REPORT

# Pathways to Climate-Resilient Cocoa: Is Solar-Powered Irrigation-as-a-Service a Viable Adaptation Strategy?

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# Contents

# Abstract

This study examined smallholder farmers' perceptions, experiences, and enabling conditions for adopting irrigation, with a particular focus on the potential of solar-powered Irrigation-as-a-Service (IAS) models in Ghana's cocoa sector. The research was conducted across the Eastern, Ashanti, and Central Regions using a qualitative design involving focus group discussions and key informant interviews with farmers, extension officers, cooperative leaders, and district agricultural officials. The analysis explored six key themes: climate impacts and the role of irrigation, perceptions and use of irrigation technologies, existing IAS models and enabling conditions, viability of solar-powered IAS bundles and business models, partnerships and financing, and barriers to adoption. Findings reveal that erratic rainfall, prolonged dry spells, and rising temperatures are significantly disrupting cocoa production, leading to yield declines and income instability. Across regions, irrigation is increasingly viewed as a critical adaptation strategy to counter these climatic stresses. However, access to irrigation remains constrained by high capital costs, weak institutional support, and limited technical knowledge. Farmers demonstrated strong enthusiasm for solar-powered systems due to its one-time investment and alignment with clean energy goals, yet implementation is hindered by financing challenges, maintenance issues, and insecure land tenure arrangements. Regional dynamics show some variation: Eastern Region farmers had slightly greater exposure to irrigation initiatives; Ashanti farmers exhibited stronger cooperative networks and interest in collective ownership models; while in the Central Region, illegal mining and water pollution emerged as unique environmental challenges limiting irrigation feasibility. IAS remains largely unfamiliar to farmers and is essentially absent within cocoa-growing communities in Ghana. The study concludes that solar-powered IAS models present a viable pathway for climate-resilient cocoa and smallholder agriculture, provided that policies promote cooperative-based management, inclusive financing, and capacity-building. Strengthened multi-stakeholder partnerships among government, private sector, and farmer organizations will be essential for ensuring sustainability and equitable access.

Keywords: Irrigation, Cocoa Farming, Climate Change Adaptation, Solar Energy, Irrigation-as-a-Service, Ghana

# 1. Introduction

Climate vulnerability in cocoa production reflects the broader structural inequalities within Ghana's agrarian system, where smallholder farmers depend almost exclusively on rainfed agriculture. This dependence has exposed cocoa farming to the increasing variability of rainfall and the intensification of dry spells. According to the International Water Management Institute (IWMI), under the CGIAR regional initiatives Transforming Agri-food Systems in West and Central Africa (TAFS–WCA) and Excellence in Agronomy (EiA), Ghana's cocoa belt has experienced a significant rise in consecutive dry days over the past three decades, indicating a steady shift toward a drier and more water-stressed climate (Obahoundje et al. 2025). Such shifts, embedded within broader socio-ecological change, have begun to redefine the structure of production and the nature of resource access among smallholder cocoa farmers.

The vulnerability of cocoa farmers to climate shocks is not merely an environmental issue but also a structural one, reflecting uneven access to productive assets such as irrigation technologies, capital, and technical knowledge. Within this structure, solar-powered irrigation pumps (SPIPs) have emerged as a transformative innovation, capable of mitigating climate-induced water stress and stabilizing yields. The Ghana Cocoa Board (COCOBOD), together with private sector partners, has initiated several programs promoting SPIPs as part of its climate adaptation strategy (Cocoa Post 2019). Empirical studies, such as those by Tilahun et al. (2023), indicate that cocoa farms utilizing irrigation produce yields up to 60% higher than those on purely rainfed farms. These findings highlight irrigation as not only a productivity-enhancing intervention but also a critical adaptation mechanism within the broader framework of climate-resilient cocoa systems.

From a hydrological standpoint, Ghana's cocoa-growing zones, particularly those underlain by the Birimian and Crystalline Basement Granitoid Complex, hold significant groundwater potential. Research by Banoeng-Yakubu et al. (2011) estimates average yields of 12.7 $m^3/h$, transmissivity of 7.4 $m^2/d$, and storability between 0.003 and 0.008, confirming the technical feasibility of groundwater-based irrigation. Evidence from the TAFS–WCA program further suggests that groundwater recharge exceeds 10% of annual rainfall, making it possible to sustainably irrigate at least 10% of Ghana's cocoa area. Despite this, irrigation adoption remains minimal. The core limitation is not technical feasibility, which concerns whether the system can function effectively under prevailing agroecological and infrastructural conditions, but rather socio-economic accessibility, particularly the capacity of farmers to finance, operate, and maintain irrigation systems.

The present study, therefore, situates the concept of Irrigation-as-a-Service (IAS) within this structural context of limited capital, irregular income flows, and collective action potential among cocoa farmers. The IAS approach, where farmers pay for irrigation services rather than owning the infrastructure outright, presents a viable institutional innovation to overcome the financial and operational barriers that constrain individual ownership. It aligns with cooperative and pay-for-use models that enable smallholders to share costs, manage risks collectively, and ensure equitable access to water resources. These arrangements embody a shift from asset-based ownership to service-based accessibility, promoting inclusivity and sustainability within cocoa production systems.

Drawing on the social structure theory (Blau 1977), this study views irrigation adoption not merely as a technological choice but as a social process embedded in community hierarchies, institutional norms, and resource distribution systems. The social structure theory posits that resource access, such as land, water, or capital, is often determined by the relational positions of groups within a community's institutional framework. Applying this lens helps explain why certain farmer groups, such as cooperative members or lead farmers, tend to have greater exposure and capacity to adopt irrigation technologies, while resource-constrained farmers remain excluded. The IAS model thus emerges as a mechanism to democratize access by reorganizing how irrigation services are distributed across social and economic categories of farmers.

Consequently, this study explores how IAS models, particularly solar-powered, groundwater-based irrigation systems, can be scaled inclusively among cocoa farmers in Ghana. It examines the interplay between institutional design, financing mechanisms, and farmer preferences to identify feasible pathways for widespread adoption. The broader goal is to inform national strategies and policy reforms under the CGIAR Scaling for Impact initiative, ensuring that irrigation scaling contributes to both climate resilience and social equity within Ghana's cocoa sector.

## 1.2 Literature Review: Solar-Powered Irrigation and Irrigation-as-a-Service (IAS) Adoption in Ghana

### *1.2.1 Overview of irrigation adoption in Ghana*

This study is informed by an extensive body of research on irrigation development, solar-powered technologies, and emerging service-based models in Sub-Saharan Africa. In Ghana, irrigation adoption remains limited despite its critical role in improving resilience to climate variability. National statistics indicate that less than 2% of cultivated land is irrigated, even though the country possesses substantial surface and groundwater potential. Existing studies consistently highlight financial constraints, limited technical capacity, weak extension systems, and inadequate institutional coordination as major barriers to scaling irrigation among smallholders.

Recent research also points to the growing prominence of solar-powered irrigation systems as a climate-resilient and economically viable alternative to diesel and other fossil fuel-based irrigation technologies. Solar systems reduce operational costs, align with renewable energy priorities, and have shown significant benefits for smallholder farmers in terms of yield stability and income diversification. However, high upfront costs, uneven water availability, and concerns about equipment quality and after sales service continue to slow widespread adoption.

Emerging business models such as Irrigation-as-a-Service (IAS) have gained considerable attention for their potential to address financial and operational barriers. Instead of owning equipment, farmers pay for water or irrigation services on a per-use or subscription basis. Evidence from East Africa and South Asia suggests that Irrigation as a Service can expand irrigation coverage, reduce upfront investment burdens, and improve system sustainability by shifting operation and maintenance responsibilities to specialized service providers who offer structured, professional maintenance and technical support. Nonetheless, in Ghana these models remain nascent and fragmented, with limited empirical assessment of their effectiveness, governance arrangements, and applicability to different cropping systems including perennial crops like cocoa.

Within the cocoa sector, irrigation remains a relatively neglected research area, despite increasing climatic pressures that threaten productivity. Recent agronomic studies show that supplemental irrigation can significantly improve cocoa tree health, pod retention, and yield performance, especially under prolonged dry conditions. Yet adoption is constrained by cost, limited technical expertise, and minimal integration of irrigation into mainstream cocoa extension programs (Agyemang et al., 2025).[1] Readers are directed to the full literature review for an in-depth analysis.

# 2. Methodology

## 2.1 Study Design

This study employed a qualitative design with embedded quantitative elements, enabling the combination of rich narrative insights with basic descriptive statistics. The primary data collection methods were focus group discussions (FGDs) with cocoa farmers and key informant interviews (KIIs) with Agricultural Extension and Advisory Services (AEAS) staff and other technical experts (PumpTech). In addition, a short questionnaire was administered to capture demographic information from the farmers. This combination of methods was chosen to explore both farmers' lived experiences and expert perspectives on Irrigation as a Service (IAS), while also providing background information on participants' socio-demographic characteristics.

## 2.2 Study Setting

The research was conducted in three of Ghana's major cocoa-producing regions, namely Ashanti, Central, and Eastern, which together account for a substantial share of national cocoa output. Within the Ashanti Region, the communities of Mankranso, Mpasaso, and Sabronum were selected. In the Central Region, data were collected from Adjumako and Breman Asikuma; in the Eastern Region, Akim Swedru, Ayirebi, and Asantiman were selected. These sites were purposively selected because they represent key cocoa-growing areas with differing geographic and socio-economic contexts and variable exposure to climate-induced water stress. Conducting the study across multiple regions enabled the researchers to capture a broader range of perspectives on IAS.

[1]Available at: **https://hdl.handle.net/10568/178011**

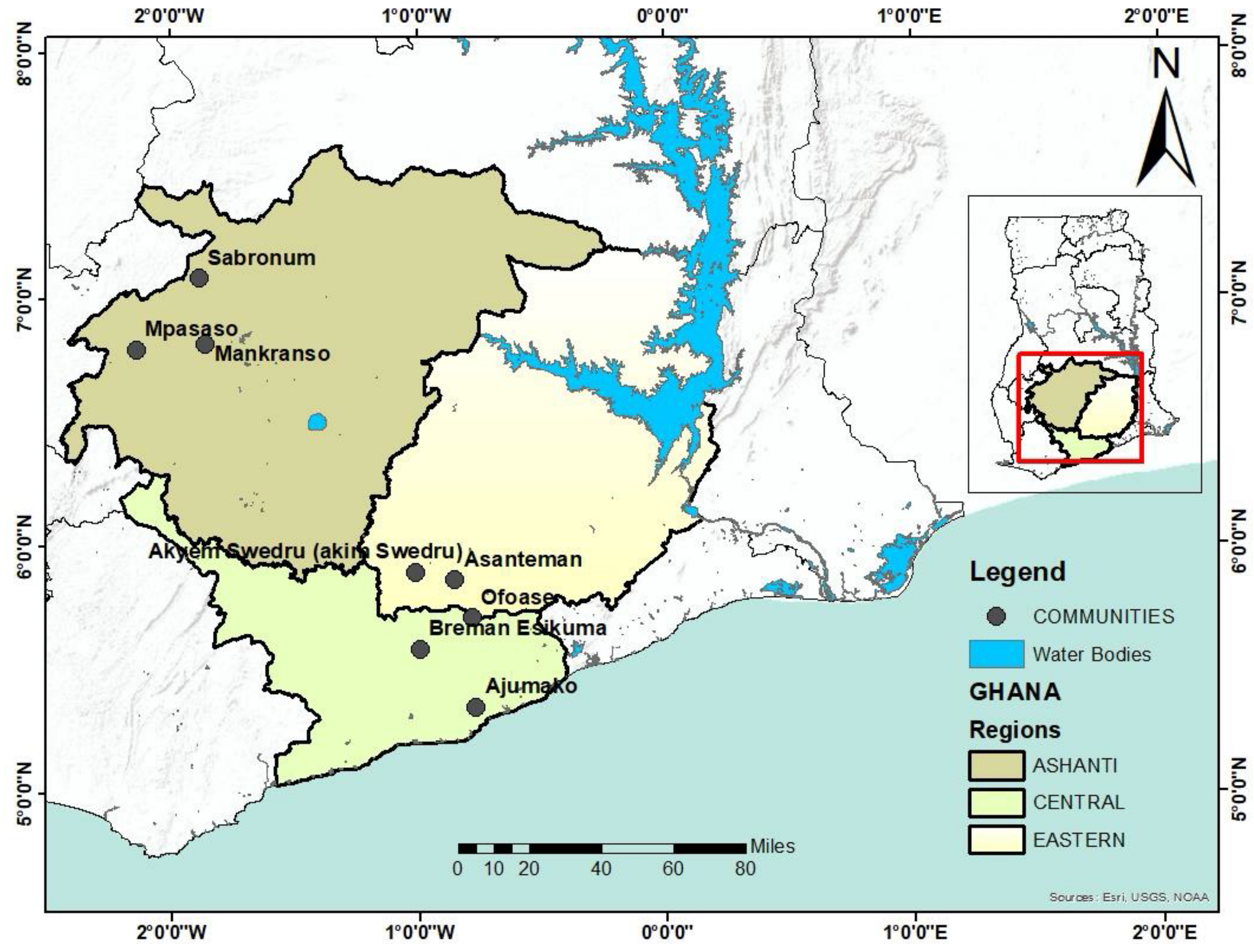


**Figure 1.** Map of the Study Area *(Source*: Author's creation)

## 2.3 Participants

Participants in the study were divided into two main groups. Cocoa farmers were the primary respondents in the FGDs. They were purposively selected for their active engagement in cocoa farming, with attention paid to including farmers of different ages, genders, and farm sizes to ensure diverse perspectives. Technical experts, particularly AEAS staff working in the cocoa sector, were engaged through KIIs, as well as, staff of Interplast and Pumptech. These individuals were selected based on their roles in supporting cocoa farmers and their involvement in agricultural advisory services. Non-cocoa farmers and stakeholders not directly engaged with IAS were excluded from the study. Each FGD consisted of between 8 to 12 participants, while at least one KII was conducted with an AEAS officer in each district.

## 2.4 Data Collection Procedures

Data collection relied on a combination of structured questionnaires, FGD guides, and KII guides. The FGDs were conducted with farmer groups in their communities, and where necessary, the discussions were facilitated in local languages by trained moderators. These sessions explored farmers' perceptions, challenges, and expectations regarding IAS. KIIs were conducted with AEAS staff, Interplast, Pumptech and other technical stakeholders to capture institutional and technical perspectives. All discussions were audio-recorded with participants' consent, and field notes were taken to document contextual observations and non-verbal cues. Data collection took place during the cocoa off-season when farmers had more time to participate fully.

## 2.5 Data Analysis

The analysis of the data followed both qualitative and quantitative approaches. The audio-recorded FGDs and KIIs were transcribed, translated where necessary, and analyzed thematically. Codes were generated from the transcripts and grouped into themes reflecting farmers' perceptions, barriers to adoption, opportunities, and institutional factors influencing IAS. The demographic data collected through questionnaires were analyzed using descriptive statistics, including frequencies and percentages, in Microsoft Excel. These quantitative results were used to contextualize the qualitative findings, giving a fuller picture of the farming communities studied.

## 2.6 Ethical Considerations

The study followed strict ethical procedures. Ethical approval was obtained from the International Water Management Institute's (IWMI) Institutional Review Board (IRB). Additional administrative clearance was secured from the regional and district offices of the Ghana Cocoa Board (COCOBOD) before engaging communities. Informed consent was obtained from all participants, and permission was sought before audio-recording interviews or discussions. Participation was voluntary, and individuals could withdraw at any time. Confidentiality was ensured by anonymizing all data and securely storing recordings and transcripts with access restricted to the research team.

# 3. Results

## 3.1 Overview of the Study Area and Participants

The findings presented here are drawn from in-depth interviews and focus group discussions conducted with farmers and extension agents across the three selected cocoa-producing regions of Ghana. Farmers represented diverse backgrounds, ranging from smallholders cultivating vegetables and cocoa to those experimenting with integrated farming systems. Extension officers included district-level agricultural officers and specialists under the Ministry of Food and Agriculture (MoFA), who provided critical insights into irrigation practices, institutional linkages, and the broader agricultural development landscape.

## 3.2 Demographics of Respondents Across the Regions

### *3.2.1 Sex*

Figure 2 presents the sex distribution of respondents involved in the study. The results show that a majority (74%) of the respondents were male, while females constituted 26%. This distribution reflects the gender composition typical of Ghana's agricultural sector, where men are often the primary landholders and decision-makers in farming activities (GSS 2021; FAO 2023). Women's relatively lower representation may be linked to gendered access to land and other productive resources, as customary norms and inheritance systems often favor male ownership and control of land in most rural farming settings (Doss and Meinzen-Dick 2020). Nonetheless, women play critical roles in cultivation, post-harvest processing, and marketing. working as paid laborers or supporting their male counterparts, highlighting the need for gender-sensitive policies that promote equitable access to land and agricultural technologies.

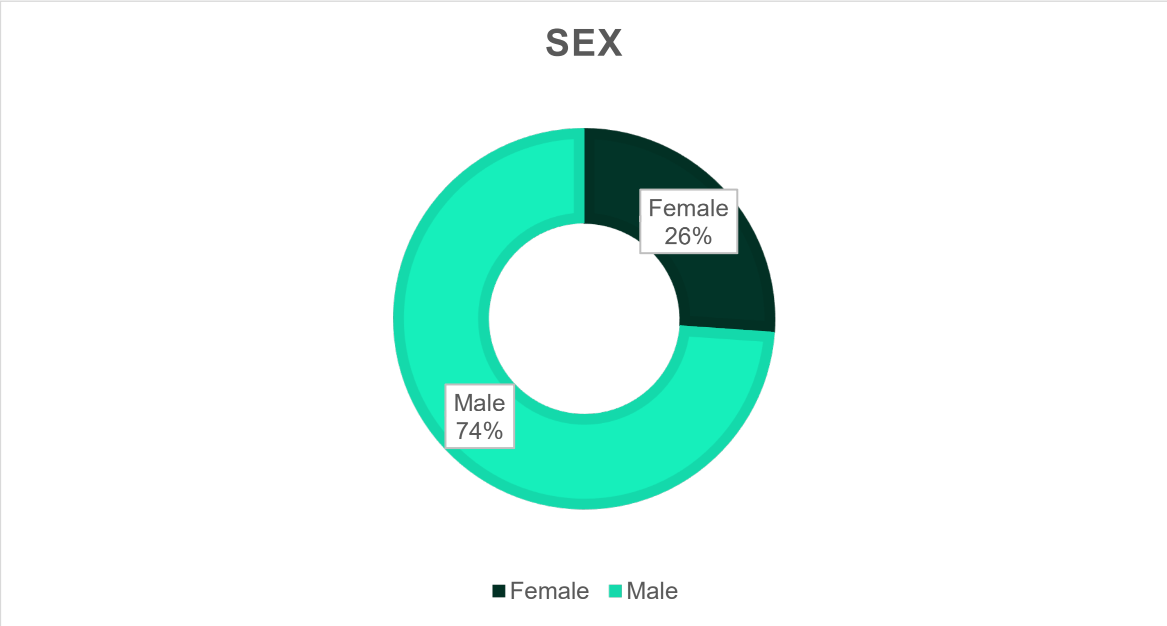


**Figure 2.** Sex Distribution of Respondents (*Source*: Author's creation)

### *3.2.2 Age*

Figure 3 shows the age distribution of respondents across the study area. The majority (62%) of respondents were aged between 36 and 60 years, indicating that most farmers are in their economically active and productive years. Respondents aged over 60 years accounted for 27%, while the youth group **(**≤35 years) represented only 11% of the sample. This age structure suggests that agriculture in Ghana remains dominated by middle-aged and older adults, consistent with national trends where the average age of Ghanaian farmers is about 47 years (GSS 2021). The low participation of youth in farming reflects a broader challenge of youth disengagement from agriculture due to limited access to land, credit, and modern technology, as well as the attraction of urban employment (Mussa 2020; Geza et al. 2022). The predominance of older farmers also has implications for technology adoption, as empirical evidence (Miine et al., 2023; Bang & Han 2025) shows that age can influence willingness to experiment with new agricultural innovations, with younger farmers generally being more receptive to modern techniques and digital tools.

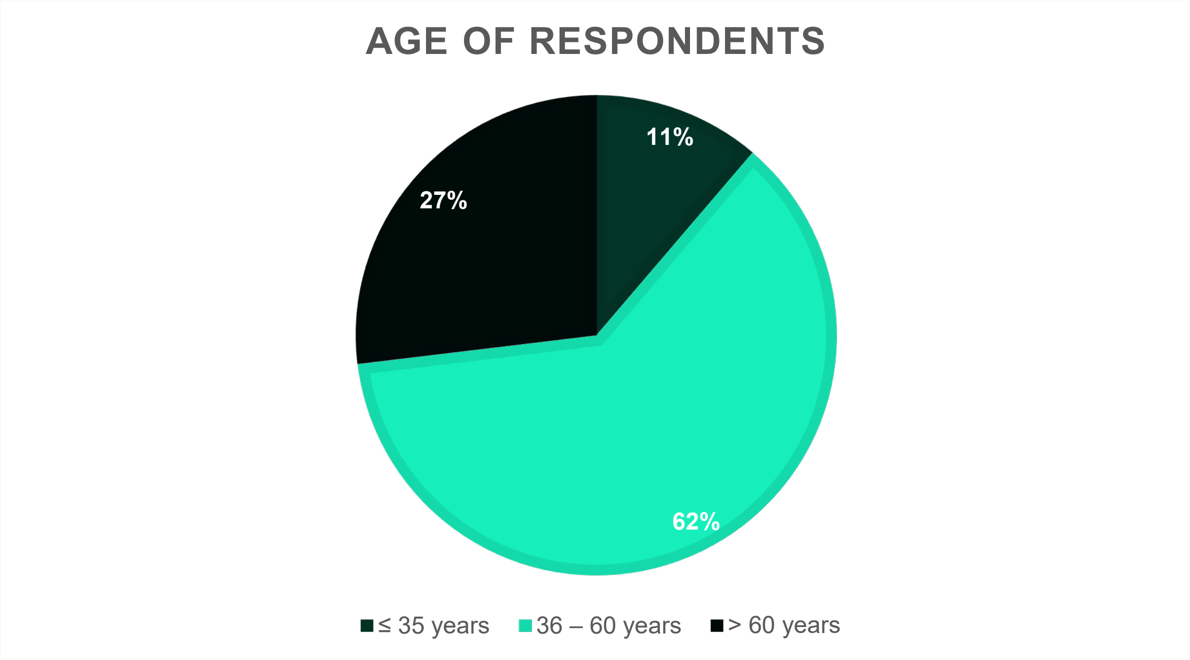


**Figure 3.** Age Categories of Respondents (*Source*: Author's creation)

### 3.2.3 *Climate impacts and the role of irrigation*

Findings from the interviews reveal a strong consensus among farmers across the three regions that climate variability has intensified and now represents a major threat to cocoa and vegetable production. Farmers consistently described delayed onset of rains, irregular rainfall distribution, and prolonged dry spells as key disruptions to their farming systems. These changes have destabilized traditional planting calendars and weakened trust in rainfed agriculture as a reliable production strategy. Instead of depending on seasonal patterns built from years of experience, farmers reported increasing uncertainty in planning farm activities, accompanied by stress linked to repeated crop losses and failed planting efforts.

This shift in rainfall reliability was clearly captured by one cocoa farmer who explained:
*"We used to plant in March, and by April, the rain would start. Now, the rains delay until May or June, and sometimes the sun burns all the crops we have planted."*

Beyond rainfall unpredictability, farmers emphasized the growing intensity of heat and its visible impact on perennial crops. Cocoa, once considered relatively resilient to climate stress, was now described as increasingly vulnerable. Farmers reported symptoms such as leaf drying, poor pod development, and general weakening of trees during extended dry periods, indicating that climate stress is no longer confined to seasonal crops but is affecting long-term productivity of cocoa farms.

One farmer shared this experience by stating:
*"The heat is too much now; even cocoa trees are drying up in some places."*

These field-level observations were reinforced by accounts from extension officers and district agricultural staff, who described moisture stress as a dominant agronomic constraint. They explained that irregular rainfall now interferes with critical growth stages such as flowering, pollination, and pod formation. As a result, yield stability has become increasingly difficult to maintain, particularly during prolonged dry seasons when soil moisture levels fall below critical thresholds for cocoa development. As a result, Cocoa Board (COCOBOD), through the Cocoa Health and Extension Division (CHED), supports cocoa farmers in establishing sustainable agroforestry by distributing free seedlings of specific forest trees, such as Ofram (*Terminalia superba*) and Odum (*Milicia excelsa*). These trees are essential because they are strategically planted across the cocoa farm to develop a permanent shade canopy, which protects the cocoa trees from excessive sunlight and heat, thereby regulating the microclimate. While the cocoa trees are planted densely at approximately 3.0 m x 3.0 m the shade trees are planted much wider apart, typically at distances of around 24 m x 24 m, to achieve the optimal 30-40 shade cover necessary for healthy cocoa growth and yield diversification.

An extension officer linked these production challenges directly to the need for irrigation support, noting:

> *"In the dry season, most farms start to wither. If this irrigation initiative is introduced, it will really help them."*

Private irrigation service providers also reported a noticeable shift in farmer behaviour. They observed a growing number of enquiries related to water pumping systems, suggesting rising awareness of the need for more reliable water sources. However, providers expressed uncertainty about the underlying drivers of this emerging demand, questioning whether it was primarily a result of lived climate stress or the effect of increased sensitization activities and promotional campaigns.

A company representative reflected this uncertainty by stating:

> *"Yes, I've seen that there's an increase… but I don't know whether I should attribute it to sensitization or climate change."*

In parallel, irrigation experts described sustained outreach efforts focused on promoting renewable energy–powered irrigation technologies. These initiatives were presented as deliberate attempts to shift farmer perceptions and encourage proactive adaptation to climate risks through improved water management.

An irrigation specialist explained:

> *"For like three years now, we've gone around the country sensitizing farmers on the need to use renewable energy pumps."*

**Figure 4.** Focus Group Section with Farmers in the Ashanti Region (*photo*: Daniel Agyemang/IWMI)

### *3.2.4 Perceptions and use of irrigation technologies*

Across the study areas, farmers generally viewed irrigation positively, recognizing its potential to improve crop yields and stabilize production during dry periods. However, their enthusiasm was often tempered by limited exposure to irrigation technologies, financial constraints, and uncertainty about whether these systems could be successfully applied on cocoa farms with existing resources and labour arrangements. Irrigation companies consistently emphasized that farmers preferred technologies that were affordable, easy to operate, and appropriate for the types of crops they cultivated. Drip irrigation was frequently highlighted as the most efficient option, particularly when paired with solar-powered pumping systems, as this combination improves water-use efficiency, reduces labour requirements, and lowers long-term operating costs.

*"The best is drip system… drip goes perfectly with solar."(A farmer explained)*

Preferences for irrigation technologies were not uniform across ecological zones. Environmental conditions strongly influenced farmers' perceptions and decisions. Farmers in northern Ghana were less inclined to adopt drip systems because extreme heat caused surface pipes to warm the water excessively, which could negatively affect crops and reduce system reliability. In contrast, farmers in the southern cocoa-growing areas were more receptive to drip systems, especially for horticultural and tree crops. This is because the heat is not as extreme as it is in the north of Ghana. These differences demonstrate how ecological realities shape both the perceived and practical usefulness of irrigation technologies.

*"Farmers up north do not like drip… the water becomes very hot… but down south, they prefer drip." (An irrigation expert explained)*

Cost was identified as a dominant factor influencing adoption across all locations. Even when farmers recognized the benefits of drip or solar irrigation, the high upfront investment often prevented them from acquiring these systems. Farmers frequently inquired about low-cost alternatives or flexible payment schemes to make irrigation more financially accessible, highlighting how economic considerations can override technical suitability in decision-making.

*"They always look at cost… if they can have interest-free loans, they would much appreciate it." (According to an irrigation expert)*

The availability of training and technical support was another important factor. Many farmers lacked the knowledge to install, operate, or troubleshoot irrigation systems independently, making after-sales support crucial for sustained use. Suppliers often provided basic troubleshooting guidance and sent technicians to assist with more complex issues, reflecting farmers' preference for technologies that come with reliable support rather than systems that they must manage entirely on their own.

*(An irrigation expert emphasized)*

*"We give training… basic troubleshooting and maintenance. If the farmer can't resolve it, we send a technician to the farm."*

Among cocoa farmers, direct experience with irrigation was generally limited. Many FGD participants had never practiced irrigation and were initially unfamiliar with how such systems worked. Once the concept was introduced, farmers expressed significant interest, especially in solar-powered systems, which they associated with lower operating costs and the potential to stabilize cocoa production during dry seasons.

*"If we could have water when the sun shines very hot, the cocoa can yield more…We prefer the solar one because fuel is costly."*

Extension officers confirmed that only a few pilot installations existed in the districts, mostly through COCOBOD or donor programs. While these demonstrated the potential benefits of irrigation, they also revealed practical challenges such as insufficient groundwater and mechanical failures, highlighting structural difficulties that can hinder long-term viability.

*"The borehole was dug, but the water was not enough. Later, another machine was brought to drill again."*

Farmers also expressed concerns about the security of irrigation infrastructure. Theft and vandalism were perceived as major risks, suggesting that protective measures would be necessary to safeguard investments and ensure sustainability.

*"If we have spent so much on this, we have to build around the setup and lock it all the time."*

Extension officers emphasized that irrigation adoption could be enhanced through adequate technical support, community sensitization, and practical demonstrations. They argued that given increasing climate variability and unpredictable rainfall, farmers need to understand not just how irrigation works but why it matters for cocoa productivity. The officers suggested that education and awareness-raising could help farmers appreciate the agronomic benefits, such as a consistent water supply for cocoa trees, while also building confidence to invest in and maintain irrigation systems.

> *"Irrigation is important because the cocoa tree, like any other tree, needs water to grow well. Now that the weather is unpredictable, irrigation will really help."*

### *3.2.5. Existing IAS models and enabling conditions*

Although formal Irrigation-as-a-Service (IAS) models are not yet fully operational in the study communities, several respondents described informal arrangements that resemble service-based irrigation systems. In many communities, farmers with private wells or boreholes sell water to other farmers during the dry season. These transactions are often trust-based, negotiated locally, and operate on a pay-per-use principle.

> *"Some people have wells, and when it's dry, they sell water to us who need it to water vegetables. You just pay for what you fetch."* (A farmer explained)

Across the farming communities, the practice of sourcing and paying for irrigation water is already deeply rooted in everyday agricultural life. During the long dry months from December to March, when rains disappear and the soils harden, farmers rely heavily on purchased water for irrigating young cocoa seedlings, watering vegetable plots, and mixing fertilizers and agrochemicals. This informal but functional system allows them to sustain crops and nurseries through the most water-stressed period of the year. In communities such as Mpasaso, Sabronum, Afreseni, Mankranso, Ajumako, and Nyamekye, it was common for farmers to buy water directly from household-owned boreholes and wells, which operate as small-scale private water points. Water is typically fetched in *Kufuor gallons*, each costing around 50 pesewas, while those needing larger quantities purchase "polytank" refills at roughly 15 cedis per tank, depending on size. As the rains return between April and July, most farmers reduce their reliance on purchased water, using it mainly for mixing foliar feeds and pesticides, or during short dry breaks in August to keep young plants alive. The minor rainy season from September to November again brings natural relief, but by late November, preparations begin for the next dry spell renewing the cycle of paid water access. Transporting this water to farms adds another layer of cost and coordination; tricycles or "*motor kings*" are widely used, charging 10 to 30 cedis per trip depending on distance. Together, these practices show how a culture of water as a service rather than a permanent infrastructure investment has evolved as a practical adaptation to Ghana's seasonal rhythms and unpredictable rainfall. Despite, these costs, farmers continue to rely on this arrangement because it allows them to maintain some level of crop watering during dry periods, especially when no alternative water infrastructure is available. This everyday practice highlights that the foundational mindset and behavioral patterns necessary for adopting formal Irrigation-as-a-Service (IAS) models are already present at the community level. Farmers are, in effect, engaging in a form of pay-per-use water management, driven by necessity and local innovation to cope with water scarcity. However, while these informal mechanisms fill critical gaps, efforts to scale them into collective or group-managed irrigation systems remain hindered by limited financial capacity, inconsistent infrastructure, and low levels of trust and cooperation among farmers. Strengthening these informal foundations through structured financial support, trust-building initiatives, and institutional coordination could thus serve as a practical entry point for formal IAS implementation in rural Ghana.

> *"Coming together is not bad, but we cannot afford to contribute. Everyone is struggling with their own farms."* (One female farmer stated)

This highlights a significant social and economic barrier: while farmers value collaboration in principle, resource scarcity and livelihood fragility make joint investment in irrigation systems challenging. These constraints reflect the interplay between economic pressures and social cohesion, which can limit the effectiveness of collective irrigation approaches. At the institutional level, district agricultural officers identified ongoing government initiatives that could create enabling conditions for IAS development.

One officer noted:

> *"If government will establish farmer service centers with irrigation and storage facilities. Farmers can rent tractors and have all-year-round farming. That could help us a lot."*

In several farming communities, irrigation services are already being provided informally through locally organized arrangements by other farmers. For instance, in Mankranso, located within the Ahafo Ano Southwest District of the Ashanti Region, a respondent described how farmers in the area used to access rental options for irrigation equipment such as pumps, pipes, and related accessories. The cost of hiring a pump was typically around 100 Ghana cedis per day, with an additional charge of approximately 50 cedis to cover repairs whenever faults occurred. Fees varied according to the type (Length) and quantity of equipment hired; for example, renting only pipes cost averagely 20 cedis per pipe, with the total amount determined by how many pipes needed, multiplied by the price of the pipe. Flexible pump hoses were also part of these rental services. These hoses commonly 25 mm (1"), 38 mm (1.5"), and 50 mm (2") in diameter were available in lengths ranging from 10 to 30 meters. The cost of renting these hoses varied depending on the length requested; shorter hoses (e.g., 10 m) attracted lower charges, while longer hoses (e.g., 20–30 m) cost progressively more due to their greater utility and higher replacement cost. These flexible hoses were valued for their ease of movement, adaptability to different field sizes, and suitability for farms with uneven terrain. These informal rental services operated effectively until around 2022 but had largely ceased by late 2024. Community members attributed this decline to a rise in illegal small-scale mining activities (commonly known as *galamsey*), which have severely degraded farmland, polluted water bodies, and sparked land tenure conflicts. Additionally, the absence of local repair workshops made it increasingly difficult to maintain or replace damaged irrigation equipment, further discouraging the continuation of these community-based irrigation service arrangements. Consequently, many vegetable farmers were forced to abandon or relocate their farms, resulting in a sharp drop in demand for irrigation rentals and the eventual collapse of these community-based systems. Nevertheless, such grassroots initiatives demonstrate significant potential as prototypes for more formalized, service-based irrigation models. When supported with targeted technical training, affordable financing mechanisms, and reliable maintenance services, they could help address many of the persistent barriers hindering the widespread adoption of structured irrigation technologies. However, the sustainability and scalability of these interventions will ultimately depend on strong coordination among key stakeholders including government agencies, district assemblies, farmer associations, and private sector partners to ensure coherent policy support, resource mobilization, and long-term operational viability.

### *3.2.6 Viability of solar-powered IAS bundles and business models*

Evidence from farmers, extension workers, and private irrigation firms reveals a strong and consistent framing of solar-powered irrigation systems as the most appropriate technological pathway for smallholder farming under current economic and environmental conditions. Respondents contrasted solar technologies with fuel-powered pumping systems, which were widely described as financially unstable and operationally risky. Rising fuel prices, price volatility, and unreliable fuel supply chains were reported to create significant uncertainty in production planning. For many farmers, fuel-based irrigation was associated with a cycle of high recurrent costs that diminished profitability and made sustained irrigation economically unattractive, particularly for small landholdings where margins are already narrow.

One farmer explained:

> *"If you buy fuel every day to pump water, the profit finishes."*

Another farmer connected the discontinuation of irrigation practices to escalating fuel prices, explaining:

> *"That's why many stop when fuel prices go up."*

Beyond economic considerations, solar irrigation systems were perceived as technically compatible with the realities of rural farming communities. Respondents highlighted their ability to function independently of unreliable fuel markets and weak grid infrastructure, making them particularly suitable for off-grid and underserved areas. Farmers and extension officers also emphasized the perceived environmental benefits of solar technologies, framing them as cleaner and more future-oriented compared to diesel or petrol alternatives. This perception positioned solar irrigation not merely as a cost-saving tool, but as a modern and climate-aligned technology that resonates with increasing awareness of environmental degradation and resource scarcity.

This institutional perspective was reflected by an extension officer who stated:

> *"Solar is the best. It saves cost and helps the environment."*

At the level of delivery models, farmers consistently demonstrated a clear preference for service-based access arrangements rather than individual ownership. This preference was rooted in concerns about the high upfront costs of equipment, the technical complexity of system maintenance, and the risk of system breakdowns. Farmers described ownership as a financial and operational burden, while service-based models were framed as more flexible and less risky, particularly when structured around small, usage-based payments. This approach was perceived as aligning better with seasonal cash flows and the uncertainty inherent in rain-dependent farming systems.

A farmer articulated this preference by stating:

> *"We don't need to own it. If someone brings it and we pay for the water, that one is good."*

Private irrigation companies expanded on the commercial and technical realities of operationalizing these preferences. They described a range of emerging and potential business models, including pay-as-you-go arrangements, cooperative service schemes, and hire-purchase systems designed to lower entry barriers for farmers. However, they repeatedly emphasized that the feasibility of these models is not determined solely by farmer demand or willingness to pay, but by underlying biophysical constraints. Variability in groundwater recharge rates, borehole depth, and yield capacity were highlighted as fundamental factors shaping the scale and reliability of irrigation services.

This technical limitation was illustrated by a company representative who noted:

> *"Sometimes boreholes cannot supply even one hectare."*

Within this context, solar-powered irrigation service models were framed as highly promising but inherently uneven in their potential outcomes. Their practicality was described as being tightly bound to the interaction between local water resources, financial structures, and institutional capacity to manage and maintain systems over time, rather than the technological merits of solar equipment alone.

**Figure 5.** Focus Group Discussion in the Central Region (*photo:* Daniel Agyemang/IWMI)

### *3.2.7 Partnerships, financing, and demand–supply linkages*

Evidence from the interviews indicates that financing represents one of the most decisive constraints shaping farmers' engagement with irrigation and other agricultural innovations. Farmers consistently describe highly constrained and seasonal cash flows, where cocoa revenues are rapidly absorbed by immediate household priorities. Income from harvests was largely directed toward food security, school fees, healthcare costs, and other basic social obligations, leaving very limited surplus for reinvestment in farm infrastructure or new technologies. This pattern of financial prioritization reflects the dual role of smallholder farming as both a production and survival system, where short-term household welfare frequently overrides longer-term investment decisions.

This lived financial pressure was expressed by farmers who described the rapid depletion of farm income following harvest periods:

> *"After harvesting cocoa, we use the money to buy food and pay school fees."*

Another farmer explained the cyclical nature of this constraint by stating:

> *"By the time planting season comes again, there's nothing left."*

From an institutional perspective, extension officers acknowledged that financial capability constraints are compounded by limited access to structured financial literacy and farm business development support. Many farmers were described as having little exposure to formal savings mechanisms, budgeting practices, or long-term investment planning. Without systematic training in farm financial management, farmers tend to operate on short-term, reactive financial strategies that further limit their ability to engage with capital-intensive technologies such as irrigation. In an effort to enhance farmers' livelihoods beyond cocoa production, some farmers are being trained in various income-generating skills such as snail farming, soap making, and other small-scale enterprises. These initiatives are designed to provide farmers with additional sources of income during the off-season, helping to buffer them against fluctuations in cocoa yields and seasonal income gaps. While these skill-development programs offer practical opportunities to diversify income, extension officers noted that formal financial management training has not yet been provided. This gap suggests that, although farmers may acquire new skills, their ability to plan, budget, and manage income from these activities may remain limited, potentially constraining the long-term impact of such interventions.

An extension officer captured this institutional gap by noting:

> *"We have not done formal financial management training for farmers."*

Private irrigation companies framed financing as a systemic issue that extends beyond individual farmer capacity. They emphasized that the scaling of irrigation technologies is heavily dependent on the availability of structured financial products from formal banking and microfinance institutions. Hire-purchase arrangements, credit facilities, and flexible repayment structures were described as central mechanisms for bridging the gap between farmer demand and technology costs. Without institutional finance, irrigation investments were viewed as unattainable for most smallholders.

This dependency on financial intermediaries was expressed by a technology supplier who stated:

> *"That's where the banks have to come in… like hire purchase."*

In addition to credit access, private sector actors highlighted the macro-level cost environment as a significant barrier. Import duties, taxes, and regulatory charges on irrigation equipment were described as substantially inflating final prices and transferring additional financial risk onto farmers. These fiscal factors were perceived to undermine affordability and weaken incentives for both suppliers and farmers to engage in irrigation investment.

One irrigation supplier described this burden by stating:

> *"The taxes are a killer… 21.9% bracket… this further burdens the farmer."*

Respondents also emphasized the importance of coordinated institutional partnerships in enabling sustainable irrigation development. Collaboration between government agencies, private companies, financial institutions, and farmer-based organizations was widely framed as essential for reducing risk, mobilizing investment, and ensuring technical and financial support across the value chain. At the same time, some extension officers expressed caution about the nature of government involvement, warning that direct operational control could introduce political interference and distort implementation processes.

This concern was captured by an officer who stated:

> *"The moment if the government gets involved, politics comes in."*

Beyond production and technology considerations, farmers consistently linked irrigation adoption to market security. Respondents stressed that increased production only becomes meaningful if reliable market channels exist to absorb surplus output at reasonable prices. Without access to stable markets, farmers viewed irrigation investment as financially risky, regardless of technical feasibility.

This market-oriented concern was articulated by one farmer who explained:

> *"Even if we get irrigation and grow more, we must have somewhere to sell."*

This perspective highlights that irrigation is not viewed by farmers as an isolated technical intervention, but as part of a broader commercial farming system that depends on functional value chains. The absence of guaranteed market access undermines incentives to invest in water management technologies, as increased production without assured sales exposes farmers to income loss and post-harvest risks. This finding underscores the interdependence between irrigation adoption, market infrastructure, and price stability, and suggests that technical solutions alone are insufficient without parallel investments in marketing systems, storage, and value chain coordination.

**Figure 6.** Focus Group Discussion in the Eastern Region (*photo:* Daniel Agyemang/IWMI)

### *3.2.8 Barriers to adoption*

Interviews across all actor groups revealed that, despite strong expressed interest in irrigation, farmers face a dense set of interconnected constraints that significantly limit actual adoption. Financial barriers were consistently identified as the most immediate and pervasive challenge. Many farmers reported operating under chronic resource scarcity, where even essential farm inputs such as fertilizers are difficult to afford. The high upfront costs of irrigation equipment, combined with irregular income flows, were described as structurally misaligned with the financial realities of smallholder cocoa production.

This financial constraint was sharply expressed by a farmer who stated:

> *"We cannot even buy fertilizers; how can we buy machines?"*

Beyond financial limitations, water availability and water quality were repeatedly described as critical environmental constraints. Farmers in several communities reported that illegal mining activities have degraded local water bodies, destroyed streams, and polluted surface and groundwater sources. These environmental changes were perceived to undermine the very feasibility of irrigation by removing reliable and safe water supplies, with some farmers reporting direct crop damage when polluted water was used for watering.

These environmental pressures were captured by farmers who explained:

*"The streams are destroyed by galamsey."*

*"When you fetch that water, the crops die."*

Infrastructure gaps further constrained irrigation practices across the study sites. Farmers consistently reported the absence of basic physical components required for irrigation, including hoses, storage tanks, reservoirs, and functional water conveyance systems. In the absence of these structures, many farmers resorted to manual water transport using buckets and gallons, an approach that is highly labour-intensive and unsuitable for scale.

This infrastructural constraint was summarized by one farmer who stated:

*"We don't have hoses or tanks. We just carry water in gallons."*

Spatial characteristics of farmland also emerged as a structural barrier. Cocoa farms were commonly described as spatially fragmented and widely dispersed, making it difficult to design and implement shared irrigation infrastructure. Land fragmentation reduced the technical feasibility of centralized water systems and complicated collective management arrangements.

A cocoa farmer described this challenge by stating:

*"Our cocoa farms are scattered everywhere."*

Security concerns further limited willingness to invest in irrigation technology. Farmers expressed fears of theft and vandalism, particularly regarding solar panels, pipes, and pumps. These risks increased the perceived exposure of farmers to financial loss and discouraged investment in fixed infrastructure. Respondents suggested physical protection measures as necessary preconditions for system installation.

This concern was articulated by a farmer who stated:

*"We should build a wall around it and lock it with a key."*

Institutional weaknesses were also emphasized by both farmers and extension staff. Respondents described limited field presence by public agricultural agencies and inconsistent technical backstopping. Staff shortages, poor logistics, and weak supervisory systems were reported to reduce the visibility and effectiveness of extension services, limiting farmers' access to technical guidance and follow-up support.

A farmer described this gap by stating:

*"Sometimes we don't see anyone from the Extension agent for months."*

Private irrigation companies further highlighted after-sales service failures as a significant implementation barrier. Suppliers reported that installers often fail to respond promptly to technical faults, leaving farmers with non-functional systems and unresolved operational challenges. This was seen as eroding farmer trust in irrigation technologies and service providers.

A private supplier explained:

> *"When faults happen, farmers call the installers, but they don't respond."*

These interconnected barriers reveal that irrigation adoption is constrained not by a single limiting factor but by the compounding interaction of financial exclusion, environmental degradation, infrastructural deficits, land tenure patterns, security risks, weak institutional capacity, and fragmented service delivery. The persistence of these constraints indicates that effective irrigation interventions require coordinated, multi-level responses addressing economic, ecological, technical, and governance dimensions simultaneously. Some farmers in the Eastern region stressed on maintenance issues. The core problem is a centralized supply chain bottleneck, requiring them to travel to Accra just to find necessary replacement parts for pipes or the pump itself. This dependency results in long downtime intervals between a fault occurring and the final fix, directly hindering agricultural progress and productivity. Compounding this logistical issue is a service failure where contacted installers often demand unforeseen and additional fees before providing assistance, creating an unexpected financial barrier to timely repairs.

**Figure 7.** Solar Irrigation facility (*photo*: Daniel Agyemang/IWMI)

# 4. Discussion

## 4.1 Climate Impacts and the Role of Irrigation

Across the three study regions, farmers consistently described climate variability as one of the most pressing threats to smallholder agriculture. Participants from the Eastern, Ashanti, and Central Regions reported that rainfall has become increasingly unpredictable, with prolonged dry spells and irregular onset of rains disrupting traditional cropping calendars. In cocoa-growing communities, these shifts have been particularly damaging. Farmers explained that erratic rainfall disrupts cocoa growth by delaying flowering and causing young pods to wither, while also increasing vulnerability to pests such as capsids. Capsid infestation, caused by insects of the *Helopeltis* species, leads to pod and flower damage, reduces pod set, and can significantly lower yields if left unmanaged. These experiences reflect national and subregional evidence showing that climate change is already undermining cocoa production through drought stress, temperature extremes, and shifting rainfall patterns (Anim-Kwapong and Frimpong 2008; Owusu and Waylen 2013; Asante and Amuakwa-Mensah 2015). The Intergovernmental Panel on Climate Change (IPCC, 2022) similarly identifies West Africa as one of the regions most exposed to climate-induced agricultural losses.

Farmers across all regions now view irrigation as central to climate risk management. In the Eastern Region, where mixed cropping systems are common, irrigation is increasingly used to secure dry-season vegetable harvests and maintain shade trees on cocoa farms. In the Ashanti Region, participants linked irrigation directly with yield stability, noting that without supplemental water, cocoa farming may lose economic viability. Community leaders in the Central Region emphasised irrigation's potential to stabilise incomes and reduce youth migration. These perceptions align with broader evidence that irrigation strengthens adaptive capacity by reducing reliance on erratic rainfall and enabling year-round food and cash crop production (Namara et al. 2011; Burney et al. 2010).

Farmers also associated irrigation with a sense of independence from the uncertainties of rain-fed agriculture. Many viewed it as a strategic investment that could allow confident planning of cropping activities and transition into higher-value production systems. This resonates with the notion of "transformative adaptation," where technological choices drive long-term resilience and shifts in livelihood trajectories (Adger et al. 2009). Yet, while irrigation is widely understood as a pathway to climate resilience, adoption remains constrained by financial, institutional, and technical barriers explored in subsequent sections.

## 4.2 Perceptions and Use of Irrigation Technologies

Farmers' awareness of climate threats was high across regions, but practical experience with irrigation technologies varied. In the Eastern Region, vegetable farmers had some exposure to motorised pumps and basic drip systems, while in the Ashanti and Central Regions predominantly cocoa-growing areas most participants had never operated a mechanised irrigation system. Nevertheless, attitudes toward irrigation technologies were largely positive. After being introduced to solar-powered systems during the interviews, farmers described them as modern, sustainable, and cost-effective alternatives to manual watering or diesel pumps.

The positive orientation toward irrigation corresponds with the diffusion of innovation theory (Rogers 2003), which underscores that adoption is shaped by perceived relative advantage, compatibility with existing practices, and observability. Farmers identified irrigation's main advantages as improved yield stability, higher pod quality, and reduced crop loss. In communities where pilot demonstrations had been implemented, farmers noted visible improvements in crop health, reinforcing positive perceptions.

Technical challenges were frequently cited. Farmers stressed the shortage of local technicians, high repair costs, and long delays in servicing broken pumps. These concerns reflect broader national challenges in irrigation diffusion, where weak technical support systems limit sustained use (Kyei-Baffour and Ofori 2015). Regional nuances also shaped perceptions. In Ashanti, irrigation was sometimes perceived as incompatible with cocoa systems due to farm size, slope, or shade cover. In contrast, farmers in the Eastern Region accustomed to vegetable irrigation showed readiness to experiment with irrigation for mature cocoa, suggesting opportunities for cross-crop learning. Concerns about theft of solar panels and pipes were most pronounced in the Central Region, where farmers emphasised security risks due to dispersed farm locations.

## 4.3 Existing Irrigation Ownership Models and Enabling Conditions

Formal irrigation-as-a-service (IAS) models remain limited across the three regions. However, informal sharing arrangements, already exist, particularly in the Eastern Region. Farmers who own pumps often rent them out during the dry season, enabling others to access water. These practices mirror the informal irrigation economies described in other sub-Saharan African contexts (Shah et al. 2016; Burney et al. 2010). In Ashanti and Central Regions, interest in IAS was strong, though few community-level precedents existed.

Participants identified several conditions necessary for successful IAS implementation. Financing mechanisms was most crucial, as farmers stressed that no single household could independently fund boreholes, pumps, or solar systems. Collective approaches such as cooperatives or community-managed systems were viewed as viable alternatives. This aligns with evidence that water user groups and collective action structures strengthen irrigation governance and system sustainability (Meinzen-Dick et al. 2014). Land tenure insecurity under Abusa and Abunu arrangements remained a major barrier in Ashanti and Central Regions. Many farmers lacked authority to install permanent structures on shared land, limiting their willingness to invest. In contrast, more secure tenure arrangements in parts of the Eastern Region created a favourable environment for IAS experimentation.

Institutional coordination emerged as another enabling factor. Farmers emphasized that IAS could only be sustained through clear partnerships involving farmer groups, technology providers, and financial institutions. These local governance arrangements provide the social infrastructure needed to scale irrigation access.

## 4.4 Viability of Solar-Powered IAS Bundles and Business Models

Solar-powered irrigation was widely viewed as a desirable technology option across all three regions. Farmers emphasised its low operating costs, independence from fuel supply fluctuations, and environmental suitability. Given Ghana's solar resource profile, participants considered solar systems to be a practical long-term investment. These views are consistent with studies showing that solar-powered irrigation can significantly reduce operational costs compared to diesel-based alternatives (Huber et al. 2017; IRENA 2021).

Participants proposed several business models to facilitate access. Cooperative ownership structures were strongly supported, particularly in the Central and Ashanti Regions, where collective action already underpins activities such as group marketing. Pay-as-you-go and seasonal repayment options were also viewed as compatible with household cash flow patterns. These financing preferences highlight the need for flexible and context-sensitive models that match agricultural income cycles.

Technical officers from irrigation companies and local dealers offered complementary insights relevant to system viability. They highlighted the importance of routine maintenance, the availability of spare parts, and appropriate system sizing based on crop water requirements. Dealers also noted growing interest from farmers but stressed that demand remains constrained by limited awareness, high upfront costs, and challenges in securing payments from individual farmers. They emphasised that solar IAS can only succeed if embedded within structured financing mechanisms and supported by effective after-sales service networks. Concerns about panel theft and system vandalism were also echoed by dealers working in the Central Region. Proposed solutions included community security arrangements and the installation of fenced or elevated systems to deter theft.

## 4.5 Partnerships, Financing, and Demand–Supply Linkages

Financing emerged as one of the most persistent constraints to irrigation adoption across all study regions. Limited liquidity between cocoa harvest seasons restricts farmers' ability to invest in irrigation hardware or pay for repairs. This mirrors broader evidence on smallholder financing constraints, where high transaction costs and limited collateral restrict access to credit (Karlan et al. 2014; GSS 2022).

Participants across the regions outlined partnership-based solutions that reflect a triadic model involving government, private firms, and cooperatives. Under this arrangement, government institutions would provide policy incentives and regulatory support; private-sector actors particularly irrigation dealers and service companies would oversee installation, maintenance, and supply chains; and cooperatives would coordinate farmer mobilisation, credit management, and repayment. Similar multi-stakeholder irrigation models have recorded success in other African contexts by enhancing accountability and reducing operational bottlenecks (FAO 2020).

Farmers and irrigation companies both stressed the importance of strengthening demand–supply linkages. Dealers highlighted that the success of irrigation systems depends not on hardware delivery alone but on the availability of local technicians, timely repairs, and district-level spare part depots. Farmers noted that distant service centres often lead to delays that can jeopardise crop health during critical periods. Together, these insights confirm that irrigation adoption depends on well-integrated service ecosystems, combining technology supply, technical support, and financial facilitation.

Innovative financing mechanisms were also discussed. Participants proposed revolving funds, cooperative credit schemes, group-based guarantees, and donor-supported subsidies as ways to reduce individual risk. In areas where pilot irrigation projects had shown visible yield improvements, willingness to co-invest increased markedly. These findings underscore the importance of credibility, demonstrated benefits, and trust in driving irrigation uptake.

## 4.6 Barriers to Adoption

The barriers identified across regions were multidimensional, spanning economic, technical, environmental, and institutional challenges. High upfront installation costs were the most consistently cited constraint. Poor road infrastructure and challenging terrain in parts of the Ashanti and Central Regions further complicated system installation and maintenance. Technical breakdowns and inadequate local repair capacity often led to long periods of system non-use, diluting farmers' confidence in investing in mechanised irrigation.

Environmental constraints were also highlighted. In the Eastern Region, illegal mining and water pollution have degraded streams and rivers, limiting both the availability and quality of surface water for irrigation. This supports earlier studies emphasising the need for environmental safeguards in irrigation planning (Namara et al. 2011).

Socio-cultural and institutional barriers intersected with these challenges. Some farmers expected irrigation systems to be provided freely by government or donors, particularly in communities where past interventions had been heavily subsidised. Such expectations reduce willingness to engage with private-sector actors. Land tenure insecurity under sharecropping arrangements discouraged investment in long-term infrastructure. Additionally, women and youth despite their increasing role in cocoa production faced greater difficulty accessing finance, land, and formal decision-making structures. Without deliberate inclusion strategies, irrigation programs may reproduce existing inequalities, echoing findings from gender and technology adoption research in Africa (Doss and Morris 2001).

# 5. Conclusion

This study examined the role of irrigation in supporting climate resilience among smallholder cocoa farmers in the Eastern, Ashanti, and Central Regions of Ghana, with a particular focus on solar-powered Irrigation-as-a-Service (IAS) models. Climate variability, manifesting as erratic rainfall, prolonged dry spells, and rising temperatures, has disrupted traditional cocoa farming systems and reduced yield reliability. In response, farmers increasingly view irrigation as a critical adaptation strategy, helping to stabilize production, secure income, and maintain livelihoods under changing climatic conditions. Across all regions, irrigation is no longer seen as an optional input but as a necessary tool for maintaining cocoa farm viability and reducing vulnerability to climate shocks.

Private-sector irrigation companies and dealers reported a steady rise in demand for irrigation technologies over the past three years, reflecting both increased climatic pressures and ongoing farmer sensitization campaigns. Companies highlighted that farmers' adoption choices are shaped by cost, crop type, and perceived ease of use, with solar-powered drip systems emerging as a preferred option, particularly for vegetables and cocoa intercropped systems. Despite growing interest, uptake remains constrained by upfront costs, limited water availability, and the need for technical support. Dealers emphasized the importance of after-sales services, including installation guidance, maintenance, and troubleshooting, which are critical for ensuring sustained use. In response, companies have piloted projects in partnership with banks, CocoBod, and development organizations, offering flexible payment options and technical training to expand access to irrigation while addressing farmers' practical barriers. These initiatives illustrate that service-based irrigation models have the potential to broaden adoption and strengthen climate resilience.

Solar-powered IAS offers strong potential for expanding smallholder irrigation because it provides low operating costs, energy independence, and suitability for off-grid rural environments. However, it remains largely unfamiliar to farmers and is essentially absent within cocoa-growing communities in Ghana. The study indicates that successful deployment of such models requires a combination of accessible financing, sustained technical support, and careful planning around water availability. Approaches such as cooperative management, pay-as-you-go arrangements, and seasonal repayment schemes fit well with farmers' cash flow patterns can help address challenges related to high upfront costs and technological complexity. Irrigation companies further stressed that correct system sizing, dependable water sources, and ongoing capacity-building are crucial to ensuring the effectiveness and long-term viability of solar-powered IAS.

Regional dynamics shape adoption patterns and the feasibility of scaling solar-powered irrigation. In the Eastern Region, farmers demonstrate readiness to adopt solar systems when financing and technical support are available. In the Ashanti Region, cooperative-based initiatives and pilot programs have facilitated adoption by enabling cost-sharing and collective oversight. In the Central Region, however, environmental challenges including water scarcity, degraded sources from illegal mining, and infrastructural limitations restrict expansion and necessitate integrated water management alongside technological interventions.

Finally, sustainable irrigation development requires attention to interconnected financial, technical, environmental, and social factors. Land tenure insecurity, limited technical capacity, and the exclusion of women and youth from decision-making continue to constrain adoption. Private-sector actors highlighted that combining flexible financing, cooperative structures, and technical training can effectively address these barriers. Strengthening capacity-building, inclusive governance, and context-appropriate financing mechanisms will be essential to fully realize the potential of solar-powered IAS in improving productivity, resilience, and livelihoods among cocoa farmers in Ghana.

# 6. Policy Recommendations

The study's findings highlight strong farmer interest in solar-powered irrigation systems but also reveal financial and institutional barriers that limit access. To translate this potential into inclusive and sustainable irrigation expansion, policy interventions should focus on developing appropriate business models, value-chain integration, and financing frameworks tailored to smallholder realities.

1. The evidence indicates that cooperative ownership and pay-for-use arrangements represent the most feasible and socially acceptable pathways for expanding irrigation among smallholder farmers. These models allow producers to share costs, distribute

risks, and contribute to system maintenance based on actual water use or cropping cycles. Policymakers should therefore prioritize piloting and scaling solar-powered, service-based irrigation schemes managed through cooperatives, farmer-based organizations (FBOs), or community associations. Such models could be supported through the establishment of community-managed irrigation hubs, strategically located to serve clusters of smallholders while improving economies of scale and ensuring local ownership. The Ministry of Food and Agriculture (MoFA), in collaboration with COCOBOD and private service providers, should facilitate technical and managerial training programs for cooperatives to build capacity in system operation, maintenance, and financial governance. Developing standardized pay-per-use tariffs would help achieve cost recovery for service providers while maintaining affordability for farmers.

2. Irrigation should be embedded within broader agricultural value chain strategies rather than treated as an isolated infrastructure intervention. Field evidence shows that farmers are more likely to invest in and sustain irrigation when they have access to reliable markets, inputs, and post-harvest support systems. Policymakers should therefore promote integrated value-chain frameworks that link irrigation to structured markets, processing facilities, and off-takers for irrigated produce. This integration can be facilitated through contract farming arrangements, aggregation centers, and public–private partnerships (PPPs) that connect irrigated production with input suppliers, agro-processors, and export actors. Embedding IAS models within existing commodity chains, especially cocoa, maize, and vegetable production, will ensure that irrigation-driven yield increases translate into stable incomes, reduced post-harvest losses, and enhanced market competitiveness.
   Extension services should also be strengthened to provide technical support for synchronized cropping and irrigation schedules, ensuring efficient water use and optimal returns. Development partners and agribusinesses could collaborate with local authorities to develop area-based irrigation development plans, which align infrastructure investment, market access, and farmer training within coherent regional frameworks. This integrated approach would maximize the impact of irrigation investments and reinforce the resilience of rural livelihoods against climate-induced disruptions.

3. Limited access to finance remains one of the most critical barriers to irrigation adoption. Most smallholder farmers depend on seasonal incomes and lack formal collateral to secure conventional loans. Policymakers, financial institutions, and development partners should therefore design innovative financing mechanisms tailored to the unique cash flow patterns and risk profiles of smallholder farmers. Flexible financing instruments such as micro-leasing, blended finance, and results-based subsidies can reduce the upfront costs associated with irrigation system installation and encourage long-term sustainability. Financial institutions could partner with solar technology providers to develop "Pay-As-You-Irrigate" models, enabling farmers to pay gradually through mobile money platforms or cooperative contributions. Over time, such arrangements would allow users to build ownership while maintaining system functionality and reducing default risk. To support these efforts, government and development partners could establish Agricultural Irrigation Guarantee Funds or interest buy-down programs to de-risk lending for irrigation investments. These mechanisms would incentivize commercial banks and rural financial institutions to extend credit to smallholders and cooperatives that

demonstrate viable business plans. Additionally, integrating irrigation financing into national agricultural insurance and climate adaptation programs could provide further protection against crop failure and revenue loss, enhancing farmers' confidence to invest in new technologies.

Regional implementation should reflect local realities: in the Eastern Region, where enthusiasm for solar-powered irrigation is high but financial constraints are severe, flexible micro-leasing schemes would be most effective; in Ashanti, where cooperative structures are stronger, group-based loans and revolving funds could sustain collective management; and in the Central Region, where environmental degradation poses an added risk, financing should be linked to watershed rehabilitation and sustainable water governance initiatives.

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