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Strengthening Nexus Collaboration to Power Food Systems with Off-Grid Solar

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GOGLA

GOGLA is the global association for the off-grid solar energy industry, representing over 200 members working to transform lives through clean, affordable, and high-quality solar products and services.

More than 560 million climate-vulnerable people already benefit from off-grid solar to power their homes, farms, enterprises and public infrastructure. With the right support, our industry is poised to scale rapidly, aiming to improve the lives of 1 billion people by 2030.

GOGLA drives this progress by serving as a central hub for the sector, offering vital market data, advocating for supportive policies and increased investment, and providing value-added services to our members.Learn more at gogla.org.

WAGENINGEN UNIVERSITY RESEARCH

At Wageningen Food & Biobased Research (WFBR), we are committed to working towards a sustainable, healthy society, and securing the food and material needs within the boundaries of our planet. With circular principles for healthy food and renewable materials, we help to advance a sustainable, healthy, and resilient society. Our applied research institute, with a team of 250 experts, takes a transdisciplinary approach to bridge the gap between science and the development of technological and organisational solutions. These solutions aim to drive the sustainable use of bioresources and ensure the supply of healthy, safe, and sustainable products throughout the entire value chain.

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EFFICIENCY FOR ACCESS

This report was supported by the Low Energy Inclusive Appliances (LEIA) Programme under the Efficiency for Access Coalition. Efficiency for Access is a global coalition dedicated to advancing high-efficiency appliances to enhance clean energy access for the world’s most impoverished communities. Current Coalition members have programmes and initiatives spanning 62 countries and 34 key technologies. The Coalition is co-chaired by UK aid and the IKEA Foundation and is co-funded by UK aid from the UK government, via the Transforming Energy Access platform, and the IKEA Foundation; however, the views expressed in this report do not necessarily reflect the UK government’s official policies.

GAIN

The Global Alliance for Improved Nutrition (GAIN) is a Swiss-based foundation launched at the United Nations in 2002 to tackle the human suffering caused by malnutrition. Working with governments, businesses and civil society, the aim is to transform food systems so that they deliver healthier diets for all people, especially the most vulnerable.

AGRA

AGRA is an African-led organisation focused on putting farmers at the centre of our continent’s growing economy. AGRA advances uniquely African solutions to sustainably raise farmers’ productivity and connect them to a growing marketplace. Together with its partners—including researchers, donors, African governments, the private sector, and civil society—AGRA seeks to create an environment where Africa sustainably feeds itself.

GIZ

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a global service provider in the field of international cooperation for sustainable development. As a public-benefit federal enterprise, GIZ supports the German Government, in particular the Federal Ministry for Economic Cooperation and Development (BMZ), as well as many public and private sector clients in achieving their objectives in international cooperation in around 120 countries. GIZ’s areas of engagement include peacebuilding and conflict prevention, governance, sustainable economic growth, health and social development, and just transition.

SNV

SNV is a global development partner, deeply rooted in the African and Asian countries where we operate. With 60 years of experience and a team of approximately 1,600 people, we strengthen capacities and catalyse partnerships that transform the agri-food, energy, and water systems, which enable sustainable and more equitable lives for all. We work on the core themes of gender equality and social inclusion, climate adaptation and mitigation, and strong institutions and effective governance. By tailoring our approaches to different contexts, we contribute to impact at scale.

IKEA FOUNDATION

The IKEA Foundation is a strategic philanthropy that focuses its grant making efforts on tackling the two biggest threats to children’s futures: poverty and climate change. It currently grants more than €200 million per year to help improve family incomes and quality of life while protecting the planet from climate change. Since 2009, the IKEA Foundation has granted more than €1.8 billion to create a better future for children and their families. In 2021 the Board of the IKEA Foundation decided to make an additional €1 billion available over the next five years to accelerate the reduction of greenhouse gas emissions.

KEY DEFINITIONS

Food systems: the network of activities and stakeholders involved in the production, processing, distribution, consumption, and disposal of food, as well as the social, economic, and environmental factors that determine how food is produced and delivered to consumers.[1]

Smallholder farmers: include producers who cultivate crops, rear poultry and livestock, or raise fish on a small-scale area, varying from less than 1 hectare to 10 hectares.[2] For the purpose of this paper, it includes farmers that sell at least 50% of their produce.

Agricultural enterprises/businesses (agri-businesses): businesses engaged in various activities along the agricultural value chain, including the sale of inputs, crop collection and distribution, food production, processing, and retailing of food products[3]

Micro-agricultural enterprises/businesses: typically informal, focused on income-generating activities, has fewer than 5 full-time employees and an annual turnover under 100,000 USD.[4]

Small and medium agricultural enterprises/businesses: meet at least 2 of the following: employ between 5 and 250 people (or at least 25 members for cooperatives), has an annual turnover of 100,000 to 5 million USD, holds total assets of at least 20,000 USD.[5]

Large agricultural enterprises/businesses: typically formal in nature, with over 250 employees and an annual turnover of over 5 million USD.[6]

Productive use of renewable energy (PURE): agricultural, commercial, and industrial activities that use electricity generated, where possible, from renewable energy sources.[7]

Off-grid solar (OGS) systems: solar-powered appliances that drive income generating activities, boost productivity and foster economic growth in off-grid regions.

Nexus: refers to a connection or collaboration between groups.

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1 FAO Sustainable food systems: concept and framework

2 FAO https://www.fao.org/family-farming/detail/en/c/273864/

3 SAFIN (2023). Agri-SME Taxonomy

4 Ibid

5 Ibid

6 Ibid

7 https://www.get-transform.eu/wp-content/uploads/2022/08/Productive-Use-of-Energy-2-0_GET.transform2022.pdf

ABOUT THE PAPER

This white paper explores the nexus between food systems, infrastructure and energy provided by off-grid solar (OGS) systems.[8,9,10] The efficiency, sustainability, and productivity of food systems are deeply intertwined with energy use.[11] The agricultural sector accounts for 30% of global energy consumption and requires power for food production, storage, transportation and processing. The infrastructure used to power food systems is heavily reliant on fossil fuels, accounting for at least 15% of fossil fuel use globally.[12] However, in sub-Saharan Africa, agricultural production consumes significantly less energy than the global average. This limits opportunities for value addition, increases food waste due to inadequate storage and processing facilities, and contributes to low agricultural yields.

Smallholder farmers are vital to sub-Saharan Africa's food production, contributing 80% of the total output. They include producers who cultivate crops, rear poultry and livestock, or raise fish on a small-scale area, varying from less than 1 hectare to 10 hectares.[13] However, more than two-thirds of rural communities, where these smallholder farmers are mainly located, lack electricity access.[14] This energy gap limits productivity and processing of farm produce, thus reducing farmers' ability to generate livelihoods. The integration of off-grid solar technologies into food system processes can lead to increased incomes, reduction in food waste, lower carbon emissions and energy costs, increased productivity and enhanced climate mitigation, adaptation and resilience. Additionally, integrating solar energy into nutrition-intensive programs can address malnutrition and its long-term effects.

This publication highlights the potential to improve agricultural and economic outcomes in the agricultural sector in Africa, and for off-grid solar to power a range of food system processes. It explores how greater collaboration between the food system and energy sectors can enhance positive impacts and reduce negative effects.

The authors of this paper work across different sectors and have been contributing—intentionally or unintentionally—to the food systems and energy nexus. This paper explores these stakeholders' perspectives and benefits from their inputs on how common language and nexus approaches can improve the efficiency and effectiveness of development interventions.

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8 The term "nexus" refers to a connection or collaboration between groups.
9 The FAO describes food systems as the network of activities and stakeholders involved in the production, processing, distribution, consumption, and disposal of food, as well as the social, economic, and environmental factors that determine how food is produced and delivered to consumers.
10 Off grid solar systems primarily refer to solar-powered appliances that drive income generating activities, boosting productivity and foster economic growth in off-grid regions.
11 IRENA and FAO. 2021. Renewable energy for agri-food systems – Towards the Sustainable Development Goals and the Paris agreement. Abu Dhabi and Rome.
12 Global Alliance for the Future of Food. Food systems account for at least 15% of all fossil fuels
13 FAO https://www.fao.org/family-farming/detail/en/c/273864/
14 Giacomo Falchetta et. Al. (2022). A renewable energy-centered research agenda for planning and financing Nexus development objectives in rural sub-Saharan Africa

OBJECTIVES OF THE PAPER

This paper is designed to help national bodies, development actors, non-profit organizations and the off-grid solar and agri-food private sector stakeholders working to improve food systems to better understand the potential of employing 'nexus' approaches within their initiatives that allow for the consideration and inclusion of energy inputs via off grid solar solutions. The relevance of the paper to these target stakeholders is outlined in Table 1.

TABLE 1: RELEVANCE OF THE PAPER TO TARGET STAKEHOLDERS WITHIN THE FOOD SYSTEMS AND ENERGY NEXUS

Target stakeholder	Role within the nexus	Relevance of this paper
National bodies (e.g. government ministries etc.)	Influence policies, regulations and funding for food systems and energy access	Provides insights on how to collaboratively align policies, regulations and funding to enhance food systems outcomes through off-grid solar technologies
Development actors and non-governmental organizations (NGOs)	Influence and support funding, design and implementation of programs in the nexus	Identifies the gaps, challenges and opportunities to guide and enhance the design of programs with a nexus approach
Agri-food private sector	Adopts and scales solutions that enhance food production and processing to achieve food security targets	Demonstrates how off-grid solar systems can improve productivity and resilience in food systems and provides insights on the need for collaboration with energy sector actors
Off-grid solar private sector	Produces and implements solar technologies within food systems	Highlights opportunities for improved collaboration with the agri-food private sector and national bodies to enhance business models and outcomes

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SCOPE OF THE PAPER

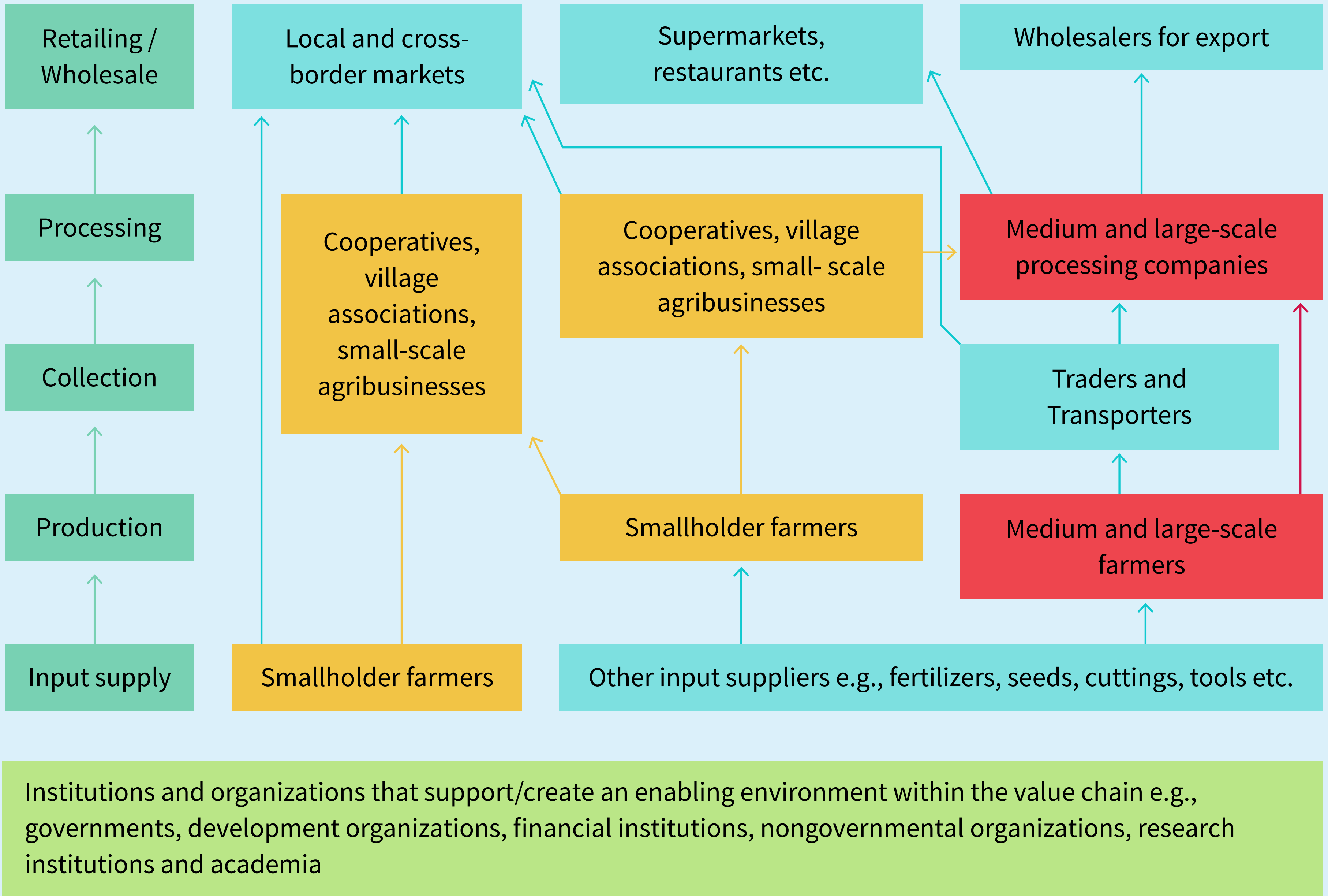
Technology scope: Micro, small and lower-tier medium-scale farmers and agri-businesses make up 85% of the agri-food private sector's activity in Africa.[15] The off-grid solar industry has developed a range of low-cost technologies powered by small solar panels that can be used by this audience to enhance agricultural outcomes.[16] This paper explores the food systems and energy nexus with a focus on the most mature of these off-grid technologies: solar-powered irrigation, refrigerators, freezers, cold rooms, mills and dryers.[17]

Areas of the food systems value chain explored within this paper: Off-grid solar solutions can be used at several points along the agricultural value chain. Figure 1 illustrates the stages, players and processes in a typical food value chain and where mature off-grid solar technologies (yellow boxes) are currently being applied.

Figure 1 Key

a. **Green boxes:** stages within a typical food value chain.
b. **Yellow boxes:** the focus of this paper - where off-grid solar technologies are currently being applied.
c. **Red boxes:** medium and large-scale farmers and processing companies. The opportunity to transform this segment using off-grid solar technologies is recognized but not explored within this paper.
d. **Blue boxes:** other stakeholders that form a critical part of a typical agricultural value chain but are not explored in this publication.
e. **Light green-box:** – stakeholders that are indirectly involved in food value chains and provide an enabling environment for the functioning and development of these value chains.

FIGURE 1: STAGES, PLAYERS AND PROCESSES IN A TYPICAL AGRICULTURAL VALUE CHAIN[18]



15 Africa Agricultural Status Report 2024 (AASR24)
16 GOGLA (2024). Leveraging Energy Access and Off-Grid Technologies to realize National Social and Economic Development priorities
17 GOGLA (2025). Productive Use Appliances Companies: A Landscape
18 Adapted from An Introduction to Agricultural Value Chains An Introduction to Value Chains - Farm Radio Scripts

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STRUCTURE OF THE PAPER

The paper's structure is outlined in the following sections:

- **Chapter 1: Introduction.** Sets the context by defining the nexus, identifying what is needed to achieve it, and acknowledging that a one-size-fits-all solution is not applicable to all challenges.
- **Chapter 2: Analysis of the Food Systems and Energy Nexus.** This section presents the priorities and perspectives of the nexus from a food systems and off-grid solar sector lens, exploring the potential of cross-sector collaborations and highlighting initiatives seeking to address the current disconnect.
- **Chapter 3: Off-Grid Solar Applications Powering Food Systems.** This section explores the most mature off-grid solar technologies categories: irrigation, cooling and processing. It demonstrates how the use-cases for these technologies map to core needs within food systems highlighting success stories as well as existing gaps and emerging challenges.
- **Chapter 4: Adopting a Nexus Approach to Scaling Off-Grid Solar Applications in Food Systems.** This chapter discusses the elements required to drive the uptake and integration of off-grid solar applications within food systems.
- **Chapter 5: Recommendations and Call to Action.** This chapter provides specific and targeted calls to action to stakeholders operating within the food systems and energy nexus to drive effective collaboration.

LIMITATIONS OF THE PAPER

This paper acknowledges that there is a broader food system and energy nexus that is not explored within this publication. The paper focuses on one sub-sector of energy i.e. off-grid solar (OGS). It is one type of renewable energy solution that operates independently from the main electricity grid, using solar panels to generate electricity directly from sunlight. OGS plays a key role in providing energy and energy services to rural and underserved areas with no access to the grid. However, not all essential elements of food systems' energy needs can be solved with one type of energy technology. And, although productive uses of energy are useful for grid applications (reducing the underutilization of the grids and increasing the financial sustainability of the national utilities), this paper specifically examines the OGS sector.

Additionally, this paper does not explore the application of OGS technologies in large agricultural enterprises.[19] Even within off-grid solar, the focus is on technologies that are already commercially viable and widely adopted, rather than on emerging or unproven solutions. Further research and development are needed to assess the energy needs of large agricultural enterprises' operations and explore the role of OGS technologies in powering these applications.

19 Large agricultural enterprises are defined as being typically formal, with over 250 employees and an annual turnover of over $5 million.

CHAPTER 1: INTRODUCTION

WHY IS THE FOOD SYSTEMS AND ENERGY NEXUS IMPORTANT?

The term "nexus" refers to a connection or collaboration between groups. The food systems and energy nexus has become increasingly important in the quest for sustainable development, particularly in Africa and South Asia. The importance of the food systems and energy nexus is explicitly noted in the Kampala Declaration adopted in January 2025, which prioritizes scaling up agricultural production, productivity, food processing, and trade to meet growing demand. Key targets include cutting post-harvest losses by 50% and increasing locally processed food to 35% of agri-food GDP by 2035, among others.[20]

Smallholder farmers produce up to 80% of the food supply in Asia and sub-Saharan Africa, yet many lack the essential infrastructure services to sustain both their operations and livelihoods.[21, 22] More than two-thirds of rural communities remain without electricity, a resource critical for agricultural processes such as irrigation, food processing, and storage, while 40% still lack access to clean water.[23] As such, addressing the food systems and energy nexus is vital—without energy access, agricultural productivity is limited, hindering economic growth, food security, and rural resilience.

The growing impacts of climate change have significant consequences on smallholder farmers across these continents and other vulnerable regions, undermining productivity and increasing the risk of food insecurity and malnutrition. The relationship between climate change and malnutrition is also a pressing yet often overlooked issue, with profound implications for public health, environmental sustainability, and economic performance. According to the Intergovernmental Panel on Climate Change (IPCC), the greatest health threat posed by climate change is likely to be its impact on nutrition outcomes.[24] This situation underscores the need for agriculture and food systems to adapt to climate change. Tackling these interconnected challenges by integrating renewable energy solutions e.g. off-grid solar power, could provide a transformative solution to two of the biggest barriers to sustainable development.

WHAT IS THE POTENTIAL FOR OFF-GRID SOLAR (OGS) WITHIN THE NEXUS?

In particular, the off-grid solar industry has developed a range of low-cost technologies powered by small solar panels that are applicable within various agricultural processes.[25] These have been developed specifically for

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20 The African Union adopts ten year strategy and food action plan to transform Africa's agri-food systems and ensure food security

21 GAIN (2020). The role of small and medium-sized enterprises in nutritious food supply chains in Africa

22 GAIN (2023). The case for increased investment in food systems infrastructure in low and middle-income countries

23 Giacomo Falchetta et. Al. (2022). A renewable energy-centered research agenda for planning and financing Nexus development objectives in rural sub-Saharan Africa

24 UNICEF (2019). Climate change and nutrition: a global health threat

25 GOGLA (2025). Productive Use Appliances Companies: A Landscape

smallholder farmers, for whom the national electricity grid remains out of reach and are often among the most vulnerable to climate change. The industry has already reached an estimated 700,000 smallholder farmers with off-grid solar irrigation and cooling technologies and has the potential to reach a further 32 million.[26] Off-grid solar technologies serve as a catalyst for economic growth due to:

i Their ability to power agricultural appliances and processes where grid infrastructure is limited or non-existent. OGS contributes to the mix of solutions needed for universal energy access that cannot only be met by extending such grid infrastructure or mini grids.

ii The modularity of solar systems provide flexibility to scale up or down based on emerging needs, including for post-disaster response such as climate humanitarian events.

iii Their position as a more reliable and resilient energy source, as solar energy is less vulnerable to supply chain disruptions, fuel price volatility, and climate-related events.

iv Their provision of clean, renewable power, which reduces reliance on fossil fuels and decreases or avoids greenhouse gas emissions.

Although this potential is largely untapped, the integration and uptake of off-grid solar within food systems applications has been supported by several pioneering development actors and governments. However, while there are success stories, for example, in the case of solar-powered irrigation creating significant improvements in income generation,[27] there are also instances where interventions have not led to the intended outcomes. For example, where there has been expensive deployment of underutilized assets,[28] or where interventions have led to concerns around unsustainable water management practices.

To deliver more optimal results, rethinking the connections between food, energy and water systems is essential, as developments in one sector can fundamentally shape options and outcomes in the other. Additionally, a common understanding of entry points for both sectors is needed, as well as how nexus interventions are perceived and deployed in practice.

Furthermore, for off-grid solar-powered solutions to be viable at scale, interventions must converge across different agricultural value chains, addressing inefficiencies such as farming practices, input costs, input quality, overextraction of water, and market access to name a few.[29] Addressing these factors concurrently will significantly improve customers' ability to establish stable businesses, pay ongoing costs of off-grid appliances and generate positive outcomes, such as greater yield or revenue.

HOW DO INTERACTIONS WITHIN THE NEXUS IMPACT THE VIABILITY OF OGS SOLUTIONS?

In addition to using off-grid solar technologies to power food system processes, it is imperative to consider the stakeholder interactions required to optimize the use of these solutions. Analysing challenges through both the food system and energy viability lens can significantly increase the impact of the intervention. This is because there are various cross-cutting interactions between food and energy systems that influence the viability of the proposed solution. For example:

Smallholder farmers using traditional energy sources, such as diesel pumps, to irrigate their land may experience price volatility. The rising cost of fuel would thus affect their ability to irrigate crops. Or, if they are unable to gain a good market price for their produce, they may not be able to afford a loan or consumer financing to pay for the solar irrigation system.

Considering the needs of smallholder farmers using the OGS systems whilst planning a food systems-energy nexus intervention - via a 'systems-based' approach - can help to ensure it has the greatest chance of success.[30] Questions that help to address some of these needs include:

26 ESMAP, GOGLA, Dalberg (2024). Off Grid Solar Market Trends Report.
27 60 Decibels (2024). Why Off-Grid Energy Matters.
28 A white elephant refers to a project that requires significant financial investment but fails to deliver expected benefits due to underutilization, overestimated demand, poor planning, or a mismatch with local needs.
29 IRENA (2025), Decentralised renewable energy for powering agri-food value chains in the Republic of Guinea, International Renewable Energy Agency, Abu Dhabi
30 Building Effective and Accessible Markets

- How would they optimally use their irrigation system?
- What is the price of the system they need to pay for?
- How will they earn an income to pay for the system?
- If they access finance to pay for the system, how will they align repayments with the seasonal fluctuation of their incomes?
- Can they reasonably assess whether the investment in the system would generate a return?
- How will the wider macroeconomic and physical environment affect them?

Better understanding the links between food systems and energy can also avoid unsustainable development approaches, such as overexploitation of natural resources like ground water – in the case of water abstraction for irrigation.

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CHAPTER 2: ANALYSIS OF THE FOOD SYSTEMS AND ENERGY NEXUS

WHAT ARE THE STAKEHOLDER PERSPECTIVES WITHIN THE NEXUS?

A challenge in building greater collaboration between stakeholders in the food systems and off-grid solar sectors is the differences in how each of these sectors view the same intervention. Understanding and bridging this disconnect in views and language can help to build new cross-sectoral collaborations and partnerships. Table 1 illustrates the different 'lenses' through which each of the sectors view key development goals and the language they use.

When addressing the food systems and energy nexus, it is crucial to acknowledge each of these perspectives. For instance, while the off-grid solar energy sector aims to promote clean energy solutions within food systems, the food systems' focus is often on the process e.g., irrigation for increased crop yields, and having clean energy is perceived as a potential co-benefit rather than the primary priority. A synergistic approach that integrates these sectors can lead to sustainable agricultural practices that not only improve crop yields but also ensure that these crops have improved food quality, reduced post-harvest losses, and enhanced resilience to climate change. This can ultimately contribute to SDG 2: Zero Hunger, by improving food production while simultaneously promoting environmental sustainability.

TABLE 2: DIFFERENT 'LENSES' THROUGH WHICH EACH OF THE SECTORS VIEW KEY DEVELOPMENT GOALS AND THE LANGUAGE THEY USE

Attribute	Off-Grid Solar Energy Lens	Food System Lens
Sustainable development goals	Ensure universal access to affordable, reliable and modern energy services, Leave No-one Behind (LNOB) - SDG7	Food and nutrition security, job creation and improved incomes and climate mitigation – SDG2, SDG 8, SDG13
Climate mitigation	Reduces reliance on fossil fuels by shifting towards renewable energy and energy efficiency	Emissions reduction through preventing land use change, reducing methane emissions, reducing synthetic fertilizers and shifting to clean energy
Climate adaptation	Facilitate adaptation and resilience through off-grid solar technologies that ensure energy access during climate shocks.	Ensure resilience of production systems and crops, post-harvest outputs and market systems. Adapt land use and conservation of water by adopting climate-smart agriculture practices
Energy focus on food systems	Integrates off-grid solar across the value chain—lighting, irrigation, processing, cooling—while reducing fossil fuel reliance and drudgery	Energy consumption (through direct inputs such as transport, storage, cooling, processing etc. and indirect inputs like fertilizers) and energy production (e.g. biomass and biogas)
Innovation lens	Advances in solar-powered agri-tech, service-based models (e.g., irrigation-as-a-service, cooling-as-a-service).	A combination of improvement of capacity, agricultural inputs, processes, practices, modernization and technological innovations.
Target infrastructure scope	Focuses on small- to medium-scale infrastructure	Includes medium- to large-scale infrastructure for food production and supply chains

HOW CAN STAKEHOLDERS ACHIEVE COLLABORATION WITHIN THE NEXUS?

While various initiatives have made significant strides in promoting off-grid solar technologies within the food systems sector, it is essential to evaluate the extent of collaboration among stakeholders. This includes national bodies, development actors and NGOs, and the OGS and agri-food private sector. This is useful to explore the most effective and efficient type of collaboration for any given intervention. In this sub-section, we explore how stakeholders engaged in such initiatives can approach collaboration strategically to enhance their impact and success.

Working within a nexus is not a binary process; it involves varying levels of collaboration. The extent of collaboration can lead to potential synergies, trade-offs, and unintended consequences. Collaboration within the food systems and energy nexus can occur:

- at various levels such as policy, program, projects or activities
- at different stages including design, analysis, implementation, and evaluation
- at different stakeholder levels including the public sector (enabling environment and market development), development sector (funding, programs, advocacy, technical assistance), and private sector (business development, partnerships, financial planning)

Figure 2 shares a conceptual framework that demonstrates varying degrees of collaboration across all stakeholder levels.

FIGURE 2: CONCEPTUAL FRAMEWORK DEMONSTRATING VARYING DEGREES OF COLLABORATION[32]

Energy and food systems stakeholder initiatives are **independent**	Energy and food systems stakeholder initiatives are **consultative**	Energy and food systems stakeholder initiatives are **collaborative**	Energy and food systems stakeholder initiatives are **facilitative**

None ← Collaboration → Full

© Popo Africa

31 Source: Wageningen University and Research (2024).

Table 3 provides an overview of various collaborative actions that could be employed within an intervention.

The level of collaboration is influenced by several factors, including awareness, efficiency, effectiveness, risks, available resources, past experiences, organizational/ institutional or individual ambitions, and competitive dynamics. It is essential to approach nexus initiatives with a deliberate consideration of the appropriate level of collaboration to maximize synergies and minimize unintended consequences. We encourage readers to reflect on a nexus project they are familiar with, assess whether they are aware of potential synergies and unintended consequences in other sectors, and consider the level of collaboration required to achieve optimal outcomes.

TABLE 3: FORMS AND LEVELS OF NEXUS COLLABORATION

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	Initiatives within one sector extend into another—either intentionally or unintentionally—without any collaboration or integration between the stakeholders. This also includes public sector initiatives operating independently of private sector consultation or involvement.	Low
Consultation	In a consultative collaboration stakeholders start working on the nexus, by consulting individuals in other sectors by seeking their input, opinions or advice. This could be at project, program, or market development level and across different stakeholder levels i.e. public/private/non-governmental etc.	Low-Medium
Co-creation	In a co-creation collaboration, stakeholders from different sectors and levels work together to design and implement initiatives, developing key elements such as objectives, goals, indicators, budgets, strategies, target outputs and outcomes etc.	Medium
Facilitation	In facilitation, one sector or stakeholder group actively supports the other one to achieve shared goals. For example, public sector stakeholders support development actors and the private sector in implementing initiatives that enhance market development.	High

WHAT ARE SOME OF THE INITIATIVES DESIGNED TO CONVERGE STAKEHOLDERS TOWARDS NEXUS PROGRAMMING?

This sample initiative demonstrates an example of nexus programming by converging diverse stakeholders to enhance food security by integrating off-grid solar energy and improving livelihoods.

CASE STUDY: INITIATIVES DESIGNED TO CONVERGE STAKEHOLDERS TOWARDS NEXUS PROGRAMMING

In Kenya, the Machakos County government, with support from the Dutch Ministry of Foreign Affairs and the Global Alliance for Improved Nutrition (GAIN), is constructing modern markets and installing solar-powered cold storage at fresh produce markets. These cold rooms, informed by vendor concerns, aim to reduce food loss, improve hygiene, and create jobs. A survey revealed that 57% of vendors in Marikiti market were concerned about food safety while 44% reported discarding unsold food (mainly fresh fruits and vegetables), highlighting the need for better storage solutions and better business practices.

A digital management system linked to M-Pesa streamlines stock tracking and payments, making storage more accessible for vendors and ensuring sustainability. Meanwhile, the University of Nairobi's Postharvest Research Team will conduct assessments on the impact on waste reduction, trader profits, and consumer access to nutritious food. By integrating policy, finance, technology, and research, this collaboration aims to strengthen food and energy systems, aligning with Machakos County's vision of "chakula mezani, pesa mfukoni"—food on the table, money in the pocket.[32]

32 https://www.kenyanews.go.ke/machakos-installs-cool-rooms-in-marikiti/

CHAPTER 3: OFF-GRID SOLAR APPLICATIONS POWERING FOOD SYSTEMS

IRRIGATION

WHY IS THERE A NEED FOR A NEXUS APPROACH?

As climate change intensifies, countries in the Global South are facing severe crises. According to the 2023 Global Report on Food Crises, approximately 140 million people in sub-Saharan Africa (SSA) face acute food insecurity.[33] In South Asia, 59.8 million people or approximately 30% of the analyzed population are facing high levels of food insecurity. Additionally, 80% of the population in SSA relies on rain-fed agriculture. This dependence leaves smallholder farmers particularly vulnerable to the increasing challenges of water scarcity, climate variability, and extreme weather conditions. Erratic rainfall patterns and prolonged droughts further exacerbate risks to agricultural productivity and livelihoods.

With water resources anticipated to decline significantly by 2050[34] due to factors including climate change impacts, improving access to reliable and affordable water supplies is critical for sustainable agricultural production. Additionally, water management monitoring is essential to maintain groundwater levels and improve river basin management. Solar-powered irrigation Systems (SPIS) present an opportunity to improve agricultural productivity, increase farmer incomes, and build climate resilience among smallholder farmers through improved access to water.[35]

WHAT IS THE POTENTIAL FOR SOLAR-POWERED IRRIGATION SYSTEM (SPIS)?

Farmers apply different irrigation methods depending on the type of crops they cultivate, water availability, terrain and pressure requirements, energy supply alternatives, and the financial capacity of the farming household. These methods typically include water harvesting, storage and distribution through pipes, flood irrigation, sprinkler or drip irrigation powered manually or using petrol or diesel.

Solar powered irrigation systems offer several benefits including:

i a reduction of operation and maintenance costs, often considerably less than traditional petrol/diesel pumps over the lifetime of the system;

ii independence from electrical grid systems, making them particularly suitable for remote or off-grid areas.

iii no fossil fuel requirement, reducing the risk of supply chain issues and greenhouse gas emissions.

iv improved health & reduced drudgery – unlike manual irrigation or diesel-powered pumps, solar irrigation reduces labor intensity, improving working conditions for farmers.

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33 Analysed countries in Asia: Afghanistan, Bangladesh, Myanmar, Pakistan, Sri Lanka

34 https://wmo.int/news/media-centre/wmo-report-highlights-growing-shortfalls-and-stress-global-water-resources

35 Efficiency for Access Coalition, Tech Trends in Energy Access: Assessing the Solar Water Pump Market, October 2023

While SPIS offer these advantages and can support various irrigation methods, they should be adapted to local conditions to optimize crop yields. Proper use is also essential to prevent water overuse, protect long-term water supplies, and comply with national or regional environmental regulations. Consideration should be given to the source of water and its quality, and the amount of water flow that the pump will generate (e.g. by assessing the pressure head and flow rates). Most solar irrigation private sector suppliers today provide agricultural expertise to properly design the irrigation scheme for each farmer, considering the water requirement of the crop and the water source.

For example, flood (surface) irrigation, though widely used with irrigation due to its simplicity and compatibility with existing practices, is not ideal for high-value crop production, is relatively inefficient in water use and can lead to erosion and loss of soil nutrients. In contrast, sprinkler irrigation, while more effective in certain contexts, demands high water pressure, necessitating larger and more expensive solar photovoltaic (PV) systems. This limits practical application in solar-powered irrigation systems.

Drip irrigation, particularly in its low-pressure configurations, offers a promising alternative. Designed for water efficiency and tailored to operate at lower pressures, modern drip systems can achieve up to 80% uniform water application, even at minimal pressure levels. This makes drip irrigation well-suited for pairing with solar water pumps, especially for high-value crops that benefit from precise water applications. Additionally, drip systems can easily be cleaned when water is muddy, enhancing their efficiency. Indeed, a filter system should be installed in the upstream part (mostly when the water goes out of the elevator tank). By enabling conservative solar PV sizing and maximizing water efficiency, solar-powered drip irrigation represents an effective and sustainable approach to irrigation.

Used optimally and applied with a water conservation and recharge strategy to avoid depletion of surface or ground water, there is a huge potential for SPIS. For example, there are approximately 350,000 SPIS in India and plans to raise that number tenfold to 3.5 million by 2026. There is also potential for solar irrigation in sub-Saharan African countries. According to research, on average 9% of irrigated and 18% of rainfed Ethiopian land would be suitable for solar pumping, when solar radiation and the availability of water resources and links to markets are considered.[37] Another study suggests that over one-third of the unmet water requirements in farmlands across sub-Saharan Africa could be met using SPIS.[38]

TABLE 4: SUITABILITY OF IRRIGATION METHODS TO SOLAR PHOTOVOLTAIC (PV) PUMPING[36]

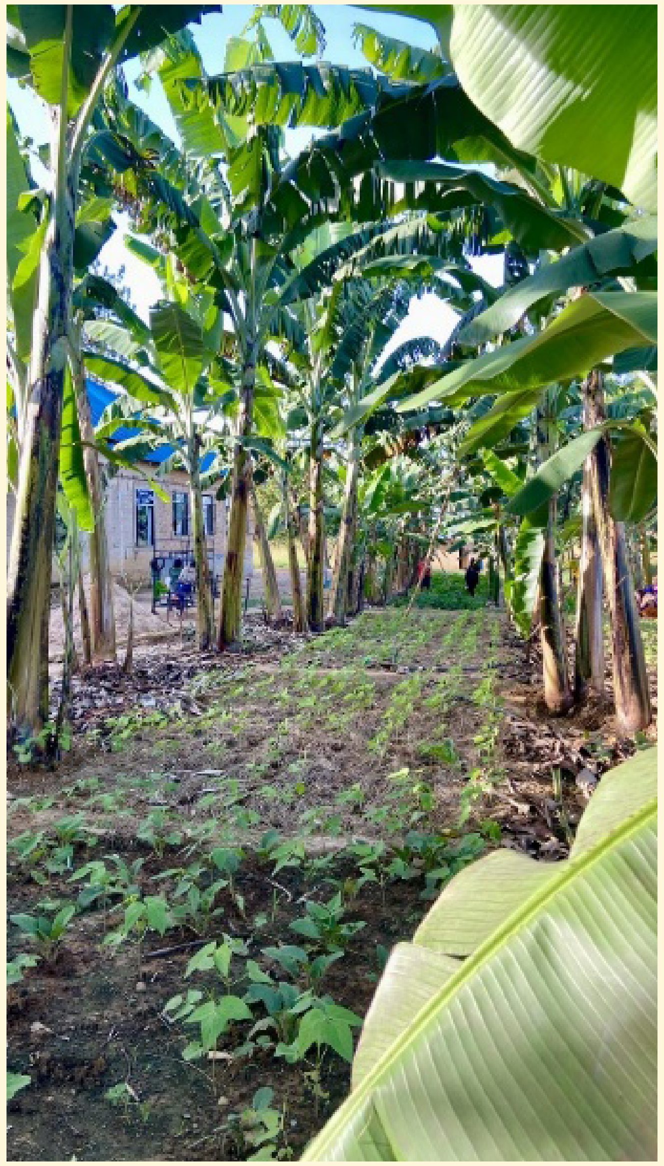
Distribution method	Typical water application efficiency	Typical head	Suitability for use with solar water pumps
Flood irrigation	40-50%	0.5m	Barely cost efficient
Open canals	50-60%	0.5-1m	Dependent on local conditions
Sprinkler	70-80%	10-20m	Yes
Low pressure drip irrigation	80%	1-10m	Yes
High pressure drip irrigation	85-95%	10-100m	Low suitability, but possible with direct pumping and pressure regulators

36 Sun4Water - Water and Energy for Food Grand Challenge

37 Schmitter, P., Kibret, K. S., Lefore, N., & Barron, J. (2018). Suitability mapping framework for solar photovoltaic pumps for smallholder farmers in sub-Saharan Africa. Applied Geography, 94, 41-57.

38 Falchetta, G., Semeria, F., Tuninetti, M., Giordano, V., Pachauri, S., & Byers, E. (2023). Solar irrigation in sub-Saharan Africa: economic feasibility and development potential. Environmental Research Letters, 18(9), 094044.

CASE STUDY: DEMONSTRATING THE ROLE OF SPIS IN IMPROVING FOOD AND NUTRITION SECURITY



Solar Panel donated by Kagera millers to Prof. Abdulrahman Babu School

KAGERA MILLERS: SOLAR WATER PUMPING FOR IMPROVED FOOD AND NUTRITION SECURITY IN KAGERA, TANZANIA

An initiative by the Global Alliance for Improved Nutrition (GAIN), installed solar-powered irrigation in a school farm in Kagera, Tanzania. The school children's nutritional status has significantly improved with consistent access to fresh vegetables and bio fortified beans. This project addresses both environmental sustainability and food security in a region where malnutrition can severely affect the health and academic performance of students.

Kagera Millers have contributed to installing solar panels in 10 schools to support their water-pumping systems. By harnessing solar energy, the pumps ensure a reliable water supply for the school farm to cultivate crops year-round, regardless of seasonal droughts. Vegetables such as spinach, kale, and carrots, along with bio fortified beans rich in essential nutrients like iron and zinc, are grown on the farm. These crops help combat nutrient deficiencies commonly seen among children in that region, such as iron deficiency anaemia, which affects cognitive function and overall health. The project has been instrumental in improving the children's diets, offering them fresh and nutrient-dense food directly from the farm.

The success of this initiative reflects the impact that integrating sustainable technology with nutrition-focused agriculture can have on the health and wellbeing of vulnerable populations. Not only does it promote self-sufficiency and environmental responsibility, but it also directly addresses the immediate nutritional needs of school children, enhancing their academic and health outcomes.

WHAT ARE THE BARRIERS TO THE ADOPTION OF SOLAR-POWERED IRRIGATION?

Despite solar water pumps' multiple benefits and their potential to transform irrigation practices, the adoption of this technology remains limited by significant barriers.

- **Regulatory and Institutional Constraints:** A lack of regulation and weak governance for integrated planning of land, data, water and energy poses significant barriers. Most developing countries lack the necessary policy and institutional coordination to scale SWPs sustainably. Therefore, two key dimensions are essential to be considered: equitability, to ensure access for smallholder farmers of all genders and income levels; and environmentally sustainable practices, managing water demand beyond the actual water boundaries.

- **Knowledge Gaps:** There is a lack of comprehensive information on solar irrigation systems with critical knowledge gaps regarding the potential, limitations, and risks. Consequently, farmers face difficulties accessing reliable information needed to make informed decisions and maintain solar-powered irrigation systems effectively.

- **Suboptimal design for Solar-Powered Irrigation Systems (SPIS):** In many cases, system designs fail to address farmers' needs or site-specific environmental, agronomic, and technical conditions (water requirement, size of the system, quantity of water available). This can result in suboptimal performance or, worse, negative ecological and economic consequences as discussed in the previous section.

- **Insufficient coordination among SPIS technology and service providers:** A key challenge for SPIS is the fragmentation of finance and delivery for different components of irrigation solutions. Not all SPIS providers have the capacity to offer financing for every essential input required for a fully-operational system. For example, while some companies can provide pumps with Pay-As-You-Go (PAYGo) financing, they may not cover the cost of borehole drilling, which can be prohibitively expensive for smallholder farmers. Similarly, certain SPIS providers supply irrigation pumps but rely on third-party specialists for drip irrigation solutions, which may result in inconsistent service quality.

Common barriers across the three OGS applications discussed in chapter 3 (such as affordability, market linkages, regulatory and policy environment etc.) are further expounded in chapter 4.

HOW CAN WE LEVERAGE A NEXUS APPROACH TO SCALE SOLAR POWERED IRRIGATION?

To address the challenges discussed and unlock the potential of SPIS, it is essential to create an enabling environment that fosters the adoption and scalability of SPIS and supports an integrated approach to land, water and energy management.

Modernization of irrigation practices - The wide-scale adoption of SPIS requires moving away from thinking of solar water pumping as silver bullets for food security. Instead, they must be and embedded into irrigation modernisation strategies such as:

i Water harvesting and storage to reduce reliance on rainfall.

ii Transitioning from inefficient flood irrigation to precision irrigation (e.g. drip systems or controlled sprinklers) to optimize water and nutrient application.

iii Using SPIS to support regenerative agriculture, reduce water waste, and enhance soil health by providing sustainable, efficient, and cost-effective irrigation while reducing environmental impact.

Improved Access to Information and Digital Tools – As stated by Lefore et al., it is crucial to provide farmers and planners with better access to information, tools, and incentives for efficient water and energy use, while also ensuring inclusive access for all farmers.[39] These include areas such as:

i Better design of SPIS systems using tools such as the web-based app developed by GIZ can help to address farmers' specific needs or site-specific environmental, agronomic, and technical conditions. SPIS Toolbox version 6 could be used by technical experts to provide more accurate design of SPIS systems.

ii Weather forecast services, sensors or any other data-driven technology to help optimize water use.

iii Capacity building and knowledge transfer programs to accompany this technology driven transformation, aiming to train farmers and supporting institutions in modern irrigation techniques and agronomic practices. This could include training in soil and fertilizer management.

iv Market linkages and financial incentives that help improve the viability of farmers' investments.

39 Lefore, N., Closas, A., & Schmitter, P. (2021). Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. Energy Policy, 154, 112313.

Monitoring, evaluation and data driven planning - to measure SPIS impact and ensure sustainable water use, real-time data tools should be used:

i FAO's WaPOR portal enables planners to monitor irrigation effectiveness via remote sensing.[40]

ii Performance tracking helps optimize SPIS systems and ensure long-term sustainability.

Some companies already provide farmers with such services through their Internet of Things (IoT) enabled solar-powered irrigation systems.

Innovative financing and business models: To effectively scale SPIS, financing and business models must be designed within the nexus, recognizing the interconnected nature of energy access, water security, and food production. Bridging these sectors requires financial mechanisms that enable smallholder farmers, agribusinesses, and communities to adopt SPIS without financial strain, while ensuring sustainable water use and enhancing agricultural productivity.

Key factors include:

i Leveraging innovative financing mechanisms e.g. Pay-As-You-Go, Energy-as-a-Service, blended finance, microfinance institutions, agricultural credit, and carbon finance. Financing products may be bundled to address both agriculture and energy needs.

ii Collaborative support through government incentives e.g. coordinated drive to exempt taxes on SPIS, reviewing and repurposing agricultural subsidies towards SPIS to deliver more cost-effective outcomes etc.

CASE STUDY: LEVERAGING IOT AND WEATHER FORECASTING TO EMPOWER SMALLHOLDER FARMERS

SUNCULTURE: LEVERAGING IOT AND WEATHER FORECASTING TO EMPOWER SMALLHOLDER FARMERS

SunCulture provides smallholder farmers with IoT-enabled solar irrigation systems that integrate data-driven solutions to enhance agricultural productivity. By incorporating an IoT-connected energy management system, the company introduces precision farming techniques, including hyperlocal and highly accurate weather forecasting, to farmers who previously had no access to such tools. To further enhance decision-making, SunCulture plans to deploy soil sensors and weather stations, ensuring that farmers receive real-time insights tailored to their specific conditions.

SunCulture's weather models, along with future yield predictions and key data like water table depth, provide useful information for financial institutions, insurers, and other agricultural and environmental organizations. These insights improve risk assessment and lending decisions, and support farmers in adapting to changing climatic conditions. This demonstrates the broader impact of weather forecasting services in supporting smallholder farmers.

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40 https://data.apps.fao.org/wapor

COOLING

WHY IS THERE A NEED FOR A NEXUS APPROACH?

Approximately one-third of all food produced globally is either lost or wasted. This has significant implications for food security, climate change, and the economy. An estimated one in ten people remain malnourished despite the volume of food produced, while food loss and waste contribute to 8-10% of global greenhouse gas emissions and result in economic losses of up to USD $1 trillion per year.[41]

Mechanical cooling revolutionized food conservation and rapidly spread in Europe and America in the late 1960's and beyond. The historical growth of the cooling sector was driven by commercial interests in export and rising disposable incomes, overcoming the seasonality of agricultural production, and is vital for animal-based products to comply with food safety regulations requiring temperature management.

In recent years, cooling has received increased attention in low- and middle-income countries, driven by the development of solar-powered cold chain solutions and their potential to reduce food loss, increase farmers' incomes and improve access to safe and nutritious food.[42,43] Since 2018, 50,000 solar-powered refrigerators have been sold globally, and approximately 56,000 more sales expected by 2030.[44] However, off-grid solar-powered cold chain technologies have seen far less market penetration than other OGS technologies such as solar water pumps (SWPs). Even more concerning, it is observed that a high number of cold chain interventions end up as stranded assets.[45] Existing reports discuss the technical potential of refrigeration to reduce food losses, but often overlook economic feasibility, which remains a challenge.[46,47]

In developing off-grid cooling solutions, it is crucial to recognize that cooling is not universally applicable across all agricultural value chains. It may not always represent a viable business opportunity, and a strategic approach is needed to identify where cooling is necessary and where alternative interventions might be more effective. Cooling should not be viewed as a one-size-fits-all solution to food loss and waste and its role must be carefully evaluated within each specific context.

WHAT IS THE POTENTIAL OF SOLAR-POWERED COLD CHAINS?

The lack of cooling infrastructure, particularly in rural areas limits farmers' ability to store fresh produce thus forcing them to accept low prices from intermediaries who exploit this vulnerability. For (semi-)commercial farmers, selling their produce to traders or directly to consumers provides essential income. This concept, known as market access, depends on the availability of relevant infrastructure. Introducing cooling solutions can play a transformative role by preserving the quality and safety of produce, thereby extending its shelf-life and enabling longer trade periods and better prices.

Evaluating the role of solar-powered cold chains requires consideration that each fresh product has unique characteristics, including its perishability, the timing of cooling, the scale of operations, economic factors and alternative preservation methods, such as passive cooling and drying, which vary by product. Considering this, the following product categories have been identified, along with reflections on the potential of solar-powered cold chains.

- **Dairy** – milk must be cooled within 2 to 4 hours after milking to preserve its quality. Beyond direct consumption, there are limited alternative preservation methods, as processing also requires cooling. Therefore, dairy products have high potential for solar-powered cold chain solutions.[48] Centralized milk chillers are the most feasible and commonly used although individual refrigerators at the first mile are occasionally deployed.

- **Green leafy vegetables, herbs, peas and berries** - in informal markets, these crops are typically grown for domestic consumption or near cities and consumed within 24 hours of harvest, eliminating the need for cooling. However, for high-end markets and extended value chains, cooling must occur within hours of harvest, making solar-powered cold rooms a viable option.

41 Food loss and waste account for 8-10% of annual global greenhouse gas emissions; cost USD 1 trillion annually | UNFCCC
42 Efficiency for Access Coalition (2023). Tech Trends in Energy Access: Assessing the Off-Grid Refrigerator Market
43 Efficiency for Access Coalition (2023). Keep it Cool: Harnessing Cold Storage to Reduce Food Loss and Support Sustainable Food Systems in Emerging Economies
44 2024-Off-Grid-Solar-Market-Trends-Report.pdf
45 Efficiency for Access Coalition, Keep it Cool: Harnessing Cold Storage to Reduce Food Loss and Support Sustainable Food Systems in Emerging Economies, October 2023
46 WRI and UNEP. (2013). Reducing Food Loss and Waste. http://pdf.wri.org/reducing_food_loss_and_waste.pdf.
47 A. Friedman-Heiman, S. A. Miller. (2024). The impact of refrigeration on food losses and associated greenhouse gas emissions throughout the supply chain. Environmental research Letters, Volume 19, Number 6.
48 Shell Foundation and SureChill (2024). Testing the feasibility of solar cooling for Kenyan dairy farmers

- **Fish** - can be preserved using various methods, such as keeping them alive in water buckets, drying, frying, or salting. However, cooling (using refrigerators, freezers and cold rooms) and ice-cooling are typically introduced when supplying more formal markets, including supermarkets, restaurants, and export markets.

- **Tomatoes, mangoes and bananas** - these crops continue to ripen after harvest, allowing them to be picked at an earlier stage and mature during transportation to the market. As a result, cooling is often unnecessary for local markets. However, for longer value chains, cooling becomes essential. That said, these crops can remain without cooling for extended periods after harvest, making centralized packhouses and storage facilities more economically viable than solar-powered cold rooms.[49]

- **Poultry** - in informal markets, poultry is typically slaughtered just before consumption, eliminating the need for cooling. However, the need for cooling arises with the introduction of modern slaughterhouses and formal markets, where compliance with food safety standards is required. The potential for cooling solutions in poultry farming is growing as it becomes increasingly common in peri-urban and urban areas in Africa with several poultry farms owning outlets with refrigerators to sell dressed chicken,and other meat products for small-scale trading.

- **Meat** - similar to poultry, the need for cooling typically arises to meet food safety standards in modern slaughterhouses and formal markets, generally at peri-urban and urban areas.

- **Potatoes and onions** - potatoes and onions are seasonal products that can be relatively easily stored in traditional sheds. A CGIAR study indicates that the economics of off-grid solar cold rooms are less favorable compared to existing storage technologies. They become economical only with increased storage capacity and are ideal for regions with poor ambient conditions and higher market prices.

Reflecting on the overview above, we emphasize the importance of market maturity in driving demand for cooling and the willingness to pay for chilled and frozen products. In agriculture, two models can be distinguished: pull and push.

In an emerging trend, some solar-powered cold room operators have shifted their business models from offering Cooling-as-a-Service (CaaS), whereby farmers or market vendors pay per crate/volume/weight to store their produce on a daily/weekly basis, to becoming traders of fresh produce (e.g. Adili Solar Hubs and SokoFresh). CaaS enhances affordability for users by eliminating the need for high upfront costs but can pose challenges to operators' cash flows due to less predictable utilization rates and extended return-on-investment periods.[50]

TABLE 5: DISTINGUISHING THE PULL VS PUSH MODEL

Model	Description
Pull	In a pull model, such as contract farming, a market player has a clear understanding of future demand and enters into agreements with farmers (or traders) to supply the produce.
Push	The push model lacks off-take guarantees, making production more speculative. From an investment perspective, greater certainty about future off-take of produce enables investor confidence (pull model).

49 Wageningen University and Research (2022). Postharvest Assessment Methodology

50 Efficiency for Access and IIR. 2023. Walk-In Cold Rooms, a Practitioner's Technical Guide.

CASE STUDY: DEMONSTRATING THE ROLE OF SOLAR-POWERED COLD CHAINS IN REDUCING FOOD LOSS AND INCREASING INCOMES

ADILI SOLAR HUBS: REDUCING FISH SPOILAGE AND IMPROVING INCOMES THROUGH COLD CHAIN IN TURKANA, KENYA

Lake Turkana in Northern Kenya could produce over 30,000 metric tons of fish per year, but infrastructure and accessibility challenges limit harvest to 5,000 to 8,000 metric tons.[51] Located 400km away from the nearest market in Eldoret, fisherfolk face high post-harvest losses from extreme temperatures (often over 40°C) and poor road connectivity. These limitations force them to practice traditional open drying methods, selling the dried fish at 40% less than the price of fresh fish.

With support from the Efficiency for Access Research and Development Fund[52] managed by Energy Saving Trust, Adili Solar Hubs set up a Cold Chain Hub in the Gulf of Lake Turkana to address these value chain gaps.[53] The solar mini grid powers a cold room and freezers to store cleaned fish; and an ice making machine to preserve fish during transportation to the market. With this end-to-end cold chain approach, Adili created a new market for fresh fish that did not exist before, increasing the value of fresh fish per kg more than 10 times compared to dried fish.

Seeing the market potential of fresh fish, Adili is expanding its cold chain to humanitarian settings and to the retail market. By equipping fish vendors at the Kakuma refugee camp with freezers, Adili is making fresh fish available at local stalls and supplying fish fillets to small restaurants.

Adili Solar Hubs' cold room powered by a solar mini grid stacked with cleaned fish (left), and fish fillets frozen for transport to local vendors (right)

51 KMFRI. 2018. The status of Kenya fisheries: Towards sustainable exploitation of fisheries resources for food security and economic development.

52 Efficiency for Access. 2024. Adili Solar Hubs: Improving Fishing Income Without Major Energy Consumption.

53 https://adilisolarhubs.com/

WHAT ARE THE BARRIERS TO THE ADOPTION OF COLD CHAINS?

When examining the challenges associated with solar-powered cold chains, the following key issues emerge:

- **Perception of a Silver Bullet:** sometimes there is a misconception that cold chains, in general, are a comprehensive solution to food waste. However, multiple approaches, including market-driven production and alternative preservation strategies, are needed to effectively reduce food loss.
- **Postharvest Knowledge:** designing effective cold chains requires a thorough understanding of the post-harvest physiology of produce and preservation techniques. Increasing awareness of postharvest management is crucial to improving the success rate of cold chain projects.
- **Sub-optimal enabling environment:** the absence of targeted or weak policies and regulatory frameworks hampers the development of cold chain infrastructure and modern food systems. Many governments have not established clear policies or incentives to promote cooling solutions or other food security practices, limiting private sector investment. Additionally, high upfront costs, inconsistent duties and taxes on refrigeration equipment make these technologies unaffordable for smallholder farmers, fisheries and small-scale agribusinesses. Weak enforcement of cold chain and food safety standards further exacerbates the issue, leading to inconsistent cooling practices that compromise food safety and quality. Addressing these challenges requires policy reforms.
- **Market barriers:** high upfront costs, weak market linkages, fragmented supply chains and lack of demand aggregation reduce economies of scale, making cold chain investment unattractive. Poor infrastructure and inadequate enforcement of food safety standards further limit market modernization. Without targeted incentives and cooperative models, smallholder farmers struggle to integrate into formal value chains.

HOW CAN WE LEVERAGE A NEXUS APPROACH TO SCALE COLD CHAINS?

To address these challenges and unlock the potential of solar-powered cold chains, an enabling environment that supports a holistic approach to post-harvest management must be created. Cooling in food systems requires a specific enabling environment that is cross-ministerial, with policies and strategies that influence the development of cold chains. This environment plays a crucial role in overcoming barriers and fostering the adoption and scalability of solar-powered cold chains.

Food Safety Regulations – Governed primarily by the Ministry of Agriculture, together with National Standards bureaus, food safety regulations are designed to protect consumer health and wellbeing. These regulations set temperature management requirements for animal-derived products such as milk, fish, and meat. The enforcement of food safety regulations often serves as a key driver in the development of cold chains for animal-based products, mainly in urban areas for the near future

Modernization of Markets – Development of cold chains is closely linked to the modernization of markets and the promotion of modern processing methods. Upgrading fresh-food markets, particularly meat markets, often involves ensuring that slaughtering processes comply with food safety regulations, which frequently leads to the establishment of (semi-)formal slaughterhouses in urban or peri-urban areas. This modernization also extends to the sale of produce through supermarkets.

Montreal Protocol and Kigali Amendment – These multilateral environmental agreements regulate the production and consumption of nearly 100 human-made chemicals, known as ozone-depleting substances (ODS). Specifically, the Kigali Amendment addresses the phase-out of Hydrochlorofluorocarbons (HFCs) with high Global Warming Potential (GWP). A phased timeline for the reduction of HFCs has been established and will impact the types of refrigerants used in cold chains, influencing the design of cooling technologies. The state of play and implications of the HFC phase-out on off-grid solar cooling technologies are detailed in the Efficiency for Access report.[54]

Nutrition Strategy – Fresh fruits, vegetables, and animal products are essential for healthy diets and are often promoted through food and nutrition security policies. These policies aim to enhance the availability, affordability, and accessibility of nutritious food year-round, supporting nutrition-sensitive interventions such as the implementation of cold chain technologies.

54 Efficiency for Access. 2021. Phasing Down HFCs in Off- and Weak-Grid Refrigeration: An Opportunity to Reduce Greenhouse Gas Emissions.

AGRO-PROCESSING

WHY IS THERE A NEED FOR A NEXUS APPROACH?

Most foods require processing before they can be utilized. Beyond milling, additional post-harvest processing steps such as cleaning, dehulling, washing, or drying are often necessary. Although not the focus of this paper, other solar technologies for food processing and preparation in small enterprises such as cous-cous preparation and chapati/roti making are emerging. These processes are typically labor-intensive and time-consuming. To alleviate this burden, various levels of mechanization have been introduced.

In rural areas, central village processing units are being established to enable local smallholders to process crops for a fee. The products generated through these processes are often used for personal consumption but can also be sold, either directly or following additional processing. The standard equipment used in these processing hubs is typically designed for higher throughput and requires substantial power inputs. This presents two key challenges. First, a reliable power source, such as a grid connection or a diesel generator, is necessary to meet the energy demands. Second, the investment cost for such equipment is relatively high. Consequently, these processing hubs are primarily located in more densely populated areas, making them inaccessible to individuals in remote regions due to the long travel distances.

Off-grid solar-powered post-harvest mechanization would logically fit between manual on-farm processing and village-level processing. The application of solar energy in agricultural processing through drying, milling, grinding, oil pressing and other applications can not only facilitate value addition and improve the marketability of agricultural outputs but also support improved food safety and nutritional outcomes. Beside these applications, there are potentially also solar-powered opportunities for dehulling and cleaning of other staple foods, especially when the seeds are difficult to process, for example teff or fonio.

WHAT IS THE POTENTIAL OF SOLAR-POWERED AGRICULTURAL PROCESSING TECHNOLOGIES?

Off-grid agro-processing equipment often takes the form of a shared facility or a small enterprise. The capacity is lower than that of village-level processing, and the equipment is designed to process small batches efficiently and requires minimal energy consumption and maintenance. For such applications to be viable, they must significantly reduce the time and cost required for processing. Additionally, to achieve a short payback period, the equipment must not only meet these conditions but also operate for sufficient hours. Equipment that is only functional during harvest seasons or lacks sufficient energy storage to operate reliably during cloudy or early morning / late evening periods may be less suitable.

To illustrate the factors necessary for achieving a positive business case, the solar-powered Agsol Micromill serves as an example. This mill fulfils these constraints and has been successfully introduced in Kenya. It is primarily designed to process maize flour, with a capacity of 55 kg/hour and an average energy consumption of 15 kWh per metric ton. The total recommended retail cost of the mill, including the necessary solar panels, is $1,300 USD.[55] With an average tolling fee of 0.11 USD per kilogram, the mill achieves payback after processing 12 metric tons (approximately 220 hours of operation), excluding labor and maintenance costs. However, this tolling fee remains relatively high, limiting accessibility to Kenya's poorest rural residents, who make up 65% of the rural population.

For fruits and vegetables, solar dryers are often promoted to preserve produce during the seasons when supply exceeds demand. Solar drying offers a more controlled environment for processing, ensuring better hygiene and food safety standards. Additionally, solar drying can be coupled with fortification methods to enhance the nutritional content of food products. The increasing consumer demand for fortified and dried agricultural products indicates a growing market opportunity for such technologies as outlined in the recent Efficiency for Access report.[56]

However, achieving a positive business case for solar dryers remains challenging. This is partly due to design inefficiencies, such as slow drying speeds and insufficient utilization of solar radiation. These shortcomings can be mitigated using solar-powered ventilators, insulation, and smart ventilation systems. However, even with an optimized design, additional factors must be considered. First, drying capacity is highly dependent on solar irradiation, which can vary significantly from day-to-day and more so across seasons. Second, solar-powered drying is most practical when supply exceeds demand and produce prices are low. The process requires a high energy input, necessitating a large dryer capable of capturing sufficient solar radiation to meet the demand.

Solar-powered dryers face competition from open-air sun-drying, which requires no investment. However, open-air drying is vulnerable to external factors such as contamination from birds, rodents, dust and unexpected rains.[57] Solar dryers become a viable alternative under specific circumstances, such as when hygienic requirements or wet climatic conditions make outdoor drying impractical, and the dried produce commands a high market value.

55 Agsol. 2024. The Agsol MicroMill in Numbers.

56 Efficiency for Access. 2024. Tech Trends in Energy Access: Assessing the Solar Dryer Market.

57 Ibid

CASE STUDY: DEMONSTRATING THE IMPACT OF SOLAR-POWERED MILLING SERVICES IN LOCAL COMMUNITIES

NADJI.BI: SHIFTING TO DECENTRALIZED, SOLAR-POWERED MILLING SERVICES IN RURAL COMMUNITIES IN SENEGAL

Nadji.Bi began locally manufacturing solar-powered milling machines in 2016 to process maize, millet, and sorghum, distributing them to non-governmental organizations and local communities in Senegal. While impactful, the initial business model faced limitations, particularly in ensuring the sustainability of the machines through effective service management and maintenance.

With funding from the Efficiency for Access Research and Development Fund in 2020, Nadji.Bi addressed these challenges by designing and manufacturing new, efficient milling and hulling machines. The company digitized its operations end-to-end, incorporating digital payment systems and Internet of Things (IoT) technology to monitor machine performance. This innovation led to the development of connected milling service hubs branded as WALALMA, the digital platform for the hubs.

The milling machines achieve production rates of 50–75 kg/hour, while the hulling machines process 45–60 kg/hour. These machines operate automatically only when payments are made in advance and sufficient sunlight is available. Beyond milling and hulling, WALALMA hubs offer additional services, such as ice making, ice cream production, mobile phone charging, and small grocery sales, enhancing the hubs' profitability.

The impact has been profound. Women were involved in the digital payment platform from the outset and comprised 100% of customers for the first three hubs. Locating the hubs within rural communities significantly reduced travel distances and saved time. Previously, women often traveled a 5–7 kilometers round trip, usually weekly. With the WALALMA hubs, this distance has been reduced to a maximum of 1-kilometer round trip.

Further, there were noticeable beneficial impacts on the health of the women. Before the hubs were introduced, women commonly processed grains manually or walked long distances under the sun, carrying heavy loads of grain. These activities often resulted in back and leg pain, blisters, curvatures, and headaches. By accessing decentralized, solar-powered milling services, women now experience fewer physical ailments and significantly reduced labor burdens.

Women using a decentralized, solar-powered milling machine hub (Nadji.Bi Senegal)

The example above highlights that solar power for processing is not always straightforward, even in the absence of a grid connection. In addition to effective design and sufficient hourly solar radiation, local conditions also significantly influence the success of solar-powered agro-processing equipment. Conducting a thorough assessment of economic opportunities and local practices can greatly enhance the likelihood of success.

WHAT ARE THE BARRIERS TO THE ADOPTION OF SOLAR-POWERED AGRO-PROCESSING?

Despite the promising potential of solar energy for agro-processing, several challenges remain.

- **Limited scale:** Adoption rates for solar-powered agro-processing technologies, such as grain milling, are still in their early stages despite significant technological progress made by innovators like Agsol and Nadji.Bi. In sub-Saharan Africa, for instance, the deployment of solar-powered grain mills, a crucial part of the agricultural value chain, remains largely at the pilot phase, with limited commercial scalability.

- **Customer behavior:** customer acceptance is another hurdle, as many smallholders and agro-processors are reluctant to switch from traditional diesel or electric mills to newer, more efficient solar-powered alternatives.

- **Technical capacity:** solar-powered agro-processing technologies require a skilled workforce of technicians to provide after-sales services including maintenance and repair.

- **Processing Capacity:** additionally, appropriately sizing the capacity of technologies to meet local needs remains an issue (e.g. solar mills having a relatively low throughput but oversized solar dryers).

HOW CAN WE LEVERAGE A NEXUS APPROACH TO SCALE SOLAR-POWERED AGRO-PROCESSING?

New opportunities are arising to address the challenges outlined in the previous section:

Leveraging the nexus between different agro-processing technologies: combining complementary agro-processing technologies to reduce food waste and enhance value addition could address some of the challenges outlined above. For example, in Kenya, ShambaniPro integrated solar drying and oil pressing technologies, to convert lower-grade avocadoes that would otherwise be waste into high-value avocado oil, demonstrating how such synergies can potentially create new income streams.[58] Programs should incentivize the adoption of similar integrated models through funding, capacity building, and support for local innovators, ensuring that post-harvest losses are minimized while increasing the value-add of agricultural produce.

Significant climate mitigation potential: incumbent agro-processing technologies are often inefficient and heavily reliant on fossil fuels. For example, CrossBoundary estimated that there are 500,000-750,000 maize mills in sub-Saharan Africa, the majority of which are diesel powered posho mills, resulting in 2.3M tons of carbon dioxide equivalent per year for maize alone.[59] According to the report, switching to electric grain mills by 2030 could generate USD $2.5 billion per year through carbon credits.

Distributed systems leading to more equitable access: decentralized solar-powered agro-processing systems provide a crucial advantage in reducing logistical challenges and improving access for smallholder farmers. Unlike centralized diesel-powered hubs, these smaller, distributed systems can reduce the need for farmers to travel long distances, saving time and reducing costs.[60] Some innovators are now exploring the use of electric two-wheelers to provide mobile milling services.[61]

Innovative financing and capacity building: to successfully scale these technologies, it is essential to develop innovative financing models, capacity-building programs, and awareness campaigns to make solar-powered solutions more accessible and appealing to smallholder farmers and rural agro-processing enterprises.

58 Enviu. 2022. Rebuilding a value chain for zero percent food loss.
59 CrossBoundary. 2024. Mini-Grid Innovation Lab. Innovation Insight.
60 ImaraTech. User research: Off-Grid Milling and Oil Extraction.
61 Efficiency for Access. 2024. Key Takeaways from the 2024 Humanitarian Energy Conference and the Global Off-Grid Solar Forum & Expo.

CHAPTER 4: ADOPTING A NEXUS APPROACH TO SCALING OFF GRID SOLAR APPLICATIONS IN FOOD SYSTEMS

Widespread adoption of productive use of renewable energy (PURE) technologies by smallholder farmers and small-scale agribusinesses has been impeded by several barriers, limiting their potential impact.

Among them are:

- Inconsistent policies and regulations, coupled with a lack of integrated planning, creating uncertainty and slowing down investment in the sector.
- High costs of PURE technologies and limited access to credit for both PURE companies and end users reducing affordability and investment capacity.
- Limited training and capacity building to enhance farmers ability to operate and maintain PURE systems effectively, leading to underutilization and reduced benefits.
- Weak market linkages resulting in farmers struggling to sell their produce at competitive prices even after adopting PURE technologies to increase productivity.
- Limited cross-sectoral engagement between energy, agriculture, and finance stakeholders preventing coordinated solutions that could drive wider adoption.

INTEGRATED PLANNING

A constant phenomenon in the public and development sector is siloed approaches in the design and implementation of policy and programs that guide different economic and social sectors. Leveraging the food systems and energy nexus should be prioritized right from the conceptual stages of relevant development initiatives, making it an integrated component at all levels, from policy, regulations, strategy and the program or project. For example at a programmatic level:

- Mapping the food value chains that would benefit from off grid solar applications and linkages between different value chain actors in relation to use of the energy to ensure maximum utilization
- Understanding the key conditions under which this utilization can be realized and those conditions can be best supported
- Identifying existing irrigation, cooling and agro-processing infrastructure for existing market actors and the associated challenges and gaps
- Identifying the technical assistance needs to ensure there is adequate technical capacity to utilize the productive use equipment sustainably.

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- Reviewing national energy and agricultural policies, rural development policies, mechanization and productivity goals, climate adaptation goals and how they integrate with PURE.
- Identifying financing options and potential implementation partners
- Assessing environmental and social safeguards e.g. water resource management, equitable access etc.

which should all feed into the program planning and design.

Detailed planning and design ensure that there is an acknowledgement and leveraging of opportunities in the nexus to avoid missed opportunities and sub optimal results.

TABLE 6: LEVELS OF NEXUS COLLABORATION IN FACILITATING INTEGRATED PLANNING

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	• Policies and programs for food systems and energy are designed and implemented separately, without cross-sector engagement. For example, rural development programs may promote energy access solar without considering food value chain integration.	Low
Consultation	• Energy and agriculture stakeholders seek input from one another, such as policymakers reviewing national energy and agricultural planning or policies to assess integration of PURE solutions or mapping food value chains to understand energy linkages and opportunities.	Low-Medium
Co-creation	• Energy and agricultural stakeholders collaboratively design and implement initiatives. For example, they jointly identify technical assistance needs, financing options, and environmental safeguards to ensure sustainable use of productive use equipment. • Energy access planning (grid, off-grid) gets inputs from the agricultural, water, or environmental ministries to enhance impact by PURE solutions into different agricultural value chains.	Medium
Facilitation	• One sector actively supports another to achieve shared goals. For instance, the ministry of energy facilitates private sector investment or energy usage data by identifying infrastructure gaps in the agricultural planning, linking value chain actors, and supporting climate adaptation through integrated policies.	High

ACCESS TO FINANCE

Financing for productive use of renewable energy solutions is a key constraint across the supply chain from both the supply side i.e. manufacturers, retailers and distributors and the demand side i.e. consumers seeking to purchase solutions.

For suppliers, these challenges include limited access to local capital, lack of relevant financial instruments such as working capital or debt financing from banks. For consumers, consumer financing options from mainstream banks, microfinance institutions (MFIs), and Village Savings and Loan Associations (VSLAs) are either scarce or available at high interest rates and short repayment terms. Financial institutions perceive lending to businesses selling these OGS technologies or rural consumers seeking to buy products as high risk due to their low profit margins and the difficulty of assessing creditworthiness. The end users, such as individual farmers, farmer groups and agricultural cooperatives, may have seasonal and unpredictable incomes, further complicating debt repayment.[62]

A blended finance approach combining grants, debt, credit enhancement schemes and guarantee programs along with technical assistance could create more sustainable funding structures on both the supply and demand side and improve affordability for all.[63] Bank guarantees for PURE companies to obtain credit for manufacturing or importing these technologies are essential. Demand-side subsidies for farmers help reduce the cost of these technologies by lowering the interest rates on loans or PAYGo financing. This makes it more affordable for farmers to access these systems, which can be offered through various financing models such as bank loans or PAYGo plans provided by PURE companies.[64]

TABLE 7: LEVELS OF NEXUS COLLABORATION IN ENHANCING ACCESS TO FINANCE

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	• Energy and agriculture sectors provide separate subsidies or public financial mechanisms for OGS PURE appliances and agricultural mechanization, but without coordination, leading to duplication, inefficiencies and missed opportunities for synergy. • Innovative financial mechanisms in the energy-sector remain unshared with agricultural stakeholders (i.e., RBF, first-lost guarantees, PAYGO, digital O&M, etc.)	Low
Consultation	• Energy-sector subsidy or financing programs engage agricultural stakeholders (farmers, cooperatives, agribusinesses) to better align financial products with user needs. • However, collaboration remains limited to input-sharing rather than joint decision-making, thus limiting impact.	Low-Medium
Co-creation	• Energy and agriculture sectors actively incorporate each other's priorities when designing financial mechanisms. E.g., agricultural sector funding is structured to support renewable energy adoption, while energy sector programs prioritize agriculture-focused applications. • Financial engagement covers private sector companies both in the agricultural and energy areas leveraging synergies and avoiding thematic siloes.	Medium
Facilitation	• Instead of separate funding streams, financing mechanisms are structured to jointly support OGS adoption and agricultural productivity. • End-user finance is structured to cover a bigger range of solutions (energy, agriculture, climate) to ensure customers adapt to their local contexts and needs. • This approach involves proactive collaboration across government agencies, development organizations, private financial institutions, PURE companies, and agricultural MSMEs to embed renewable energy solutions in agricultural development.	High

62 GET.invest (2023). Financing and scaling productive use of energy: challenges and opportunities for catalytic growth

63 Ibid

64 GOGLA (2023). Kenya Roadmap and Market Assessment for PURE

Public sector stimulus packages can also enhance access to finance. For example, repurposing agricultural subsidies can contribute to transforming food systems. Currently, 87% of the 540 billion USD in agricultural support either distorts prices or harms nature and public health.[65] A nexus approach integrating energy, water, and food systems offers a strategic pathway to maximize the impact of repurposed subsidies. Securing water access can boost agricultural productivity, ensuring more efficient and resilient food production. Additionally, reducing food loss and waste can also enhance food availability while minimizing environmental harm.

Using an example of various financing mechanisms we illustrate the various levels of nexus collaboration that could exist to respond to these challenges.

BUSINESS MODEL INNOVATION

Affordability remains a major barrier to the adoption of productive use of renewable energy (PURE) technologies, particularly in Sub-Saharan Africa, due to high upfront costs and limited financing options. Solar water pumps, cold chain technologies and agro-processing equipment remain expensive for smallholder farmers and small-scale agribusinesses, partly due to limited market development and economies of scale. These factors continue to slow widespread adoption and deployment.

Although public sector support in the form of subsidies and results-based financing as discussed in the previous section are key, private sector companies are also playing a significant role in the development of innovative business models suited to address these affordability challenges and the diverse needs of smallholder farmers. Some of the most mature business models for PURE include:

- **Pay as You Go (PAYGo):** Reduces initial investment costs by paying a down payment that lowers the entry barriers.[66] Farmer or other end user pays on a fixed or flexible basis spread over an agreed period thus easing financial strain. However, this may constrain the operations of the companies who must bear the financial burden of providing customers with credit to purchase these systems. There is also a risk of customer payment defaults owing to the seasonal nature of farming and farmers face being locked out of using the systems when they are unable to pay owing to the variability of their incomes.

- **Energy-as-a-Service (EaaS):** could take the form of Irrigation-as-a-Service (IaaS), Cooling-as-a-Service (CaaS) or Milling-as-a-Service for agro-processing. This model lowers operating costs and offers convenience by providing the energy services as needed. It also allows for multiple farmers benefiting from the service at a central site. Farmers can choose from different payment models depending on the service sought, making costs predictable and manageable. However, farmers who are unfamiliar with the technologies may misuse the equipment leading to frequent breakdowns and ensuring reliable maintenance and service quality in remote areas can be challenging. For capital intensive models such as CaaS, the viability depends on securing enough long-term users to justify infrastructure investment.

- **Lease-to-Own:** farmers pay in instalments with the goal of eventually owning the equipment, making these technologies more affordable by spreading costs over time. This helps farmers improve productivity and reduce losses without needing large upfront investments. It also enables them to generate income while paying for the equipment, making it easier to manage cash flows. Limited access to after-sales service or maintenance can affect long-term usability and efficiency.

Other business models are emerging to respond to various user needs. Some examples are provided below.

65 A multi-billion dollar opportunity: repurposing agricultural support to transform food systems

66 Scaling irrigation for small-scale producers: the role of private sector solutions

- **Off taker-led models:** Companies such as Soko Fresh are implementing models led by off-takers. In these models, off-takers of produce in a specific value chain e.g. horticultural produce or dairy finance the deployment of PURE solutions such as cold storage facilities for farmers within their supply chain to facilitate value addition or quality improvements in their outputs.

- **Other models:** For companies like SowPrecise,[67] which provide affordable irrigation services to low-income farmers in arid and semi-arid lands (ASALs) in Kenya, innovation in IaaS models also includes looking ahead. While this model requires the company to own the hardware and 'rent' it out to farmers, they are working on the 'Uber-isation' of solar water pumps where they offer a software platform which can connect farmers who have a solar water pump to those who need irrigation services.[68] Sharing of high-cost equipment like solar water pumps through such models can make them affordable for smallholder farmers, and renting them out can further enhance income and livelihoods.[69]

The viability of PURE technologies for smallholder farmers and small-scale agribusinesses depends on their ability to achieve a return on their investment. Several factors influence this outcome, including the enabling environment—such as access to markets for their produce and the technical skills required to effectively use these systems. Without adequate market linkages or proper training, farmers may invest in PURE technologies but remain unable to realize their full benefits. This can hinder their ability to repay financing, and ultimately reduce the adoption of these solutions.

MARKET ACCESS

Lowering entry barriers for farmers through innovative financing models is essential. Yet, without reliable market access, they may hesitate to invest in these technologies. If they struggle to sell their produce or face low demand, the upfront costs and long repayment periods can be discouraging. To address this, stronger market linkages—such as farmer aggregation and off-take agreements—are crucial. These approaches not only help farmers secure buyers and improve their incomes but also ensure equipment cost repayments, ultimately supporting both their livelihoods and the growth of companies providing these technologies.

TABLE 8: LEVELS OF NEXUS COLLABORATION IN FACILITATING MARKET ACCESS

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	• Farmers adopt PURE technologies without structured connections to markets, making it difficult to generate returns and discouraging adoption. • Public programs deliver general non-targeted PURE handouts, disrupting markets and competition. • Agricultural stakeholders deliver non-quality or untested PURE equipment, with no guarantees or poor O&M services.	Low
Consultation	• Energy sector stakeholders consult agricultural actors on market constraints, raising awareness, but without structured solutions, market linkages remain weak. • Agricultural stakeholders understand how to connect customers and value chains to existing PURE business models and companies.	Low-Medium
Co-creation	• PURE financing models offered to farmers are bundled with market access strategies, such as cold storage linked to off-take agreements or solar-powered processing integrated with aggregators.	Medium
Facilitation	• Governments, development actors and private sector actors create an enabling environment that ensures OGS adoption by farmers aligns with structured market access through affordable financing, aggregation channels, and off-take agreements, ensuring farmer profitability.	High

67 https://www.sowprecise.org/
68 https://gogla.org/blog/irrigation-as-a-service/
69 Ibid

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REGULATION AND POLICY COHERENCE

Tariff regulations, product performance standards and labelling influence OGS adoption and the type of productive use appliances that enter the market. Both over- and under-regulation can impact market entry and development by affecting business registration, licensing, access to financing, appliance standards and the quality of service provided by OGS energy providers. Transparent, fair, and stable regulations build investor confidence, helping Micro Small and Medium Enterprises (MSMEs) and other stakeholders manage risks and identify opportunities, driving greater investment in PURE.

LOWERING ENTRY BARRIERS FOR PRIVATE SECTOR COMPANIES THROUGH TAXES AND INCENTIVES

Taxes and incentives are instrumental for stimulating investments in productive energy use. By offering exemptions on duties and value added tax (VAT) for system components and simplifying regulatory processes, such as registration, licensing, and permitting, the overall cost of investment is reduced.[70,71,72] Additionally, innovative tax reforms that involve long-term support to local assembly are necessary to gradually lower the cost of energy supply.

Government and development partner financial support can help offset market entry costs and risks, making it easier to introduce efficient appliances to rural areas. Simultaneously, VAT exemptions for productive use appliances can increase affordability, ensuring they remain competitive with diesel alternatives. In combination with measures to phase-out subsidies on fossil-based energy, these interventions can lower consumer costs and stimulate greater use of productive energy technologies.

ENSURING QUALITY IN PRODUCTIVE USE APPLIANCES TO ENHANCE CONSUMER PROTECTION

Making entry-level productive use energy solutions affordable for smallholder farmers and small agribusinesses is a foundational part of the energy ladder, where the users start with smaller investments and gradually scale up to more efficient technologies as their income grows. While these solutions may provide essential first-time access to energy, ensuring their safety, reliability, and performance remains a challenge.

The use of quality-certified appliances is essential to market growth and long-term adoption.[73] MSMEs face financial constraints when adopting new technologies, so early adopters must have reliable products to encourage broader uptake. If low-quality, cheaper alternatives end up flooding the market, it could undermine consumer confidence and slow demand for better products. Quality standards, certifications, warranties, and labeling help maintain product integrity, while awareness campaigns educate consumers to identify low-quality brands.

National bureaus of standards and regulatory frameworks help establish minimum safety and performance thresholds, ensuring that even the most affordable solutions provide value while mitigating risks for end users. Certification mechanisms, such as the Kenya Bureau of Standards (KEBS), could safeguard consumers while maintaining access to cost-effective energy solutions. Additionally, global initiatives like VeraSol and the Collaborative Labeling and Appliance Standards Program (CLASP) support governments in enforcing regulations that promote high-quality appliances, fostering a sustainable market.

70 GOGLA (2023). Uganda Roadmap and Market Assessment for PURE
71 GOGLA (2023). Kenya Roadmap and Market Assessment for PURE
72 GOGLA (2023). Ethiopia Roadmap and Market Assessment for PURE
73 GOGLA (2023). Kenya Roadmap and Market Assessment for PURE

POLICY CONVERGENCE

Productive use of renewable energy must be embedded in both national electrification and agricultural strategies and other cross-sectoral policies. Policy coherence and programmatic alignment can maximize the impact of PURE technologies and streamline efforts. For example, Kenya and Uganda exhibit differing levels of policy integration between the energy and agriculture sectors:

- **Kenya:** energy and agriculture policies operate in silos, with limited cross-referencing or alignment. While the National Energy Efficiency and Conservation Strategy (NEECS) acknowledges agriculture as a key sector to promote energy efficiency, it does not include actionable pathways for collaboration with agricultural stakeholders. Similarly, the Agriculture Mechanization Policy recognizes renewable energy's role but lacks a robust implementation framework linking it to energy policies.[74]

- **Uganda:** demonstrates alignment between energy and agriculture policies. The Energy Policy (2023) explicitly outlines the role of energy in agricultural development, proposing incentives and renewable energy solutions tailored to the sector. The Agriculture Policy (2013) also identifies energy as a critical enabler and outlines coordination mechanisms involving multiple sectors under the Office of the Prime Minister. However, Uganda's policy framework relies heavily on traditional energy sources, reflecting the need for stronger commitments to renewable energy.

TABLE 9: LEVELS OF NEXUS COLLABORATION IN FACILITATING REGULATORY AND POLICY COHERENCE

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	• Energy and agriculture policies are developed separately, causing fragmented regulations on tariffs, appliance standards, and service quality. This limits market development support for productive use technologies. • Heavy tariffs hamper growth of the sector and innovation. • Lack of standards limit the adoption of quality services and equipment.	Low
Consultation	• Policymakers engage in discussions, considering sectoral needs (e.g. tariffs, standards), but without formal alignment. • New policies and strategies embed some but limited elements from other sectorial policies and strategies.	Low-Medium
Co-creation	• Energy, agriculture and nutrition policies align, integrating incentives for renewable energy in agriculture and including productive uses of renewable energy in national strategies. • Joint approaches to standards and appliance and service quality improve the life cycle of products, enhance the quality of life of customers.	Medium
Facilitation	• Fully integrated policies ensure coordinated funding, incentives, and interministerial collaboration, creating a strong regulatory environment for adoption of productive use technologies.[75]	High

74 EnDev (2021). The market for productive uses of solar energy in Kenya: a status report

75 GOGLA (2024). Powering Lives and Livelihoods: Scaling PURE Handbook for Governments and Development Partners

National energy and agriculture policies often address energy access and mechanization in isolation, missing opportunities to integrate PURE as a solution for productivity enhancement. Additionally, addressing the dual threats of climate change and malnutrition through collaborative, forward-thinking policies—coupled with scalable off-grid solar solutions—is an urgent necessity and a critical step toward building a sustainable, healthy, and equitable future for all. To create a more enabling environment for PURE, governments should explicitly include PURE in energy and agriculture policies, supported by clear implementation frameworks.

INTERMINISTERIAL COORDINATION

Optimizing the food systems and energy nexus requires the continent wide adoption of a broader food systems lens that recognizes complementarities across ministries and sectors. Current mechanisms for interministerial collaboration across governments are limited, hindering pan-African approaches to scaling these technologies. Interministerial task forces are also important in aligning energy and agriculture policies and programs and ensuring policy coherence and efficiency.

AGRA has been supporting countries to develop National Food Systems Strategies and Investment Plans (FSSIPs) that integrate the core elements of the food supply, environmental, health as well as the social, economic and political system. The FSSIPs have helped foster a more food systems thinking among African decision makers, enhancing coordination across key sectors, including the energy, environment and health sectors that are traditionally overlooked. Countries such as Rwanda, Malawi and Ghana are among pathfinder countries that have been supported to develop the FSSIPs.

For example, the national food systems strategy for Malawi identifies keys constraints that could potentially compound the food systems and energy nexus.[76] These include:

- the insufficient application of sustainability plans in off-grid energy projects and
- limited available financing for alternative energy providers.

As part of its strategic transformation anchors, the Malawi FSSIP identifies key priorities including incentives for private sector participation in renewable energy and promoting investments in renewable energy solutions for agricultural production, storage, processing, logistics, and irrigation.

Critically, the FSSIP clearly articulates the complimentary roles of the different ministries, including Finance, Industry, Environment, and Trade, among others, and the respective roles of different value chain actors in achieving the desired transformation.

Moreover, most existing agricultural policies disproportionately serve industrial agriculture over climate-smart agriculture. The policy and institutional architecture necessary to support the transition must be proportional in addressing these agribusiness models. Overall, optimizing the food systems and energy nexus will require African governments to progressively align agricultural, food, climate, and energy policies to create coherent strategies for an effective food systems transformation.

Uganda is demonstrating strong interministerial collaboration through its National Irrigation Policy, jointly

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76 Productive uses of energy for resilient livelihoods in LDCs

developed by the Ministry of Agriculture, Animal Industry and Fisheries and the Ministry of Water and Environment. This policy is designed to increase efficient water use for irrigation and enhance agricultural productivity. Rather than operating in isolation, it aligns with the National Water Policy and complements key strategies in agriculture, climate change, land use, and environmental management. Uganda is fostering a coordinated approach to agricultural development, by integrating multiple sectoral policies and engaging various stakeholders, ensuring that irrigation efforts are both sustainable and impactful.[77]

TABLE 10: LEVELS OF NEXUS COLLABORATION IN FACILITATING INTERMINISTERIAL COLLABORATION

Form of Collaboration	Description	Level of Nexus Collaboration
Independent	• Ministries develop policies and programs in silos within their own mandates. • Conversations with Multilateral Development Banks (MDBs) remain siloed, provoking an upstream siloed effect at the MDBs too. • While these efforts drive sector-specific progress, opportunities for cross-sectoral alignment remain unexplored.	Low
Consultation	• Ministries engage in consultations to identify synergies between energy, agriculture, and food systems. • Ministries engage in multi-stakeholder unbiased conversations, i.e. increasing productive engagement with the private sector, broadening understanding of private sector challenges and interest in supporting programmatic efforts.	Low-Medium
Co-creation	• Cross-ministerial task forces and national strategies align policies across sectors. • Clear mandates help define complementary roles, though coordination challenges persist. • Definition and implementation of joint sectorial indicators (KPIs)	Medium
Facilitation	• Governments establish structured frameworks that align energy, agriculture, food, and climate policies. • Establish interagency coordination platforms and channels to connect ministry departments and representatives.[78] • Proactive collaboration ensures coherent strategies, unlocking investment and accelerating food systems transformation. • Provision of energy technical support provided organically within the Ministries of Agriculture, Water, or Environment.	High

77 Uganda National Irrigation Policy (2017).

78 GOGLA (2024). Powering Lives and Livelihoods: Scaling PURE Handbook for Governments and Development Partners

CHAPTER 5: STRENGTHENING THE FOOD SYSTEMS AND ENERGY NEXUS

This white paper underscores the inherent connection between food and energy systems, whether fully recognized or actively prioritized by the stakeholders from either ecosystem or not. Acting upon urgent global and national priorities with a proactive and integrated approach that leverages this nexus can unlock opportunities to achieve Sustainable Development Goals (SDGs).

The case studies presented highlight successful implementation and lessons from projects that fell short of their intended impact goals. However, this white paper also recognizes the inherent challenges of cross-sector collaboration. Among them, differences in priorities, perspectives, language, and methodologies. Several recommendations follow to overcome these barriers and effectively adopt an integrated nexus approach both in policy and practice.

i. Clearly Recognize and Define Both the Challenge and Opportunity of the Food Systems and Energy Nexus Before Designing Solutions

Fully leveraging the potential opportunities created by the food systems and energy nexus, first requires an assessment of the core public sector / social need or imperatives, the real constraints and challenges faced by actors and stakeholders in the agri-food system along the full value chain, and the potential role that the new energy solutions can provide. Rather than relying on assumptions shaped by sector-specific perspectives and past practices, it is important to step back and fully explore the nexus' possibilities.

For instance, to increase agricultural productivity and reduce the reliance on rain-fed agriculture and its accompanying vulnerabilities in the face of climate change, rural farmers who are also likely to be off-grid will need access to irrigation solutions. However, due to low-income levels, inadequate expertise and poor access to markets, they may not only have low awareness of the solutions available but also have low ability to afford the solutions they need. In addition they may face minimal capacity to fully utilize the potential of an irrigation system when available, and may fail to realize the full returns of their production due to weak market access. Without fully mapping this in entirety, interventions may be ineffective and fail to achieve their intended impact.

A broader, user-centric ecosystem approach ensures solutions are relevant, adaptable, and truly address stakeholder needs.

ii. Adopt an Ecosystem Approach

Developing and implementing approaches that leverage opportunities availed by the food-energy nexus, requires recognition of the challenges inherent in seeking results in sectors with significant challenges and weaknesses. Realizing the full potential for PURE to positively impact the food systems sector must acknowledge the entire ecosystem within which it exists, including the strengths, weaknesses, opportunities and threats.

For example, introducing irrigation interventions for farmers doesn't necessarily guarantee success if farmers

do not have access to appropriate inputs, don't adopt modern farming practices, or have access to appropriate storage solutions for their produce or access to markets to ensure adequate returns on investment. In this case, the challenges and actions necessary do not exist within the food systems and energy nexus, but solely within the food ecosystem. Inadequate recognition and action to address these challenges will undermine the realization of results from the nexus.

In this regard, driving a productive use of renewable energy (PURE) program within the food systems and energy nexus will require the identification of the appropriate OGS systems that meet the specific user needs, necessary capacity amongst farmers to successfully adopt and utilize the systems, provision of adequate extension services to support the beneficiaries and support in the development of adequate market linkages among others.

iii. Determine the Right Level of Collaboration

Particularly within public and development sectors, stakeholders act in line with their individual policy, legal and/or regulatory frameworks and within the scope of their enabling or guiding mandates. Successful nexus initiatives require intentional and strategic multi-stakeholder collaboration to be effective and impactful. Partnerships should be built not solely around shared goals but also require each partner to fully recognize their individual responsibility and necessary contributions for required results.

In this regard, collaboration is needed at leadership, technical and program levels. The collaboration required may include aligning policy frameworks for individual sectors, examination of the legal and regulatory frameworks within individual pillars and alignment within individual sector programs and interventions. Early consideration of the level of collaboration ensures partnerships are aligned with project goals and have the appropriate level of buy-in and support.

For example, realizing effective cross-sector and or interministerial collaboration for a solar irrigation program requires effective engagement from energy, agriculture and water sectors and may require alignment within the policy, legal, regulatory and program instruments in each individual pillar.

iv. Adopt Integrated Approaches for Greater Impact

In the context of the food systems and energy nexus, traditional, sector-specific approaches—with individual actors focused on their individual core mandates—can lead to suboptimal outcomes. For instance, many agricultural projects that may focus on mechanization may adopt or promote fossil-fuel-based solutions and see their results undermined by reliance on high-cost imported fuel while also undermining their own national clean energy goals. An integrated approach in this regard would see actors in the agriculture value chain seek to leverage and mainstream solutions, while benefiting from energy officials' expertise, to ensure sustainable solutions are adopted while national climate targets and plans also advance climate smart solutions.

In terms of financing, funding programs or windows that combine the efforts of agriculture, water and energy funders, investors or various government institutions with specific key performance indicators and goals for each sector would enhance outcomes across the nexus. Similarly, interministerial cooperation—such as redirecting energy subsidies to promote off-grid solar adoption while agricultural ministries phase-out fossil fuel incentives—can lead to systemic impact. A holistic perspective enables better alignment with multiple Sustainable Development Goals (SDGs) and enhances long-term impact.

v. Repurpose and harmonize food systems, energy & other policies

The global community has recognized that the agricultural sector exists in an ecosystem of interconnected activities and actors involved in producing food from farm to fork, now defined as the food systems. This definition encompasses all stages of production including agricultural production and processing, distribution, consumption, and waste management and acknowledges the critical role of economic, social, and environmental factors in shaping how food reaches the consumer.

Considering this, realizing shared goals in the agri-food sector will require African governments to progressively align agricultural, energy, climate, and any other relevant policies, to create coherent strategies for food systems transformation. Specifically, optimizing policy, legal and regulatory frameworks that may directly or indirectly impact the food systems and energy nexus is imperative.

Intentional policy actions are required to integrate clean energy solutions into practices in the agri-food system, from farm to fork while ensuring policy alignment across sectors.

vi. Strengthen Cross-Sector Technical Assistance (TA)

To enable all actors within the food systems and energy nexus to not only recognize their role, but also appreciate the role and contribution that other actors can play and understand their individual ability to mutually support each other requires capacity building across the board. Effective implementation of nexus solutions recognizes capacity building is required across different sectors—private sector, government, farmers, and financiers. Technical assistance and capacity building can raise their awareness and build their capacity to look beyond their individual technical mandates and see their role within the nexus.

However, technical assistance programs often operate in silos, for example focusing only on either energy or agriculture. Energy programs may support off-grid solar training on the technical aspects of designing and installing a solar system, but neglect training on the specific use cases e.g. agricultural expertise and necessary factors for successful deployment in an agricultural context. A reimagined approach should integrate not just the technical aspects of installation of solar systems, but also how the system would be used. The benefit is twofold: energy actors would not only understand how to install systems but ensure they would fit within the operating environments; agriculture actors would be trained on how solar systems work and how they should be best used or adopted. Ensuring knowledge transfer and skill-building across all actors fosters long-term sustainable use.

vii. Recognize Off-Grid Solar as Part of a Larger Energy System

Energy and energy-based solutions are essential for food systems. However, energy access remains a critical constraint across Africa. Even countries with high energy access, where most agricultural activities are undertaken by rural farmers, energy access remains a constraint. OGS offers a pathway to clean, decentralized, and sustainable energy access for productive use particularly for rural and off-grid communities.

It is essential to communicate to stakeholders particularly in the agricultural sector that OGS is just one of several viable approaches to enable the transformation of the food value chain while achieving clean energy integration. Adoption and leveraging the opportunities presented particularly for rural and/or off-grid communities by modern OGS solutions can be very cost-effective and provide pathways to inclusive economic opportunities and growth in the food system where it is most needed, at the bottom of the income pyramid, and where the majority of food is produced in Africa.

CONCLUSION

This white paper is the result of collaborative efforts from experts across the agriculture, nutrition, off-grid solar, and water sectors, aimed at finding common ground for addressing the food-energy nexus. We encourage stakeholders engaged in nexus initiatives to take a proactive approach in shaping effective collaboration, using the recommendations outlined here as a guide. By sharing experiences, successes, and lessons learned, we can enhance our collective understanding and improve the design and implementation of future projects. This will contribute to more efficient solutions, drive sustainable outcomes, improve livelihoods, and support broader environmental goals.

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The Voice of the Off-Grid Solar Energy Industry