsidy-driven uptake raises concerns over long-term viability (Kato et al. 2024). For Laos, this suggests that financial instruments must balance affordability with sustainability, avoiding over-reliance on donor support while ensuring risk-sharing mechanisms for smallholders.

Institutional and policy environment: Laos lacks dedicated policies for solar irrigation and has weak groundwater regulation. Experience from SSA demonstrates the risks of not having adequate institutional intervention. For instance, in Ghana and Zimbabwe, rapid solar pump adoption without effective regulation has contributed to localized depletion (Durga et al. 2024). Both Laos and SSA share abundant groundwater and significant untapped irrigation potential, but SSA highlights that institutional neglect can lead to pockets of unsustainable exploitation. Laos' groundwater authorities therefore face a strategically important opportunity to establish monitoring systems, regulatory frameworks, and incentives for efficient use before adoption accelerates.

Social dimensions: In Laos, uptake has been cautious, shaped by the conservative attitudes of farmers to new technologies, male-dominated decision-making, and limited extension support. In SSA, land tenure insecurity and gender inequality similarly reduce incentives to invest. However, targeted interventions such as farmer field schools for women and the integration of solar irrigation into broader extension services, have enhanced inclusivity (Durga et al. 2024). These experiences show that technology adoption is driven by social structures as much as by technical or financial feasibility. Adapting extension models to address gender gaps and build farmer confidence could accelerate adoption in Laos while promoting equitable access.

5. Conclusions

Solar irrigation is emerging as a climate-smart solution for farmers in lowland Laos. SIPs provide reliable and affordable access to water, helping to improve crop productivity, livelihoods, and food security. This study provides the first empirical evidence of SIP adoption in the country, showing that SIPs can be technically effective, financially viable, and socially beneficial. The key findings can be summarized as follows:

(1) SIP systems are relatively recent but already display diverse applications across scales, crops, and farming contexts.

(2) Farmers report high levels of satisfaction, supported by reductions in fuel and electricity costs and payback periods of about five years.

(3) Adoption to date has been predominantly privately financed, with limited government incentives or policy support.

(4) Operational constraints, particularly reduced pumping capacity under low solar radiation, limits flexibility for users.

(5) Awareness of groundwater sustainability risks remains scarce, highlighting the importance of supportive measures such as capacity building, water-use awareness campaigns, and improved groundwater monitoring.

Overall, the benefits of SIPs for smallholders outweigh the risks, and thus further adoption should be accelerated based on sound evidence and careful planning. However, realizing the full potential of SIP development and managing long-term risks requires proactive policy measures—particularly with respect to financing, technical support, adaptive management and groundwater sustainability.

Comparative experience from SSA demonstrates that the expansion of solar irrigation adoption depends not only on physical resource availability, but also on considerations relating to financial systems, supply chains, institutional frameworks, and social inclusivity. Laos is at an early stage of development, which presents a timely opportunity to learn from SSA's successes and failures. By addressing quality assurance, strengthening financing models, improving groundwater governance, and integrating context-specific and gender-sensitive support services, Laos can avoid the issues observed elsewhere and ensure that adoption is broad-based and sustainable. Comparative evidence suggests that the design of policies, institutional frameworks, and support systems in Laos will play a critical role in determining whether solar irrigation scales sustainably and equitably.

The key recommendations are as follows:

1. Strengthen and align solar energy policies: Update national solar energy policies to reflect technological advances and to provide support to farmers by reducing high upfront costs. Fiscal measures such as lowering import duties and taxes on solar equipment would greatly improve affordability and accessibility.

2. Promote public–private partnerships and innovative financing: Leverage partnerships to expand concessional credit schemes and explore alternative financing models that align repayment with smallholder cash flows.

3. Build institutional and farmer capacities: Invest in capacity-building for provincial and district authorities, and provide advisory services for farmers on SIP operation, maintenance, and adaptation under variable sunlight. Include gender-sensitive approaches to ensure equitable participation and benefits.

4. Safeguard groundwater sustainability: Establish groundwater monitoring in areas with high irrigation potential, coupled with clear guidance on appropriate well-siting, and promote efficient irrigation practices at the farm level.

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Appendix. Questionnaire Administered to the SIP Operators.

Name of the Interviewer:

Date of Interview/Visit:

Consent Form Signed by Respondent: Yes / No

A. General Details of SIP

1. Information about the SIP System Owner: Name: Gender: Phone Number:
2. Location of the SIP: Village: District: Province: GIS Coordinates:

B. Technical Information About SIP System

This technical information about the SIP system should be completed based either on field measurement or through discussion with owner.

Supplier of the SIP equipment *(Give name, address & phone number – note, this would not be disclosed in any reporting)*
Date of purchase of SIP equipment *(Month and year are sufficient)*
When was the well/borehole constructed? *(Month and year are sufficient)*
Total depth of well/borehole below the ground (in feet or meters)
Brand of Pump *(Share specifications sheet or photo where possible)*
Type of Pump (surface / submersible)
Age of pump (months or years)
Capacity of the pump (in kW or HP)
What is the typical flow rate of the pump (in Liters per minute)
Does the SIP include water storage tanks? *(If YES, please share details about volume/elevation etc.)*

Type and number of solar panels. Total capacity of panel array (in kW) *(Give height above ground, angle and direction of orientation of panels if possible)*
What type of energy system did the solar system replace? *(Chose from these options: 1. Electricity; 2. Diesel; 3. Solar; 4. none)*
What was the type of investment? *(Chose from: 1. own funds; 2. bank loan; 3. borrowed from relatives and friends; 4. government subsidy; 5. Other – please specify)*
Total area of farmland CULTIVATED in the WET season and DRY season (in rai or ha) Total area of farmland IRRIGATED in the WET season and DRY season (in rai or ha)
Type and number of livestock raised and purposes*
Main types of crops grown and purposes*# What method(s) are used to apply water to crops? *(Chose from 1. furrow; 2. basin; 3. drip; 4. sprinkler; 5. other. If multiple methods are applied then describe which crops use which method)*
When there is no pumping usually how deep is the groundwater level below the ground during the WET and DRY seasons (in meters or feet)?
Is the well/borehole the ONLY water source used for irrigation?
Is regular maintenance of the SIP system carried out? *(If yes then give details)*
** is it for home consumption or for market (or both)? If for market how/where are crops sold?* *# Add a crop calendar similar to the one shown here:*

C. Sketch or Photos of the SIP System

Add photo(s) or sketch here.

D. Opportunities and Constraints

Why did you decide to use the solar system? *(Give details)*
How often do you use the SIP system in the WET and DRY seasons? *(Give details on frequency and duration. Options for frequency could include: 1. every day; 2. every few days; 4. weekly; 5. Hardly at all. Options for duration could include: 1. <1 hour; 2. 1-3 hours; 3. >3 hours)*
What do you think are the main advantages of the SIP system? *(Give details)*
What new information or knowledge would assist you to make better use of your SIP system?
How would you describe the performance of the solar system? *(Choose from: high, medium or low. Please give details)*
How many years do you expect before you pay for your investment in full?
What is the most serious problem(s) you face in your irrigated agriculture?
Do you have enough labor to grow crops over the available area during the dry season?
Do you have a problem getting enough water from your well for your current uses? *(If YES, then what are the months when this problem occurs)*
In priority order, what are the three most important limiting factors in expanding solar-powered irrigation? *(Choose from: 1. sunshine availability; 2. land availability; 3. Water availability; 4. family labor; 5. fuel cost; 6. repair and maintenance of the equipment; 7. working capital; 8. market for the produce; 9 other - please specify).*
Are there any water quality problems associated with the use of the groundwater? *(If YES then please describe the type of problem. Options might include: 1. odor/smell 2. taste 3. salinity 4. turbid/ cloudy 5. other – please specify)*

E. Economics

What are the Capital Costs for the SIP system? *(Provide costs for all parts of the system if available. All in Lao Kip. Cost items would include: 1. well/borehole; 2. pump; 3. solar panels; 4. water storage; 5. distribution pipe; 6. irrigation system)*			
Complete the table below to establish the financial returns from the SIP system:			
Particulars	Crop number		
	#1 (monsoon)	#2 (winter)	#3 (summer)
Crop type			
Area grown			
Total crop yield (kilograms)			
Crop sold to market (kilograms)			
Cost of Inputs: a) Labor (how many members; if this is family labor) b) Fertilizer (inorganic + organic) c) Pesticides d) Transportation (if relevant)			
Selling price (Lao Kip)			

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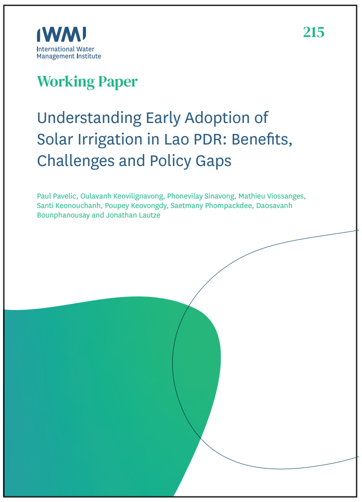
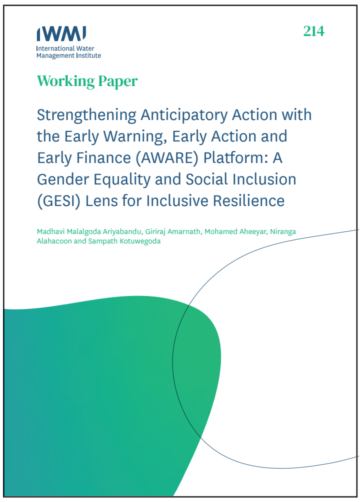
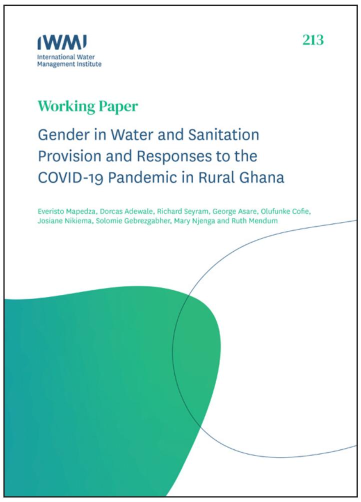


215 Understanding Early Adoption of Solar Irrigation in Lao PDR: Benefits, Challenges and Policy Gaps
https://doi.org/10.5337/2025.228



214 Strengthening Anticipatory Action with the Early Warning, Early Action and Early Finance (AWARE) Platform: A Gender Equality and Social Inclusion (GESI) Lens for Inclusive Resilience
https://doi.org/10.5337/2025.228



213 Gender in Water and Sanitation Provision and Responses to the COVID-19 Pandemic in Rural Ghana
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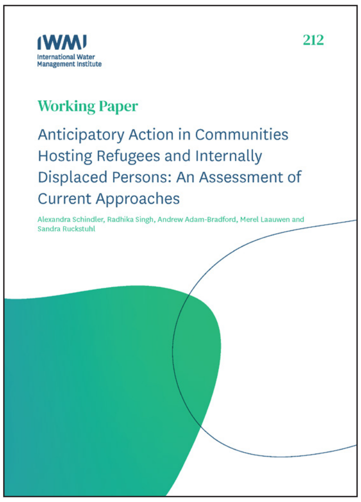

212 Anticipatory Action in Communities Hosting Refugees and Internally Displaced Persons: An Assessment of Current Approaches
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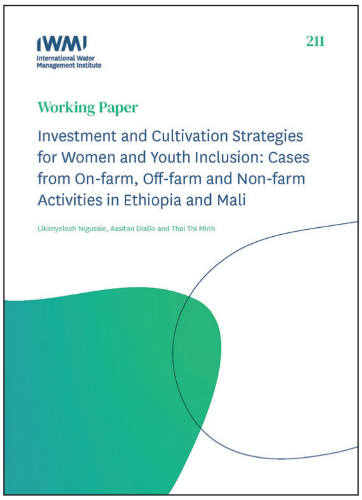

211 Investment and Cultivation Strategies for Women and Youth Inclusion: Cases from On-farm, Off-farm and Non-farm Activities in Ethiopia and Mali
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