

SOLAR-POWERED AGRI-FOOD SYSTEMS

SEVEN SUCCESS STORIES



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About the Coalition

The IRENA Coalition for Action brings together leading renewable energy players from around the world with the common goal of advancing the uptake of renewable energy. The Coalition facilitates global dialogues between public and private sectors to develop actions to increase the share of renewables in the global energy mix and accelerate the energy transition.

About this publication

This report has been developed jointly by the members of the Coalition's Working Group on Empowering People and Communities. The Working Group brings together a diverse range of stakeholders united by the goal of accelerating the energy transition in a just and inclusive way. This report is a collection of successful projects outlining how the integration of solar photovoltaics with agriculture can contribute to climate, nature, and sustainable development goals, and showcasing successful business models and financing options.

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Contributing authors: The contributing authors of this report are Miriam Di Blasi (Enel Green Power), Christian Doedt (Institute for Sustainable Energy Policies – ISEP), Brian Kawuma (Power for All), John Chettleborough, Unelker Maoga (Practical Action), Mohammad Hassan Ghafouri, Narges Khosroshahi, Sama Hamel (SATKA Renewable Energy Association of Iran), Benson Ileri, Shengnian Xu (World Resources Institute – WRI) and Giedre Viskantaite under the guidance of Ute Collier (IRENA).

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Abbreviations

°C	degrees Celsius
AMCOS	Agricultural Marketing Cooperative Society
BEFS	Bioenergy and Food Security
CAP	Common Agricultural Policy
CBD	Convention on Biological Diversity
CNY	Chinese yuan
CO ₂	carbon dioxide
DIDF	District Irrigation Development Fund
EGP	Enel Green Power
EUR	euro
FAO	Food and Agriculture Organization
GBEP	Global Bioenergy Partnership
GDP	gross domestic product
GWH	gigawatt hour
IRENA	International Renewable Energy Agency
IRR	Iranian rial
JPY	Japanese yen
KW	kilowatt
KWH	kilowatt hour
MFT	modern farming technologies
MW	megawatt
MWH	megawatt hour
NDC	Nationally Determined Contribution
NEA	National Energy Administration
PPA	power purchase agreement
PREO	Powering Renewable Energy Opportunities
PURE	productive use of renewable energy
PV	photovoltaics
RE4A	Renewable Energy for Agriculture
SATBA	Renewable Energy and Energy Efficiency Organization
SATKA	Iranian Renewable Energy Association
SDG	Sustainable Development Goal
TATEDO	Tanzania Traditional Energy Development Organization
TW	terawatt
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar
VAT	value-added tax
WEFE	water-energy-food-ecosystems



Executive summary



Agri-food systems are a major consumer of energy, derived primarily from fossil fuels, while also being highly susceptible to the impacts of climate change. Both food and energy systems need to be transformed to achieve universal access to nutrition and affordable energy in alignment with climate and nature goals. Renewable energy integration in agriculture not only reduces carbon emissions but also enhances food and energy security. More needs to be done to identify best practices and to create enabling conditions to scale them up across different contexts.

This report outlines seven success stories of integrating solar photovoltaics in agriculture that showcase viable business models, financing options and positive synergies of dual land use for food and energy production. These examples demonstrate that renewable energy is an effective solution in highly diverse contexts and conditions. Different business models are being adopted to fit local circumstances, ranging from direct ownership and co-operatives to public-private partnerships and third-party financing. Solar panels have been successfully integrated with aquaculture, horticulture and livestock projects.

The projects delivered wide-ranging benefits that, with the right enabling measures, can be replicated. Renewable energy use in agri-food systems contributes to climate change mitigation and adaptation efforts. Integrating energy and food production achieves more efficient use of land resources with the potential to increase food production and farmer incomes. Switching to renewables reduces negative impacts on air, water and soil, thereby improving health outcomes. Decentralised energy solutions provide a reliable and affordable energy supply in settings with low energy access. By facilitating productive use of energy, renewables improve local economic opportunities and livelihoods and empower women.

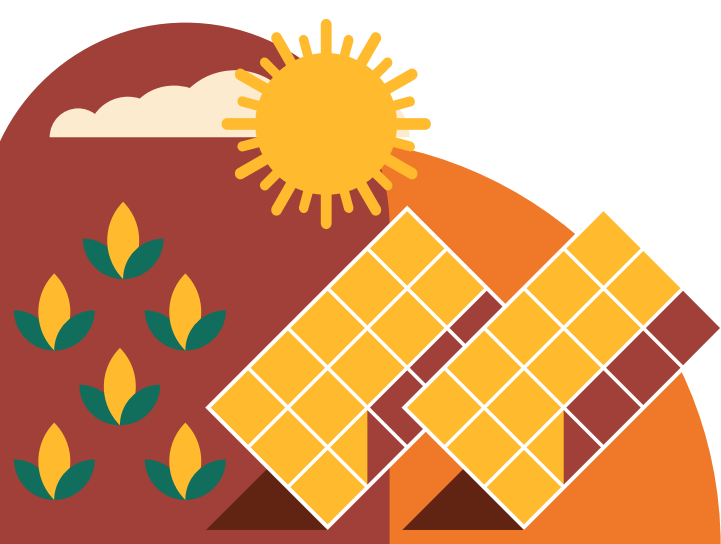
Despite such benefits, renewable energy adoption in agriculture still faces barriers. Agricultural, environmental, and energy plans and policies are often disconnected, failing to achieve synergies among

sectors. Many farmers struggle to access affordable finance and technologies and lack the required skills and knowledge to take advantage of renewables. The following targeted measures are essential to remove these barriers:

- **Develop cross-sector strategies with a holistic water-energy-food-ecosystems (WEFE) nexus approach.** Specific policies and targets for renewable energy deployment in agriculture should be integrated into Nationally Determined Contributions (NDCs), rural development plans, agricultural policies and strategies, and budgets. Collaboration across energy, agriculture, finance and environment ministries is necessary to create coherent strategies, allocate funding and drive action.
- **Ensure that renewable energy integration into agriculture creates synergies with food production, rather than competition.** The WEFE nexus approach, targeted research, appropriate design and regular monitoring should ensure a positive impact from dual land use without compromising food output. Integrating renewables with nature-positive farming methods can enhance productivity, native vegetation and biodiversity.
- **Enable access to affordable finance and markets.** Governments should use climate finance, public-private partnerships, blended finance, low-interest loans, grants and guarantees, tax incentives and subsidies to increase funding and de-risk investments. Innovative models such as lease-to-own can enable ownership by smallholder farmers. Initiatives that boost productivity and profitability for farmers, such as facilitating market access for their produce, increase incomes and enable the repayment of energy investments.
- **Use local knowledge, incorporate gender perspectives and collect context-specific data to inform user-centric project design.** This requires engaging local stakeholders and gathering information on capacities, needs and market demand. Capacity building and technical assistance should be provided in line with local needs to build awareness, trust and relevant skills for long-term operational and maintenance activities. All local land users should be involved in participatory, integrated land-use planning to ensure the most appropriate and inclusive solutions and efficient use of resources, contributing to the viability and long-term success of projects.

As countries work towards their climate, nature, energy and food security goals, renewables provide a promising solution for sustainable agriculture and livelihoods. The success stories in this report offer practical lessons and a clear path for how to scale up such projects.





Introduction

Human well-being and development hinge on access to nutritious food and energy security. Agri-food systems consume around 30% of the world's energy, derived mostly from fossil fuels, and account for around one-third of global emissions (IRENA and FAO, 2021). Energy is used in all stages of food production, such as irrigation, processing, storage and distribution (FAO, 2025a). Additionally, agriculture is one of the most climate-vulnerable sectors. Climate change exacerbates threats to food security and rural livelihoods. The increasing frequency and intensity of extreme events, such as storms and heatwaves, as well as changing rain patterns, drought and sea-level rise all undermine food production. Food insecurity already affects more than 2 billion people, while access to electricity in rural areas remains limited, particularly in Asia and Sub-Saharan Africa (United Nations, 2024). Global food demand is set to surge by 2050, putting further pressure on limited land and water resources (van Dijk *et al.*, 2021). Food waste remains a serious issue, with 13% of all food lost between harvest and retail (United Nations, n.d.).

Given these challenges, agri-food and energy systems and their interactions must urgently be transformed. The objectives of the three Rio Conventions, all directly relevant to agriculture, are interconnected and interdependent. Countries must adopt a water-energy-food-ecosystems (WEFE) nexus approach to meet their commitments under the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD) and the Convention on Biological Diversity (CBD). Sustainable agriculture must be powered by renewable energy. The deployment of renewables is not only instrumental in fulfilling international commitments, but it also brings substantial socio-economic benefits. There is a need to identify the best practices and to create enabling conditions to scale them up.

This report showcases seven successful projects around the world that illustrate the transformative potential of solar photovoltaics (PV) to power agriculture. These examples were selected to demonstrate solar PV applications in different geographies and natural conditions; in developed and developing economies; and in small- and large-scale projects. Each case study shows measurable positive impacts in one or more of seven dimensions (Figure 1), indicating a wide range of interconnected benefits for livelihoods, food and energy security, nature and climate:

- 1. Climate change mitigation.** Replacing fossil fuel use with renewables in food systems leads to reductions in emissions.
- 2. Climate adaptation and resilience.** Renewable energy systems enable a reliable power supply for irrigation and other activities, enhancing resilience and supporting climate adaptation in agriculture. Solar panels provide a shield against extreme weather, such as excessive sunlight and heat, protecting crops and livestock.
- 3. Resources efficiency and environmental protection.** Dual use of land for food and energy production addresses land scarcity issues while also reducing environmental impacts. Locally produced energy and the shading effect of solar panel infrastructure (which reduces water evaporation) contribute to energy and water conservation. With the right design, renewables integrated with agricultural land can create improved habitat for wildlife, including pollinators, and maintain soil health by reducing erosion. If renewables are replacing fuelwood sourced from forests, deforestation is reduced.

4. Improved health outcomes. Switching from fossil fuels or traditional biomass to renewables improves air quality and reduces negative impacts on water and soil, resulting in positive health outcomes for local populations and ecosystems.

5. Local economic development. Through renewables, communities are empowered with more reliable power supply and employment opportunities in renewable energy project operations and related activities. Co-producing food and energy can lead to higher incomes. With the right measures, women farmers can benefit from the improved access to productive technologies and resources.

6. Improved food security. Consistent renewable-powered irrigation and shading from appropriately designed solar arrays can greatly increase crop yields. Renewable-powered cold storage systems lead to reductions in post-harvest losses.

7. Enhanced energy security. Locally generated clean energy lowers energy costs, minimises transmission losses, reduces reliance on imported fuels and mitigates vulnerabilities to price volatility and supply disruptions. Solar PV systems have relatively low maintenance requirements compared to other power generation systems, which helps reduce operational costs in the long term.

The seven case studies support multiple Sustainable Development Goals (SDGs), especially SDG1 (No Poverty) by improving livelihoods in rural areas; SDG 2 (Zero Hunger) by enhancing food security; SDG 7 (Affordable and Clean Energy) by increasing energy access and the share of renewables; and SDG 13 (Climate Action) by contributing to mitigation by reducing carbon emissions and to adaptation by improving resilience. Replacing fossil fuels with renewables reduces air, soil and water pollution, contributing to SDG 3 (Good Health and Wellbeing) as well as SDG 5 (Gender Equality) by providing economic opportunities and access to productive resources and enabling technologies. Renewables can be integrated to support ecosystem restoration and sustainable land management, advancing SDG 15 (Life on Land).

Figure 1 Interconnected benefits of renewables in agriculture














The case studies capture wide-ranging learnings, from project strategy to implementation, that governments, private sector actors, entrepreneurs, donors and non-governmental organisations can apply in the following areas:

1. **Business models** that support access to inputs, including renewable energy technologies, extension services and access to markets, such as contract farming.
2. **Co-benefits** of modern techniques that increase productivity and build climate resilience.
3. **Transformative economic development**, using agriculture and energy to empower farmers and entrepreneurs.
4. **Productive use of renewable energy (PURE)** that provides opportunities for farmers and small businesses to increase farm productivity, add value and raise incomes.

Table 1 summarises the key characteristics of each project included in this report. The projects demonstrate that integrating renewables with agriculture can deliver benefits across highly diverse settings and situations.

Table 1 Overview of business models applied in the seven projects

Project	Crop type(s)	Annual electricity production	Funding source(s)	Estimated yield increase	Annual estimated CO ₂ reduction	Success factors	Policies
 Fishery-solar project combining ecological aquaculture with solar panels	Shrimp, sea cucumber	260 GWh	Financed by the energy company	50%	214 499 tonnes (t)*	Project design, balanced solar PV coverage, regular monitoring	Tax incentive (three-year tax exemption, three-year 50% tax reduction)
 Solar power for agriculture irrigation	Saffron, grape, pistachio	476 MWh	Self-financed with 20-year power purchase agreement (PPA)	Not available	310 t	Collaboration with the distribution system operator, ensuring reliable power supply	Government incentives (exemptions from electricity cuts)
 Small-scale agrivoltaics for horticulture	Okra, tomato, broccoli, beans, lettuce, sweet potato, snap bean, cucumber	51 MWh	Self-financed	Not available	25 t	Low-maintenance design with minimal shading	Feed-in tariff directives on agrivoltaics by Ministry of Agriculture, Forestry and Fisheries
 Horticulture cultivation with solar irrigation and refrigeration	Tomato	21 MWh	Grant funding	100% yield increase, 53% post-harvest loss reduction	30 t	One-stop-shop model, rent-to-own scheme	Strengthening gender equality in communal land management
 Solar-powered mango cultivation	Mango	Not available	Grant funding from local government and partners	186%	Not available	Partnership with local organisations, value chain assessment	Integrated local development plan
 Solar milk cooling	Dairy	66.5 MWh	Public-private partnership	100% reduction in post-harvest milk losses	72 t	Strong stakeholder engagement and capacity building	Government grants
     Tests in different climate regions, integrating solar PV and zoological activities	Aromatic and medicinal herbs, vegetable and fruit species, cosmetic crops, fodder, melliferous flowering mix, sheep	Not available	Self-financed as part of innovation activities	20% to 60%	Not available	Smart sensors network to collect data; open innovation multistakeholder approach tailored to the local area	Not available

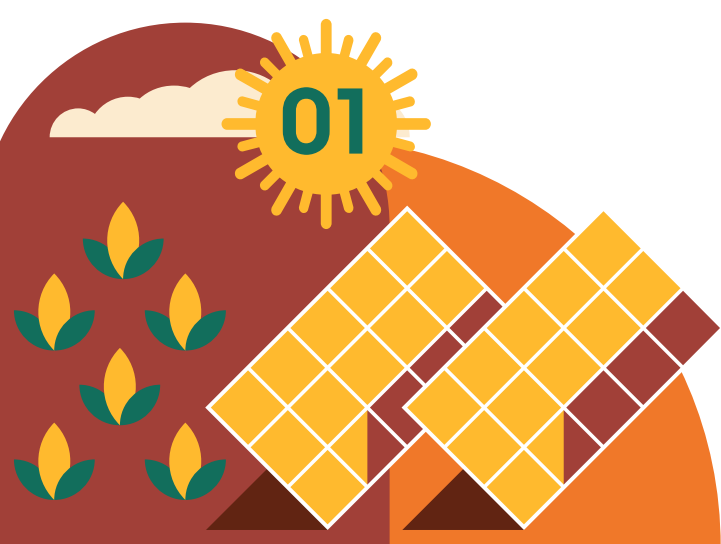
Notes: *(China Climate Change Info-Net, 2016); GWh = gigawatt hour; MWh = megawatt hour; PV = photovoltaic; t = tonnes.

Agrivoltaics – combining agriculture and photovoltaics – enables both agricultural and electricity production on the same plot of land by installing solar panels either horizontally or vertically, positioned above or beside crops or livestock. Agrivoltaics in fisheries involves floating solar PV on water. The dual use of resources can decrease land-use conflicts and is especially beneficial for countries that have limited land for agriculture and renewable energy expansion. Agricultural land is often flat, and agrivoltaics opens up many new areas for renewables.

While this report focuses on agrivoltaics, close connections also exist between agriculture and another form of renewable energy – bioenergy. Bioenergy production can contribute to energy independence, foster rural development and reduce carbon emissions. However, it may create trade-offs, such as increased pressure on land and water resources, that could adversely affect food security and the environment. For this reason, countries should develop and implement sustainable bioenergy policies. The Bioenergy and Food Security (BEFS) approach from the Food and Agriculture Organization of the United Nations (FAO) provides a framework for governments to assess sustainable energy options within their food security and development goals (FAO, 2014). For impact monitoring, the Global Bioenergy Partnership (GBEP) has developed a set of 24 voluntary sustainability indicators (FAO, 2020). These indicators evaluate bioenergy value chains and support policy makers and practitioners to make evidence-based decisions for food security, rural development and environmental protection.

The following sections describe each project in detail, providing the context, business model and financing options, and relevant policy frameworks. Key outcomes are outlined, offering recommendations on how to replicate learnings and address barriers. The final section of the report summarises the high-level recommendations derived from all projects.





Fishery-solar project in China: One resource, two industries

The Dongying fishery-solar project in China combines ecological aquaculture with solar panels. The project generates 260 gigawatt hours (GWh) of renewable energy each year, enough to power 113 000 households in China. In addition to generating electricity, the aquaculture project has boosted shrimp and sea cucumber yields by 50% due to improved pond conditions and the shading effect of the solar panels, which results in better temperature regulation and reduced algae growth. Local farmers save on land lease costs, benefit from infrastructure investments (fully funded by the private company Tongwei New Energy) and achieve higher aquaculture yields. This model leads to more efficient use of land resources while enhancing food production and minimising the environmental impacts of solar development – delivering a win-win solution for socio-economic development and the environment.

1.1 Background and country context

China is the world's largest producer of aquaculture – farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants (FAO, 2024). In 2020, the country produced 65.5 million tonnes of aquatic products, with 52.2 million tonnes coming from aquaculture alone, providing around one-third of the high-quality animal protein consumed by urban and rural residents (MARA, 2021). China's aquaculture industry primarily employs methods such as pond farming, large water surface farming, tidal flat farming, paddy field farming and marine farming. Shandong Province is a leading region in both aquaculture and solar PV development in China. In 2019, Shandong's fishery sector generated a total economic output of USD 62.3 billion, accounting for 15.6% of China's total fishery production (China Daily, 2020). Moreover, solar PV expanded rapidly in Shandong, representing 9.3% of China's total installed solar PV capacity.

In 2021, China's Nationally Determined Contribution (NDC) submitted to the United Nations included a goal to achieve 1.2 terawatts (TW) of combined wind and solar capacity by 2030; this target was met ahead of schedule in July 2024, with the total capacity reaching 1.21 TW (People's Republic of China, 2022). The rapid expansion of solar PV installations puts pressure on land use. Agricultural land is often the most suitable area for solar PV development – particularly in eastern coastal provinces, where power demand is high – but the availability of undeveloped land for solar PV projects is limited. In recent years, the government has established a red line for farmland, restricting its use for purposes other than agriculture.

To address these challenges, China has implemented a “Whole County Photovoltaic” policy, promoted by the National Energy Administration, that encourages large-scale rooftop solar installations across entire counties, covering public, commercial and residential buildings (NEA, 2021). This approach maximises the use of existing structures for solar energy generation and alleviates pressure on land.



1.2 Need for intervention

Given the limited land availability (with arable land, forests and protected areas excluded from energy development), additional solutions are necessary to sustain the growth of renewables in China. Agrivoltaics provides a good solution. The dual land-use strategy for the simultaneous production of food and energy maximises land-use efficiency and addresses both energy and food security concerns. As China continues its renewable energy expansion, integrating policies such as the Whole County Photovoltaic initiative with innovative approaches like agrivoltaics balances energy needs with sustainable land management.

Fishery-solar integration, an important form of PV development within China's agrivoltaics sector, involves installing solar panels above or on water bodies while farming fish below. This dual-use approach significantly addresses land scarcity issues, especially in economically constrained areas. The Dongying fishery-solar integration project, located near the mouth of the Yellow River in Dongying City in Shandong Province, has developed intelligent ecological aquaculture, enhancing resource use efficiency in food production.



Floating solar PV

1.3 Business model

The Dongying fishery-solar project is fully owned and operated by the private company Tongwei New Energy. The company was responsible for the project's investment, planning, design, construction, operation and management, building the PV power plant and improving fisheries infrastructure on the pre-existing aquaculture ponds. Tongwei restored supporting facilities such as pond dams, water inflow and outflow systems, pond bottoms, roads, hydropower, and buildings, standardising ponds. The investment in fisheries facilities construction exceeded USD 6.5 million.¹

Tongwei New Energy financed the project entirely by raising the capital internally and through private equity investment. According to Tongwei, the initial investment cost for the solar PV power plant of the fishery-solar project was CNY 3.99/W (USD 0.55/W) (a total of CNY 798 million or USD 110 million), with an annual operating cost of CNY 0.03/W (USD 0.004/W). The project has a fixed depreciation period of 25 years and benefits from a tax incentive policy, offering an initial three years of tax exemption followed by a 50% reduction in income tax for the subsequent three years. The full lifecycle cost of electricity, including taxes, is CNY 0.19 (USD 0.026) per kilowatt hour (kWh). The internal rate of return for the total investment is 8%, with a direct payback period of 11 years.

¹ Unless otherwise noted, this and all currency figures that follow are in 2025 USD.

Phase one of the project has a construction scale of 200 megawatts (MW), with the PV power plant achieving the equivalent of 1300 hours of annual generation and an average annual grid-connected electricity output of 260 million kWh (Tongwei, 2021). Construction of the intelligent ecological aquaculture project began in 2019, with renovation and transformation work completed across 215 hectares (ha) of fishponds and adjacent areas. In June 2020, construction started on the 200 MW solar PV project, which was connected to the grid and began operations in January 2021. The electricity price is set at CNY 0.3949/kWh (USD 0.054/kWh) based on Shandong Province's benchmark coal-fired power grid price (CNY 0.35/kWh or USD 0.048/kWh excluding value-added tax, VAT). The Dongying project's PV power generation yields an average annual profit of around CNY 36 million (USD 5 million) (Tongwei, 2020).

1.4 Policy frameworks

On 22 March 2022, China's National Energy Administration released the 14th Five-Year Plan for a Modern Energy System (NDRC, 2022). This plan sets the goal of increasing the share of non-fossil energy in total energy consumption to around 20% by 2025. Non-fossil energy sources are expected to generate around 39% of the country's electricity.

The plan emphasises the acceleration of clean energy development, promoting the expansion of both wind and solar power generation, especially in rural areas. To achieve this, the plan introduces initiatives such as the "Thousands of Households Bathed in Sunshine" for solar and "Wind Power in Thousands of Villages" for wind that support the construction of rooftop solar, agrivoltaics, fishery-solar integration and other decentralised solar PV and wind power projects.

The local tax incentive policy that benefited the fishery-solar integration project is a "Three Exemptions and Three Halves" policy in Shandong Province. Under this policy, for the first three years, the project is exempt from paying income taxes. For the subsequent three years, the project pays only half of the standard income tax rate. This policy lowers the financial burden on new projects during the initial years, reducing risks and making projects more attractive for investors by enhancing cash flow in the early stages of operation.

As solar PV projects expand across China, grids can become strained to accommodate additional electricity. For this reason, renewable energy projects seeking grid connection are required to incorporate energy storage systems. This consequently raises project costs and impacts investment returns.

1.5 Project outcomes

Since becoming operational and connecting to the grid in 2021, the Dongying project has achieved a "threefold harvest", comprising the fishery, electricity generation and environmental protection. The project produces a total of 315 000 kilograms (kg) of seafood annually, yielding 63 000 kg of protein. Additionally, the project supports China's clean energy transition, generating 260 GWh of renewable energy annually and contributing to reduced reliance on fossil fuels.

Local farmers have achieved three main benefits:

1. **Infrastructure improvement** – Tongwei fully funded the significant initial investment, during which the project enhanced pond conditions and modernised facilities, improving aquaculture operations.
2. **Land-lease savings** – Local farmers are not required to pay for the land lease for aquaculture, as this is covered by the energy company.
3. **Increased production** – Shrimp and sea cucumber production have increased 50% – from 750 kg/ha to 1125 kg/ha – compared to the pre-existing fishery set-up, owing to the improved pond conditions and the shading effect of the solar panels. A scientifically designed module configuration reduces sunlight on the water surface and keeps water temperatures at a consistent 2-3 degrees Celsius (°C)

cooler than outdoor ponds without panels. This promotes fish growth and improves water quality – as excessive algae growth is prevented, oxygen levels are stabilised, and temperatures are lower during hot seasons. A healthier environment for fish reduces disease and medication use, producing safer, high-quality aquatic products.

The project includes smart facilities and ecological wetland parks that attract visitors for educational and recreational purposes. Aquaculture, solar power generation and educational eco-tourism transform solar power stations into multifunctional systems. Such a multipurpose development model increases the economic value per unit of land and provides a win-win solution for social, economic and environmental benefits.

1.6 Lessons learnt and recommendations

The key to the success of the Dongying fishery-solar integration project in Shandong Province is its effective use of land. The solar company invested in upgrading and improving the fisheries infrastructure, providing both technical and financial support for aquaculture. The shading effect of the solar panels increased fishery yields, and the resulting higher income benefited the aquaculture farmers. This case provides valuable insights for modernising and upgrading Shandong's aquaculture industry and integrating it with new energy projects.

Fishery-solar integration is highly effective and should be supported and promoted, in line with the following recommendations:

- **Provide targeted financial incentives.** Governments should provide appropriate incentives, such as tax subsidies for fishery-solar projects, to attract investment and reduce risks, particularly in the early stages.
- **Align project development with aquaculture needs.** This requires strategic planning with necessary upgrades to infrastructure to ensure efficiency and maintain yields.
- **Optimise PV coverage.** It is crucial to consider factors such as light and air penetration and water temperature to avoid negative impacts on aquatic ecosystems and fishery yields.
- **Support comprehensive baseline data collection and ongoing monitoring.** It is essential to collect quality pre- and post-project data to support impact evaluation, and to implement regular monitoring to ensure that aquaculture production remains unaffected.
- **Facilitate renewable energy integration.** Governments should prioritise grid infrastructure upgrades and incentives for energy storage to accelerate implementation.



Achieving a reliable power supply with solar in Iran

Solar PV projects in the agricultural areas of Khorasan Razavi Province in the Islamic Republic of Iran enabled farmers to gain reliable electricity for irrigation. The power generation resulted in increased income and helped reduce yield losses that were previously caused by power shortages. Twenty-year power purchase agreements (PPAs) contributed to financial viability, providing farmers with stable, long-term contracts to sell their electricity to the grid.

2.1 Background and country context

Agriculture contributes significantly to Iran's economy – providing 11% of the gross domestic product (GDP) – and is a large source of employment (around 20% of the workforce), dominated by smallholder activity (IsDB, n.d.). Farmers frequently experience water resource pressures and electricity shortages. The use of solar energy to power water pumping systems could alleviate these challenges.

In the past, most irrigation systems in Iran were powered by diesel fuel, but such systems are increasingly being electrified using pumps connected to the grid. This offers economic and environmental benefits by reducing direct fossil fuel use and related carbon emissions. However, electricity shortages remain an issue, impacting agricultural productivity.

2.2 Need for intervention

Reliability is a significant challenge in Iran, with frequent, lengthy power outages (Arzani *et al.*, 2022). For farmers, these electricity shortages often result in damaged or reduced production. Grid-connected solar PV projects can feed electricity to the grid during the day, which, if combined with supportive grid infrastructure, can enable farmers to access stable and reliable electricity for continuous operation of water pumps.



Solar energy powering agriculture in Khorasan.

In Khorasan Razavi Province, solar radiation is abundant. It is most intense during the summer, coinciding with the peak electricity demand in Iran. The power generated from PV systems provides a great opportunity to minimise electricity shortages across the country, especially during the peak months of June to September. This matching of peak solar energy production with peak electricity demand strengthens the reliability of the national energy system while improving farmers' access to power.

2.3 Business model

The farmers of three projects in Khorasan Razavi Province – cultivating saffron, grapes and pistachios – integrated solar PV systems with their agricultural activities. The solar installations were largely financed and fully owned by the farmers themselves, allowing them to gain the full benefits of both energy and food production. The indicative investment amounted to IRR 8.1 billion (USD 127 600) for the 290 kW total installed capacity of the three projects.² Due to the smaller size of these installations, local contractors handled the construction of the solar plants. Local companies provide maintenance and monitoring of the systems.

Electricity distribution companies handle the electricity exchange process that allows farmers to trade or exchange their generated power with the grid and to balance their energy needs throughout the year. During the peak demand months (June to September), when overall electricity demand is high and consumers can be required to participate in mandatory electricity cuts, solar power is fed into the grid and exchanged for grid electricity without any financial benefits. This helps the farmers obtain more stable electricity for their production. During the eight off-peak months, farmers benefit from long-term, guaranteed PPAs for the electricity they generate. The Renewable Energy and Energy Efficiency Organization (SATBA) provides 20-year PPAs, giving farmers a stable, long-term contract to sell their electricity to the grid during off-peak times. Alternatively, they have an option to sell their energy on the energy market, such as on the Green Board of the Energy Exchange for renewables.

The renewable electricity price in the Energy Exchange Market varies depending on the electricity demand from the industries that are the current buyers of renewable electricity from the Green Board of the Energy Exchange. Demand is higher in peak months and lower in off-peak months. The feed-in tariff in the PPA systems is adjusted according to inflation and the currency exchange rate (EUR/IRR) and therefore increases every month. Calculating the internal rate of return and payback period for both scenarios is difficult because of the variation in the above-mentioned items, and also because after installing PV systems, the farmer no longer faces crop damage caused by electricity shortages, as before. This generates additional profits, which can be added in the cash flow and increase the internal rate of return. Almost all projects under this business model have been financed by the farmers themselves, as there are not enough loans for renewable projects with reasonable interest rates accessible to farmers yet.

2.4 Policy frameworks

According to the Ministry of Energy in Iran, farmers who install a solar PV plant with a nominal capacity of at least 80% of the motor pump demand, and provide the generated electricity to the national grid, may be exempt from load management programmes (electricity cuts) during the summer peak period (June to September) (Dehkordi, 2025). In addition to the load management exemption, farmers are allowed to sell the generated electricity to the grid during the eight off-peak months.

Collaboration with the local distribution system operator is an important aspect of policy implementation. Electricity supply to each electro-pump can be cut remotely and individually; therefore, the distribution system operator can disconnect pumps without PV installations while keeping pumps with solar PV connected to the grid.

² *Indicative conversion.*

2.5 Project outcomes

By switching to solar, the three projects in Khorasan Razavi Province gained access to reliable and affordable energy for irrigation, which enabled them to stabilise their agricultural operations and increase productivity. Higher agricultural outputs and electricity sales during the off-peak months enabled farmers to generate more revenue.

The farmers reduced their dependence on fossil fuels, aligning with sustainability goals and lowering emissions and environmental pollution. Local solar power generation minimised transmission losses. Table 1 demonstrates carbon dioxide (CO₂) emissions savings for these projects, based on the grid emission factor in Iran (kgCO₂/kWh).

Table 2 Annual CO₂ emissions savings from three projects in Iran's Khorasan Razavi Province

Location	Khalilabad County	Khalilabad County	Bardaskan County
PV power plant capacity	65 kW	125 kW	100 kW
Electricity produced per year	106 762 kWh	205 312 kWh	164 250 kWh
Grid emission factor in Iran	0.65 kg CO ₂ /kWh		
CO₂ savings	69 395 kg/year	133 453 kg/year	106 762 kg/year

Notes: CO₂ = carbon dioxide; kg = kilogram; kW = kilowatt; kWh = kilowatt hour; PV = photovoltaic.

In addition, solar projects in agricultural regions in Iran provide employment opportunities for young, educated individuals, potentially curbing rural-to-urban migration and supporting rural revitalisation. Local economic development was fostered by using local contractors for construction and maintenance.

2.6 Lessons learnt and recommendations

Measures related to grid integration, access to finance and farmer awareness can create more supportive conditions for such projects in Iran. Recommendations include:

- **Strengthen collaboration with distribution system operators.** One of the success factors of the three projects in Khorasan Razavi was the collaboration with the local distribution system operator. The distribution system operator facilitated the permitting process, using the “Mehrsun” platform for developing small-scale PV projects (below 200 kW). The Iranian Renewable Energy Association (SATKA) made the recommendation to raise the permitting procedure for PV plants to up to 3 MW on the Mehrsun platform system.
- **Facilitate access to finance for farmers.** The solar irrigation projects have been largely financed by the farmers themselves. However, many farmers in Iran do not have the means to finance such projects. It is important to facilitate access to finance and to establish accessible loan programmes tailored to farmer needs. Government efforts to provide incentives such as feed-in tariffs or exemptions from electricity cuts during peak demand times for solar-generated electricity can encourage farmers by offering better returns.
- **Support awareness and capacity building initiatives.** Raising awareness and providing accessible information are critical elements for enabling farmers to adopt renewable energy. In Iran, a Renewable Energy Service Centre in Tehran, founded by SATKA, was instrumental in helping farmers connect with renewable energy companies and access information in one place. The centre plans to eventually host monthly informational seminars on policies, successful cases, and technical and financial issues in each province in Iran, which would reinforce outreach efforts.

Agrivoltaics makes small-scale farming profitable in Japan

By enabling agricultural and electricity production on the same land, agrivoltaic projects create diverse revenue streams. The Waku Waku Solar Sharing Farm in Higashi-Hiroshima is one of the farms that uses this innovative solution, making small-scale farming economically viable in Japan.

3.1 Background and country context

Japan is the world's fourth largest economy, with a GDP of USD 4.03 trillion in 2024 (World Bank, n.d.). Agriculture accounts for just 1% of the GDP. Even so, it is seen as an important sector by the government and the public. However, the agricultural sector has been in decline in recent years. The high percentage of mountains results in a scarcity of land for agriculture. Only 34% of Japan's land is flat, and only 20% is suitable for farming (Klein, 2023). The available land is mainly used by small-scale farmers, with an average area of cultivated land per farm of only 3.4 ha (2.4 ha excluding Hokkaido) (MAFF, 2023). Many of these farmers struggle to survive on farming alone and need other income sources to make a living. These conditions are not favourable to attracting young farmers; the average age of farmers has risen to 69 years, and the number of agricultural entities has fallen 33% over the last ten years (Kushida, 2024).

Climate change is expected to exacerbate the challenges in Japan's agricultural sector in the near future. More frequent extreme weather events, such as extreme heat, longer droughts, and stronger typhoons, will negatively impact harvests. Moreover, natural disasters can lead to a failure of centralised power plants, resulting in widespread power outages that directly affect agricultural production.

Overall, Japan is highly dependent on imports to fulfil its food demand. The food self-sufficiency rate on a calorie basis was only 38% in fiscal year 2022 (MAFF, 2020). Similarly, the island nation is highly dependent on energy imports. The energy self-sufficiency rate was only 12% in 2022 (METI, 2022). With a renewable energy share of just 25% and few natural resources, Japan spends 3% of its GDP on fossil fuel imports (Climate Group RE100, 2024). In addition to the high cost of fossil fuels, this trend is not in line with the government's goal to become carbon neutral by 2050. The country's agriculture sector is still far from becoming carbon neutral, and the shift to sustainable agriculture is progressing only slowly.



Wakuwaku Solar Sharing Farm.

Photo credit: Masafumi Shigeie.

3.2 Need for intervention

Agrivoltaics is a promising technology that can help solve many of these pressing challenges in Japan. The country is a pioneer in combining agricultural and electricity production on the same plot of land. The first pilot project was implemented over 20 years ago in Chiba, and since then agrivoltaics has spread to 46 out of 47 prefectures in Japan. Most of the projects are small in scale, with 97% being under 1 hectare (Doedt *et al.*, 2024). Given the weather conditions in Japan, the cultivated crops are very diverse. Already, 120 different crops are being grown under agrivoltaics systems in Japan.

The Waku Waku Solar Sharing Farm in Higashi-Hiroshima, a one-hectare rice field in a rural area of Japan, is one of the first farms in the region to demonstrate the potential of agrivoltaics. Small-scale rice farming typically would not be economically viable due to the need for expensive machinery. Without the agrivoltaics solution, the farmland likely would have ended up abandoned, as often happens in Japan.

3.3 Business model

The farm owner estimated that agrivoltaics would be a good investment and decided to build a 38 kW agrivoltaics system on one-tenth (0.1 ha) of his farmland in 2015; it started operation in January 2016. In total, the farmer installed 333 solar panels on 52 pipe scaffolding posts with a manual rotating system, achieving a low-maintenance and cost-effective design. The shading rate of the solar panels is only 33% and the panel height is 3 metres to allow for the cultivation of a large variety of crops. The mounting frame structure for the solar panels is used for attaching 1-millimetre mesh nets to protect the crops from harmful insects and birds, subsequently reducing costs and the use of pesticides.

As an early adopter, the Waku Waku Solar Sharing Farm was able to secure a high feed-in tariff of JPY 35/kWh (around USD 0.24/kWh) for 20 years. A net yield of 6% per year on average was estimated for electricity production during this period, in addition to the return from the sale of crops. The farmer self-financed the project with no initial financial support from the government or other sources.

3.4 Policy frameworks

Two major legal and policy changes mainly enabled the expansion of agrivoltaics in Japan, including the Waku Waku Solar Sharing Farm.

In 2013, the Ministry of Agriculture, Forestry and Fisheries passed a directive that allowed agrivoltaics projects on all types of farmland. Agrivoltaics projects need to fulfil certain requirements to receive the necessary land-use conversion permit to non-agricultural land for the area of the mounting frame of the agrivoltaics system. One of the most consequential requirements is that the agricultural yield reduction must be under 20% compared to the average level of the same crops in the surrounding farmland. This requirement was included to ensure that agricultural production will continue under the solar panels and to close the loophole to build conventional ground-mounted solar PV on high-quality agricultural land under the name of agrivoltaics.

Additionally, in 2012, Japan introduced a generous feed-in tariff for renewable energy projects, including agrivoltaics. It allowed farmers to experiment with agrivoltaics even though the costs were slightly higher than for ground-mounted solar PV systems.

3.5 Project outcomes

On average, the Waku Waku Solar Sharing Farm produces around 51 MWh of generation per year, resulting in annual electricity sales worth JPY 1.75 million (USD 12 500). The solar panels are rotated once a month to increase electricity production. Rotating the panels also helps reduce the wind load during extreme weather events such as typhoons to avoid damage to the system.

The main agricultural production was changed from farming rice to cultivating a variety of crops such as okra, tomato, broccoli, beans, lettuce, sweet potato, snap bean and cucumber. Annual sales of agricultural products from the 0.1 hectare agrivoltaics plot exceeded JPY 1 million (USD 7 000) in 2022. If the land had continued to be used to cultivate rice, the profits would have amounted to only around JPY 100 000 (USD 700). The combined sales of electricity and crops of the agrivoltaics system bring in JPY 2.75 million (USD 19 300). The project demonstrates the potential to increase and diversify the income of small-scale farmers in rural areas of Japan. The farm also adopted the “Radical Carbon Farming” approach, which boosts carbon sequestration in the soil and produces even more micronutrient-rich crops under the solar panels without the use of fertilisers or pesticides or the need for tillage.

3.6 Lessons learnt and recommendations

The project demonstrated the need to address several barriers to promote agrivoltaics projects in the region. Recommendations include:

- **Increase awareness and capacity building for local authorities and farmers.** The local agricultural council, which must approve the land-use conversion, was initially sceptical about the idea of an agrivoltaics project in their community. Local officials still lacked knowledge about the viability and benefits of agrivoltaics. The Waku Waku Solar Sharing Farm proved the viability of such initiatives. Proper awareness and education of local authorities and farmers can ensure that such projects are streamlined in the future.
- **Address regulatory uncertainties and research gaps to encourage agrivoltaics projects.** In Japan, uncertainty for farmers is caused in particular by the 80% yield requirement. Farmers are unsure if they can fulfil the necessary agricultural yield due to a lack of research on crop cultivation under solar panels and fear the dismantling of their projects. Similarly, financial institutions fear that loans cannot be repaid if projects are cancelled and are hesitant to take the risk of providing loans for agrivoltaics projects. Advanced research on crop cultivation under solar panels in diverse climate regions is needed to reduce uncertainty and to increase farmers’ confidence in agrivoltaics.
- **Provide financial mechanisms to support small-scale agrivoltaics.** The strong financial incentives and a high stable income for farmers that was guaranteed by Japan’s generous feed-in tariff in the early 2010s are now in the past, and current tariffs are too low to make small-scale agrivoltaics projects economically attractive. New business models such as PPAs are being explored, but these models are mainly suitable for large-scale projects. Access to finance and targeted incentives should be available to support small- and medium-scale agrivoltaics projects.
- **Outline a clear vision for agrivoltaics and enabling legal frameworks.** To fully advance agrivoltaics in Japan, a clear vision for agrivoltaics and amendments to the current legal framework are needed to reassure relevant actors and to provide appropriate financial incentives. These measures can also help attract new and younger farmers to stop the decline of the agricultural sector and help with rural revitalisation.

Many countries face similar societal challenges as Japan and could benefit from agrivoltaics. Policy makers in countries interested in introducing or advancing agrivoltaics can reflect on the lessons learnt from over 20 years of experience in Japan.

Contract farming empowers off-grid women in Malawi

At the shores of Lake Malawi, fishing is the most prevalent occupation, dominated by men, while women often have few to no livelihood opportunities. The Renewable Energy for Agriculture (RE4A) project, a joint effort between Practical Action and Modern Farming Technologies (MFT), has become a reliable and timesaving income stream for women farmers in fishery communities owing to its uniquely designed business model. The project has worked with women group farmers to develop alternative livelihoods through energy access, improved horticulture practices and contract farming.

4.1 Background and country context

The economy in Malawi is primarily driven by the agricultural sector, accounting for 30% of GDP and employing over 60% of the population, especially women and youth (JICA, 2022). The region's mainly rain-based agriculture is highly susceptible to extreme weather events, such as drought and intense rainfall, which are exacerbated by climate change. Almost 90% of Malawians lack access to electricity, and over 80% of the population faces food insecurity (FAOSTAT, n.d.).

In northern Malawi, many smallholder farmers live far from road infrastructure and struggle to reach markets for their produce. A low rural electrification rate also impacts farmers' ability to preserve perishable farm produce. Smallholder farmers across Malawi grapple with an estimated 30% post-harvest loss of their produce, reaching 50% for more perishable goods due to the absence of refrigeration. Erratic rainfall due to climate change progressively causes unreliable harvest yields, often making farmers' income sources irregular. Women farmers face even more barriers, including limited land ownership, inability to access finance and time pressures when balancing family care responsibilities with income generation.

4.2 Need for intervention

The RE4A project is based in Chinthetche, on the edge of Lake Malawi. The area is predominantly rural, with a large town, Mzuzu, located 50 kilometres away. Farming communities experience only one dominant wet season, spread over four months, and a hot climate throughout the year.

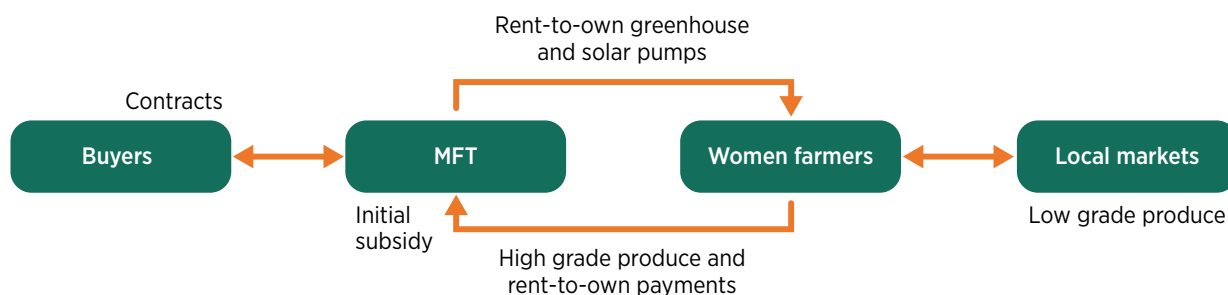
Working with marginalised women, many of whom do not own their farmland, the project uses targeted interventions to address the unique challenges that hinder their ability to invest in agribusiness. MFT, a local social enterprise, began by working with women and the local government to identify community land to establish greenhouses. MFT also worked to build women's capacity to grow horticultural produce, procure energy technologies and engage fully in commercial agriculture through contract farming.



4.3 Business model

The project has emerged as a social business providing an end-to-end solution for women farmers. MFT developed the business model by selecting a co-operative of women farmers, training them on improved farming techniques and financial literacy, and providing direct access to farming inputs such as seeds and fertiliser. The women collectively secured communal land and, through the project, received the support they needed to procure greenhouses and solar irrigation kits through a rent-to-own scheme (Figure 2).

Figure 2 The rent-to-own scheme for the contract farming model



Note: RTO = rent-to-own; MFT = modern farming technology.

In this contract farming approach, 135 women farmers in Chinthetche grow horticultural produce (tomatoes) and sell their harvested produce to MFT, which retails to local and national markets, having negotiated supply contracts for the farmers' produce. The revenue earned by the women enables them to earn a stable income, make monthly payments for their greenhouses and solar irrigation kits, and reinvest towards another growing season.

The financial model that was used to establish the project in the first two years was grant-dependent. The Powering Renewable Energy Opportunities (PREO) Fund provided funding through the PREO programme. It is a demand-led initiative on productive use of renewable energy (PURE) that stimulates partnerships, innovation and learning. Renewables are harnessed to increase incomes, enhance climate resilience and reduce dependence on fossil fuels. The funding mainly covered the upfront procurement risk of the irrigation kits (which the women pay back), the full cost of a solar refrigerator for the social enterprise and the cost of extension services.

Figure 3 Contract farming model

Women farmers who were members of a single over-arching co-operative signed a formal agreement with MFT covering a “rent-to-own” scheme for productive use of renewable energy technologies and the sale of vegetable produce.

Women organised themselves into groups of three farmers each, and farming equipment was then provided by MFT on a rent-to-own basis:

- One greenhouse and solar irrigation kit for every three women.
- One solar pump for every five greenhouses.

Produce is stored in the MFT-owned and -managed solar refrigerator, which maintains produce quality and improves shelf life.

All grade 1 produce is sold by the women to MFT, which then deducts 25% of the value of crop sales to cover rent-to-own payments. Other produce is sold by the women, independently, to other local buyers.

MFT sells the produce to several local and national buyers.

MFT re-invests all surpluses back into the establishment of new greenhouses, allowing new women farmers to take up horticulture.

The project design focused on “controlled environment agriculture”, which uses greenhouses and solar irrigation kits to grow crops and a solar refrigerator to improve post-harvest handling. The specific PURE technologies adopted for the project were:

- **Solar pumps:** Farmers purchased the Futurepump SF1 model from dealers in Malawi (Futurepump, n.d.). The kit is used to pump water from Lake Malawi to farmers’ greenhouses. The model was locally available and portable enough for the women to assemble and store after use.
- **Solar refrigerator:** A bespoke 12-metre walk-in cold room was developed for the project by transforming an old shipping container into a solar refrigerator. The solar panels, manufactured separately from the cold room, were consolidated onto the container on-site in Malawi. The unit’s heavy insulation greatly reduces energy costs, maintaining produce at 8-10°C, reducing post-harvest loss and increasing crop shelf life.





Women carrying irrigation kits outside their greenhouses.

4.4 Policy frameworks

The Malawian government aims to improve food security, encourage crop diversification and reduce dependency on rain-fed agriculture and harvest losses. The International Renewable Energy Agency (IRENA) collaborates with the government on improving ways to integrate energy into agrifood value chains as part of the Lives and Livelihoods initiative (IRENA, 2024). The national land policy in Malawi aims to ensure equitable access to land and to enhance community management of local resources (MLHS, 2002).

This approach to communal land management facilitated implementation of the project. The contract farming model enabled the women to organise themselves into farming groups and lobby for the allocation of communal land. They have engaged in shared labour and co-operative marketing, which has lowered individual costs and investment risks in agribusiness. As a whole, the government's approach to communal land management has helped women gain a collective voice, one that has the potential to influence long-term land-use decisions and advocacy efforts for gender equality in land governance.

To advance gender and social inclusion across the energy and agriculture nexus, the RE4A project demonstrates the need for multistakeholder alliances that include civil society, the private sector and government. These alliances can help to eventually influence and leverage policies and multilateral agreements that include gender mainstreaming commitments in Malawi's agriculture sector. This will enable, for example, better access to land in traditional contexts, empowering women to fully benefit from renewable energy technology.

Development actors should prioritise similar projects that work with both public and private actors to sensitise decision makers and use evidence and the success of women to demonstrate the value of women's empowerment in the agri-food sector.



4.5 Project outcomes

The contract farming business and the end-to-end support provided by MFT have made the off-grid project a success for many of the women who previously had limited access to land and, in some cases, no assets. They have gained financial literacy, agricultural skills, and energy access services, which have contributed to their overall agency. The highlight for most women is that the project has been an avenue for them to own technologies through an inclusive financing mechanism, something they previously were unable to obtain.

Over a span of four years, and once the rent-to-own payments equal the cost of the farming equipment provided, full ownership of the technologies will pass from MFT to the farmers' co-operative. By farming in greenhouses, the women spend less time at the farm and earn more from selling high-value crops. Market access has been a valuable function considering the small size of markets in the Chintheche community. Through the contract farming arrangement, all farmers recurrently receive extension services and sell their grade 1 produce to MFT, which retails to supermarkets and the hospitality sector. The women sell their lower-grade produce to local informal market vendors, whose demand has constantly outstripped supply due to the improved tomato variety grown and post-harvest preservation techniques (see Figure 2).

The solar chiller has played a crucial role in maintaining the quality and shelf life of produce, increasing the local demand for women's produce over time. Over the two-year pilot phase, no farmer defaulted on payments or breached their contract agreement, which can largely be attributed to the tenacity and functionality of the farmers' co-operative.

Analysis of the social business and the revenues generated indicated that:

- The women spent at least two hours a day working in the greenhouse, which translates to 16% of their working week.
- The women previously earned less than EUR 18 to EUR 45 (USD 21 to USD 53) per month. Through the project, farmers now earn an additional EUR 33.3 (USD 39) monthly from tomato farming, which has doubled the income of more than 50% of farmers.
- An overwhelming 87% of the women indicated that revenue earned from the project had become their primary source of income.
- The current loan payback period is four years. At the current annual percentage rate (APR) in Malawi, women can continue to make all necessary payments and still earn an annual income.
- The project data suggest a return of 141% on the original grant investment. Over four years, the rent-to-own repayments and income from produce sales will be enough to double the number of farmers participating in the scheme.
- For a traditional grant funder, this model offers an opportunity to recycle capital within a commercially viable business, enabling scale-up and a significant contribution to the local economy.
- Overall, the income that farmers obtain from the project has proven sufficient for them to access the equipment independently using commercial funding.
- Private sector investment is a feasible option for funding, although the business would scale up at a slower pace. Therefore, replication of the model is restricted by cost.

4.6 Lessons learnt and recommendations

In summary, the project outcomes and learnings indicate that:

- **Rent-to-own models are strategic for increasing asset ownership for women.** This model enables sufficient income and allows payback, paving the way for women to access finance and technologies. The project also enabled women to obtain a credit history, which is beneficial for future investments. If projects adopt a similar approach, it might be possible to comprehensively assess this viability as a stepping stone for women to access finance and assets. There is a need for financial institutions to design specific financial products that adjust to the co-operative conditions.
- **The interrelationship between markets, productivity and PURE is critical to success.** All elements are mutually supportive and depend on one another. If there is no access to markets or no support for productivity, farmers will not be able to make enough money to pay for renewable energy assets. If there is no access to renewable energy, the opportunities to improve productivity will be more limited, and so on. The one-stop-shop model enabled all three to be achieved.
- **Modern farming techniques are critical for women's economic empowerment.** The project has illustrated that agricultural systems can help overcome two major constraints affecting women: time poverty and access to land. For instance, greenhouse-based horticulture requires minimal land and time. As such, the women farmers spend less time farming and earn more income, allowing them to increase their savings and still have time for family care responsibilities.
- **Solar refrigeration initiatives will require in-depth market understanding.** Determining the required refrigeration capacity prior to implementation is crucial to justify the steep cost and viability of commercial funding. In the case of the project, the unit drastically improved the quality of produce, which translated to constant demand from formal and informal buyers. However, participants realised that a smaller chill plant may have been more investment-worthy, because the demand and sell rate for produce turned out to be high, with the unit only storing at a capacity of 25% (although maximum production has yet to be reached). Market research should also determine if a chiller is best suited at the production site or closer to markets to serve traders. The size of the chiller should be dependent on the optimum combination of the following information:
 - » Anticipated total production and formal and informal market demand
 - » Data on the likely frequency of produce collection
 - » Data on the turnover rate at which produce stays in the chill plant.

Energy for agriculture projects and businesses working with smallholder farmers face similar obstacles, and this project's solutions are replicable. Piloting this business model quickly translated into an off-grid success for women farmers, with multiple best practices that other development actors and private sector players can adopt.



Co-operative triples mango cultivation with solar energy in Tanzania

Smallholder farmers, organised under the co-operative society AMCOS, transitioned from diesel to solar power, reducing energy costs and increasing agricultural output. Factors behind the project's success included government support, data collection, a clear diagnosis of local needs and community involvement.

5.1 Background and country context

In the United Republic of Tanzania, the agriculture sector contributes around 25% of GDP and 85% of exports, while employing roughly three-quarters of the population (AECF, 2022). Smallholder farmers supply around 80% of all agricultural produce. Climate change is increasingly impacting the sector. Yearly rainfall is declining, with an average decrease of 2.8 millimetres per month (3.3%) per decade (Rweyemamu *et al.*, 2024). The mean yearly temperature in Tanzania has increased by 1°C since 1960. The country, highly vulnerable to climate change, is at the bottom quartile of the readiness score to address its impacts (IMF, 2023). Rain-fed agriculture dominates and has been severely affected by recurrent floods and droughts.

Recognising agriculture's significance, as well as the challenges facing it, the government is prioritising interventions to support the sector through initiatives such as the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). SAGCOT is a public-private partnership aiming to increase agricultural business investments in the country's southern corridor, as well as other policy interventions needed to address sectoral growth (SAGCOT, n.d.).

Access to affordable and reliable energy can play a major role in this endeavour through interventions such as powering irrigation for increased productivity, as well as reducing post-harvest losses through cooling and drying. In addition, powering agro-processing opportunities would help farmers add value to their produce, increasing incomes while creating local jobs and improving rural economies. Only 37% of the total population has access to electricity, and only 25% of rural populations have access to power (World Bank, 2022). Immediate interventions aimed at increasing investment in the energy access sector, particularly targeted at productive use opportunities, would have dual benefits of stimulating the agriculture sector and thus increasing the demand for energy, which is a pre-requisite for attracting investments in the energy access sector.



5.2 Need for intervention

While more than 90% of the population of the Chamwino district depends on agriculture as a source of livelihood, the opportunity and potential of this sector have not been fully exploited. As in the rest of Tanzania, over-reliance on rainfall (greatly affected by climate change), coupled with low adoption of technology and limited farming skills, have contributed to the challenge. As a result, only around 30% of the vast areas of arable land in the district are cultivated. This has led to a continued decrease in agriculture's contribution to the district's economy, including declining levels of food production, income generation and job opportunities for local populations.

With this recognition, the local administration established a District Irrigation Development Fund (DIDF), which supported the construction and rehabilitation of irrigation schemes across the district. One of the beneficiaries was a group of smallholder farmers organised under a co-operative society, AMCOS (Agricultural Marketing Cooperative Society), who were supported to dig a borehole and to install a diesel-powered generator for their mango farming project. However, the high cost of diesel, coupled with the long distance from the closest fuel supply source, as well as maintenance-related challenges, forced targeted farmers to abandon the project. This informed the decision by the World Resources Institute (WRI) – a global research organisation supporting sustainable development projects – to intervene.

5.3 Business model

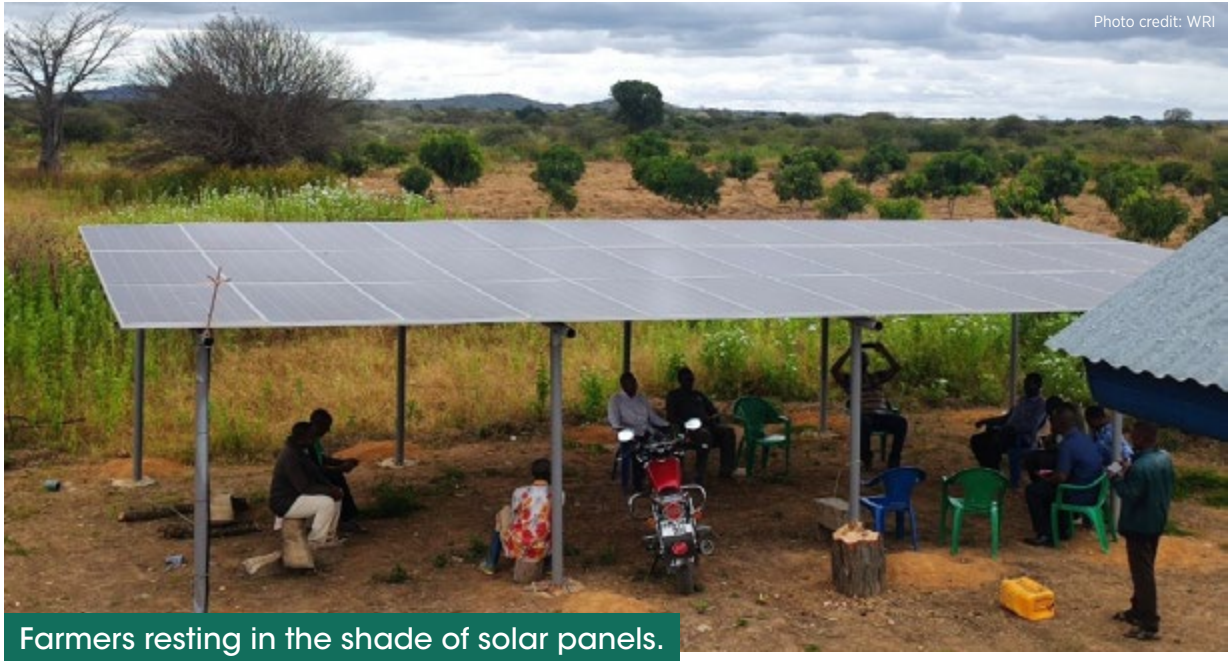
AMCOS and WRI collaborated with a local partner, Tanzania Traditional Energy Development Organization (TaTEDO), and representatives from the district government of Chamwino to develop a project of renewable energy supporting agriculture tailored to local conditions.

WRI undertook a value chain assessment and cost-benefit analysis to identify specific stages of the mango value chain where the integration of renewables would lead to maximum social, environmental and economic impacts. Data from the cost-benefit analysis helped quantify the economic benefits that farmers would realise because of the intervention. This was complemented with an energy needs assessment that informed the design and size of an energy system that could meet the current and future energy needs of the project. Future considerations included any plans the society had for expanding land under irrigation or additional interventions such as cooling and agro-processing, and the implications that this might have on energy demand.

Based on the findings from the data collection and analysis described above, two alternative investment scenarios were explored: a solar water pump with continued manual water distribution, and a solar water pump with drip irrigation. The integration of drip irrigation was considered due to the arid conditions in the targeted region, as well as to address potential negative impacts of over-drawing ground water because of access to cheaper energy. As a result, a 15 kW peak solar PV system was installed, complemented with a drip irrigation system, aimed at promoting efficient use of water.

The project relied on a 100% grant model provided by the local government development partners. The aim of this approach was to demonstrate to the local community that solar energy was more affordable and reliable for powering their agricultural project compared to a diesel-powered genset. This was informed by previous experience that the targeted farmers had with the diesel genset, which had raised doubts about the affordability of such technologies.

The investment was implemented through the farmer co-operative group AMCOS. Recognising the need for local ownership, AMCOS also owns the project. The leadership of the co-operative society is responsible for managing the day-to-day operations of the society and the project, maintenance, as well as linking the group members with the targeted market, which largely includes the domestic market for raw mango fruits, as well as processed products such as mango juice and puree. The district government and the local partner TaTEDO provide support.



5.4 Policy frameworks

Several policies and initiatives facilitated the execution of the project. To realise the goal of universal energy access for all by 2025, the government of Tanzania adopted a Sustainable Energy for All Regionalisation Implementation plan. The plan focuses on promoting inclusive energy planning that is responsive to local development needs. It identifies local governments as critical levers for developing local energy plans and linking these local plans with national-level energy planning as well as private sector and development partner interventions.

The regionalisation plan acknowledges that ad hoc and disjointed energy projects fail to make concrete contributions to overall local development. The plan further appreciates that integrated local development plans are needed to signal opportunities for electrifying critical development services in agriculture, small-scale industry, health, education, and others, with off-grid resources such as mini-grids and standalone systems. This plan was a major lever to the success of the project, as it prepared the foundation for the sub-national government (Chamwino) to invest in local energy planning for development.

Other notable policies and initiatives that played a role in the success of the initiative included:

- The Agricultural Sector Development Program II (ASDP II), which seeks to promote sustainable agriculture, strengthen food security, and increase income for farmers through various interventions, including infrastructure development, such as rural roads, irrigation systems, storage facilities, capacity building and technology transfer (ASDP, n.d.).
- The Kilimo Kwanza (agriculture first) policy, which aims to render the agriculture sector more modern, commercial and competitive. It encourages public and private investment, provision of credit facilities to farmers, and infrastructure development, enhancing agricultural value chains (Kilimo Kwanza, 2025).
- The SAGCOT programme, which targets agricultural production and productivity, food security, poverty reduction and environmental conservation through commercial formalisation for small farmers. It includes projects of infrastructure development, such as roads, irrigation systems and energy facilities, and implementation of sustainable farming practices (SAGCOT, n.d.).

5.5 Project outcomes

A recent project evaluation revealed that, because of the intervention, beneficiary farmers increased mango production from an average of 35 fruits per tree to around 100 fruits per tree. Previously, high diesel costs, frequent maintenance and breakdowns resulted in an unreliable water supply. The switch to solar power resolved these issues by providing continuous irrigation, which in turn boosted productivity. In addition, farmers are intercropping with other high-value crops including pepper, onion, tomato, watermelon, cucumber, okra and maize, thus improving their resilience and increasing income. Finally, the project has helped reduce the distance covered in search of water for domestic use and livestock.

While men comprise around 70% of the co-operative leadership, a significant share of the beneficiaries (smallholder farmers) are women. The project continues to train all group members on the significance of increasing women's leadership in the co-operative as an approach to achieving gender equity.

"Huu mradi ulitusaidia sana. Kitambo wakati tulikuwa tunatumia mfumo wa diesel, wanachama wetu walikuwa wanaumia sana kwasabu bei ya diesel ilikuwa ghali mno, na hawangewezana nayo'. Lakini kutoka tupate mfumo wa solar, tumeona mapato yakizidi, na wakulima wamenufaika sana kutokana na kupungua kwa matumizi ya hela." - **Mwenyekiti, AMCOS**

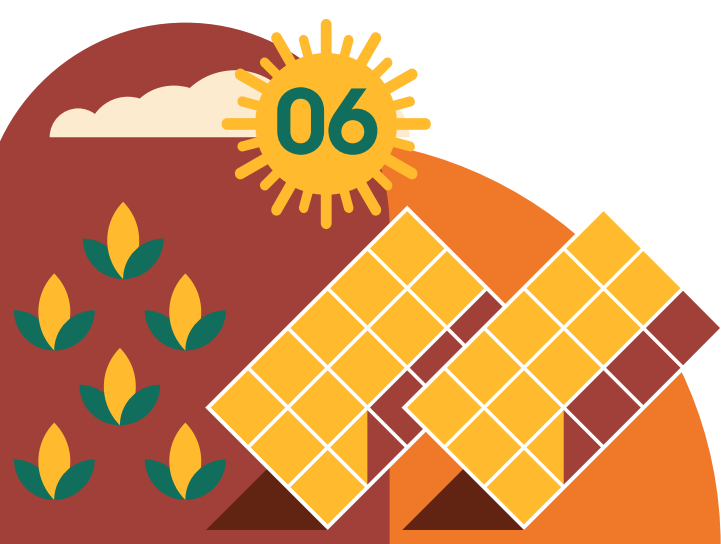
"The solar project has been of great help to the community. When we were relying on diesel, our members used to complain a lot because of the high cost of diesel, and they could not afford it. But since transitioning to solar, we have seen an increase in agricultural produce, and more income for our farmers due to affordable energy to power water." - **Chair, AMCOS**

5.6 Lessons learnt and recommendations

Several factors made the project a success. Policy makers could use the following learnings and recommendations to enable this type of project:

- **Partner with local organisations.** Engaging the community, local organisations and co-operative societies will be essential for long-term success, as they understand the local context and needs. It is also important to collect data and to model the potential of the project tailored to local circumstances.
- **Secure commitments and enabling policies from national and sub-national governments.** National and sub-national governments need to prioritise the integration of renewables for the agriculture sector in their policies and plans. Sub-national governments can play an important role by providing necessary training, as well as allocating their additional resources for capacity building, monitoring and evaluation, and investing in the initial project phase.
- **Use an ecosystem-based model.** To enable sustainability and scaling of this kind of intervention, policy makers and funders should support an ecosystem-based model, which brings together multiple actors to co-create solutions in the PURE space that enable the provision of holistic support to smallholder farmers. They should develop policies that facilitate smallholder farmers' access to profitable markets with their produce. This would enable farmers to increase their income and pay back energy investment.
- **Provide innovative finance mechanisms.** There is a need to scale up innovative finance mechanisms, including blended finance to de-risk investments to smallholder farmers, as well as mechanisms to facilitate access to carbon finance through initiatives such as Decentralised Renewable Energy Certificates (D-RECs).³

³ Tradeable certificates issued for distributed renewable energy generation.



Smallholder farmers eliminate milk loss with solar cooling in Uganda

The Solar for Sustainable Income in Dairy project implemented by Heifer International Uganda proved that using solar energy for milk cooling can increase output and the incomes of smallholder dairy farmers while reducing reliance on imported fossil fuels. A mix of grants, commercial lending and a lease-to-own model provided a feasible funding option.

6.1 Background and country context

The Republic of Uganda, situated in East Africa, boasts a diverse climate that ranges from tropical rainforest in the south to semi-arid conditions in the northeast. Agriculture is a vital sector in Uganda, employing a large share of the population and contributing around 24% of GDP. Dairy farming is particularly important, with many rural communities drawing income from milk production.

Dairy farming contributes 6.5% of Uganda's agricultural GDP through milk production and the processing and sale of dairy products. Uganda produces around 2.9 billion litres of milk annually for both domestic consumption and export (DDA, 2023). Dairy farming also stimulates other economic sectors by creating demand for inputs such as animal feed, veterinary services, equipment and transport services (DDA, 2021). The country exports more than USD 131 million in dairy products such as powdered milk, butter, and cheese, which have a higher value in export markets.

The dairy industry and food security, in general, are increasingly impacted by climatic changes such as rising temperatures and more frequent and severe droughts and floods. Another major challenge that affects the dairy farming sector is a lack of electric power, which results in spoilage and losses for farmers.

Milk collection centres, set up by producer organisations and dairy co-operatives, play an important role in the milk value chain. These centres serve dairy farmers living within a 10-kilometre radius. Farmers deliver milk to these centres, where quality tests are conducted and the milk is sold to dairy processors. In this way, smallholder farmers in rural areas gain access to markets and reliable income. The producer organisations also facilitate the supply of quality seeds, insurance, financial services, mechanisation, training, extension services and other farm inputs. Producer organisations typically have several hundred farmers as their members, with the larger organisations having over 1 000 members. Dairy farming supports the livelihoods of 1.2 million households (FAO, 2025b), and the sustainability of producer organisations therefore has a major impact on the lives of farmers that rely on them.

According to Heifer International's analysis from past experiences of working with co-operatives in central and northern Uganda, 50% or more of milk collection centres are off-grid, and producer organisations spend 40% of monthly expenses on diesel fuel to run them (PREO, 2024). On-grid milk collection centres use the grid as the primary source of power, with diesel generators providing back-up for milk chilling during power outages. Off-grid centres depend exclusively on diesel generators, with no back-up solution in case the generator breaks down. In both cases, producer organisations operate diesel generators that are expensive and unreliable (PREO, 2024).

6.2 Need for intervention

Typical agricultural practices in Uganda include smallholder farming, which is often characterised by limited access to modern technologies and infrastructure. Many smallholder dairy farmers experience significant milk losses and reduced profitability due to inadequate cooling and storage facilities. This problem is compounded by the unreliable and expensive nature of grid electricity and diesel generators.

Heifer International in Uganda works with dairy farmers and private sector players to address energy deficiencies and water for production to improve the dairy sector's performance. Heifer International is committed to empowering farmers and eradicating poverty following a sustainable, locally led development approach. To date, Heifer International has set up and strengthened more than 87 dairy producer organisations across Uganda with over 244 milk collection centres. However, more than 80% operate solely on diesel generators for energy. "The producer organisations that are connected to the grid lose 5-10% of their revenue due to power outages, which leads to poor-quality milk that has to be sold for a low price on the open market," stated Edna Nyamwaka, project manager at Heifer International.

Intervention was necessary to reduce post-harvest milk losses, thus boosting the incomes of smallholder dairy farmers. Solar-powered milk cooling systems were selected because of Uganda's abundant solar insolation, which provides a reliable and renewable energy source, reducing dependency on fossil fuels. Solar energy powers refrigeration units that preserve milk, reduce spoilage and extend milk's shelf life.

6.3 Business model

The business model was structured as a public-private partnership. Two local renewable energy companies – Aptech Africa Limited and All in Trade Limited – provided the solar cooling technology. Local dairy co-operatives facilitated technology adoption among farmers. The value proposition for dairy farmers is reduced post-harvest losses, lower energy costs and increased income. Farmers received education on the benefits of solar milk cooling. Following the installation of the cooling systems, local technicians were trained for maintenance and continuous technical support.

A lease-to-own model was adopted where each dairy co-operative pays fixed quarterly payments of USD 7 440 over a period of nine years to eventually own the equipment. For example, the Dwaniro Dairy Cooperative Ltd, located in Kiboga district in central Uganda, is successfully paying back the loan without any defaulting so far. This structure ensured that farmers had access to the technology without the burden of high upfront costs, making the solution profitable, sustainable and scalable.

For maintenance of such services, the financier (in this case, Shared Wealth Ventures) signed a five-year operation and maintenance agreement to conduct both scheduled maintenance and trouble-shooting needs. This contract is renewable, based on satisfactory performance.

The project was financed through a mix of grants from development partners, loans from financial institutions and contributions from the co-operative. One of the beneficiary entities, Dwaniro Dairy Cooperative Ltd, was able to finance its 41.4 kW peak capacity solar milk cooling system using 30% grant subsidies and 70% commercial financing at an interest rate of 9% annually. This diversified financing approach ensured the project's sustainability and scalability, addressing the issue of the high upfront costs associated with solar cooling systems.



Milk refrigeration unit powered by solar.

6.4 Policy frameworks

Existing policies promoting renewable energy adoption and sustainable agricultural practices facilitated the project's implementation. Specific policies included tax incentives for renewable energy investments and subsidies for smallholder farmers. In Uganda, solar PV modules are exempt from import duty and VAT, while solar charge control units and lead acid batteries are exempt from VAT (UNREEEA *et al.*, 2020).

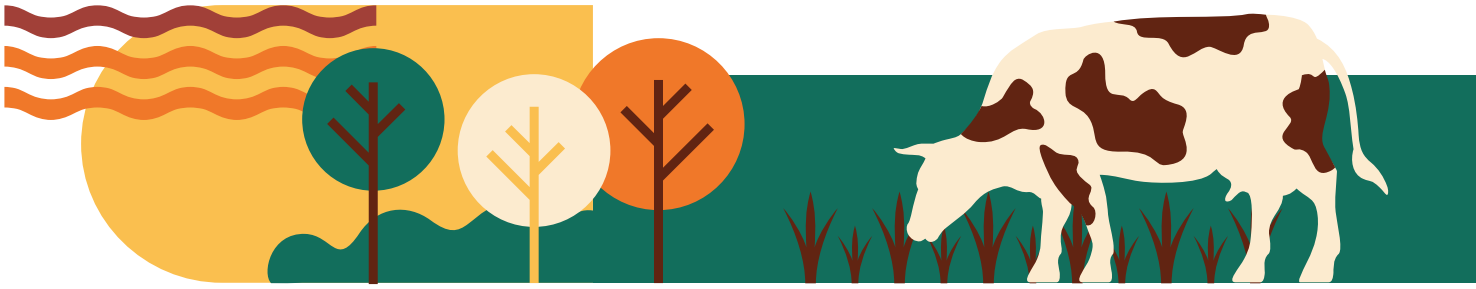
The project encountered regulatory challenges, such as obtaining approvals for installing solar systems. Continuous engagement of the regulators and sensitisation of the local authorities helped overcome the challenges.

6.5 Project outcomes

The project created substantial local value by greatly reducing post-harvest milk losses and lowering energy costs for farmers. Quantitative results showed a 46% reduction in power costs and a 100% decrease in milk losses at the Migina Milk Collection Centre for Dwaniro Dairy Cooperative Ltd. As of 2025, around 197 321 litres of milk worth USD 50 000 was being chilled monthly.

The project benefited low-income dairy farmers by providing an affordable and sustainable energy solution that improved their livelihoods. The milk collection centre saw a 22.6% increase in milk supplies over five months. The project contributed to long-term environmental benefits by reducing greenhouse gas emissions (5.98 tCO₂ equivalent per month) and promoting sustainable farming practices. It also enhanced food security and economic stability within the farming communities.



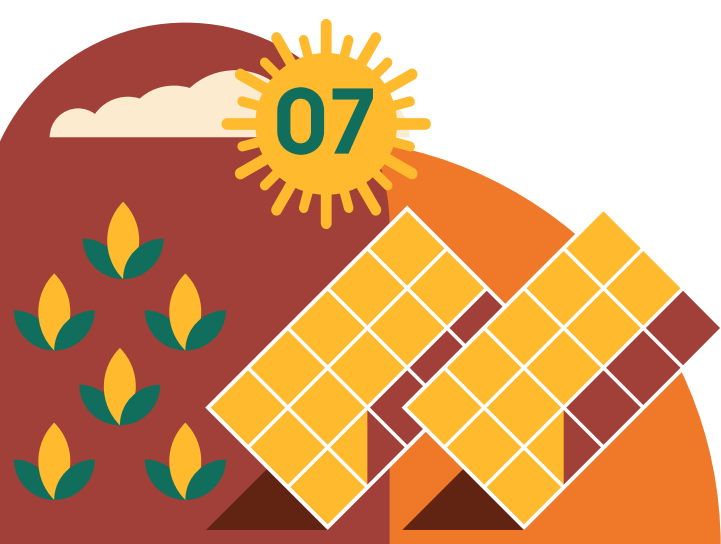


Milk refrigeration.

6.6 Lessons learnt and recommendations

This case study on solar milk cooling in Uganda demonstrates the transformative potential of renewable energy technologies in enhancing agricultural productivity, reducing post-harvest losses, and promoting climate resilience, while providing the following lessons and recommendations:

- **Invest in stakeholder engagement and training.** Farmers were initially sceptical about the new technology and their ability to secure sufficient financing. Strong stakeholder engagement and effective training programmes should build trust, addressing scepticism and lack of awareness of new technologies and financing options.
- **Provide diverse capital streams and affordable financing.** Access to diverse capital streams contributed to the project success. Given the benefits and viability of the lease-to-own model, the potential for replicability is high. To enable similar projects, governments should provide financial incentives for renewable energy adoption, such as guarantees for derisking investment for private sector players.
- **Offer enabling policy frameworks.** Governments should streamline approvals for installation, and support capacity building initiatives for local stakeholders. Additionally, integrating renewable energy solutions into national and district local government plans and budgets can further promote sustainability and resilience in the sector.



Multi-country programme demonstrates agrivoltaics feasibility

Sustainable land management is relevant to support the energy transition, which foresees rapid growth of the solar PV sector in the coming years. With this target, Enel Green Power (EGP), an Italian multinational renewable energy corporation, launched a massive demonstration programme related to agrivoltaics in 2021 to evaluate the feasibility of integrating PV plants with agro-zoological activities. The programme, completed in 2024, demonstrated that a multistakeholder approach and open innovation can achieve renewable energy integration with agriculture, increasing food production and improving biodiversity. The programme covered more than 15 MW across different PV technologies, layouts and climate areas.

7.1 Background

The demonstration programme consisted of simultaneous tests in Europe (Greece, Italy and Spain), North America, and Australia, located in different climate regions and related to different solar layouts and technologies. Demonstrations included the integration of sheep and lamb grazing, as well as various crops ranging from aromatic and medicinal herbs to vegetable and fruit species, cosmetic crops, fodder and a melliferous flowering mix that also encourages the establishment of pollinator species. A smart sensor network was installed at each selected site to enable massive data collection on agricultural and energy production, to estimate water savings and the need for fertilisation, and to generally improve the management of the crops across their phenological cycle. At some sites, high-tech beehives were installed, equipped with sensors (humidity, temperature, weight, hive sound) to assess the health of the surrounding environment, through the analysis of the bees' state of health.

The EGP demonstration programme aimed to improve the sustainability of solar energy plants through an innovative approach enabling sustainable practices for:

- multipurpose land use (crops/flora and vegetation)
- safeguarding wildlife habitat and biodiversity
- improvement of ecosystem services and
- a collaborative multistakeholder approach.

The programme also fostered the adoption of sustainable agricultural practices by participating farmers. The use of a holistic approach, assessing all the exogenous factors related to large PV plants, allowed for the identification of actions to mitigate the environmental and social impacts of these installations.



7.2 Business model

The business model was based on an open innovation collaborative multi-stakeholder approach. The demonstration programme involved local farmers and agronomists, beekeepers, and other stakeholders such as universities, research centres, start-ups and companies with specific competencies. This model promoted continuous knowledge sharing, enabling the development of new skills for each partner. A scientific and experimental methodology aimed to promote multipurpose land use, improving ecosystem services and providing shared value for the local community. In particular, 48 entities were evaluated in a preliminary phase, and 18 partners were selected. The partnerships made it possible to build a virtuous innovation mechanism and to validate the experiments on a solid scientific basis by third parties.

EGP financed the demonstration programme as part of its innovation activities. The business model created a win-win framework in which all the involved partners collaborated, exchanged knowledge and acquired new skills. For example, the use of dedicated sensors to monitor agricultural and livestock activities – such as microclimate, temperature, water content and electrical conductivity – helped increase the digital skills of those involved. Through continuous monitoring provided by the sensors, farmers could better plan irrigation and fertilisation operations. In addition, the dissemination and sharing of the project's details and results with the local community enabled training and awareness-raising activities aimed at promoting sustainable renewable energy production and respect for the environment and ecosystems.

In the demonstration programme, different PV technologies were considered: standard layout, with fixed structures or with trackers, equipped with monofacial or bifacial modules, with different pitches (the distance between the structure's axis from one PV row and another), allowing a cultivable area of up to 70%. Innovative PV technologies were also included, such as vertical installations that allow a greater than 90% cultivable area. At each site, the interaction with the operation and maintenance activities of the PV plants was assessed. Within the demonstration tests, PV plants differing in the number of years of operation (less than one year, greater than five years, for example) were considered, to evaluate the effect of sustainable agricultural practices to mitigate soil compaction, potentially occurring after years of operation. Compacted soil has lower water and air penetration, which can reduce yields.

The agro-zoological activities were selected in compliance with local employment opportunities, market demand, and local traditions, creating ecological continuity with the surroundings. The projects brought value to local communities through the development of new business models tailored to the specific features of the site and directly involving local stakeholders. The demonstration programme not only promoted the integration and co-existence of multiple businesses but also fostered the adoption of the most sustainable farming techniques. High-tech and digital tools benefited farming partners and improved the competitiveness of the market.



Beehives implemented in a marginal area of a PV plant.

7.3 Policy frameworks

No barriers arose for the project development, due to its experimental and demonstration nature. In the future, such research should be encouraged to cover wider geographical and environmental conditions and crops. Depending on the country, the approach to agrivoltaics can be related more to agricultural activities or to biodiversity safeguarding measures. A homogenisation is needed to integrate these two approaches in a win-win common agrivoltaics concept in a holistic vision, across countries.

7.4 Project outcomes

The main outcomes of the demonstration programme were as follows:

- Energy production increased from between 0.5% and 6% (depending on the irrigation regime) thanks to an evapotranspiration effect that decreased the PV module's temperature. Albedo (the amount of energy reflected by a surface) decrease does not affect energy production more than the energy gain due to evapotranspiration effect.
- Agricultural yield increased by between 20% and 60%, depending on the species.
- Irrigation water consumption decreased by between 15% and 29%.
- Sheep/lamb wellbeing improved due to shading offered by the PV modules.
- Biodiversity improved due to the implementation of specific habitats to host pollinators and wildlife, such as birds. The most relevant Key Performance Indicators increased when compared to before the launch of the experimentation: pollinator abundance by 75%, availability of flowers by 74% and suitability for nesting by 3.2%.

Valdecaballeros PV plant in Spain, one of the host sites of the demonstration programme, was expanded as part of a European-funded project. Specifically, the implementation of rosemary, which initially was tested over a 3-hectare area corresponding to around 1.5 MW of energy production, was scaled up to cover an area of 10 ha, equivalent to 5 MW of energy production.

In the long term, the integration of agricultural activities is being carried out with sustainable practices, which guarantee a soil vegetal cover, reduce soil erosion issues, preserve the soil nutrient content and promote microbial activity. This enables improvements in biodiversity safeguarding measures and ecosystem services, through the creation and/or restoration of habitat for specific target species.



Sheep grazing in the shade of a PV plant in Spain.

7.5 Lessons learnt and recommendations

The massive data collection conducted in the demonstration programme – covering multiple countries, climate conditions, PV technologies, and layouts, as well as the agro-zoological activities – has a potential to expand agrivoltaics applications and encourage experimentation. The main aspect to consider in the design of an agrivoltaics application is the selection of the agro-zoological solution, which must be compliant with the specific livelihood activities of the area, the pedoclimatic conditions and the market demand. Recommendations for agrivoltaics development include the following:

- **Seek synergies.** The land-use designation should not be changed from agricultural to industrial due to the installation of PV systems. In the agrivoltaics plants, dual use of the land should be regulated. In the European Union, Common Agricultural Policy (CAP) support and contributions for farmers should be maintained for the agricultural partners of agrivoltaics plants, avoiding potential conflicts of interest between PV and agriculture.
- **Adjust rules as necessary.** An agrivoltaics plant is authorised to exist for its entire lifetime, as agricultural activities are integrated in the solar plant. Any potential changes in the agricultural activities could be considered partial non-compliance with the legal requirements of the plant. Introducing flexibility mechanisms in the agrivoltaics plant operation, which decouple the integrated agricultural needs from the solar plant operation, could prevent an early plant shutdown.
- **Use a holistic approach.** A common approach for countries could foster and facilitate the adoption of agrivoltaic plants. Currently, the exclusive approaches adopted by environmental administrations at the country level tend to foster solutions to improve ecosystems and biodiversity rather than promoting the integration of agricultural activities. Alternatively, they promote intensive agriculture, with little attention to safeguarding biodiversity and local ecosystems. An agrivoltaics initiative should promote a collaborative multistakeholder approach, adopt a holistic vision and guarantee sustainability for the environment, biodiversity, agriculture and renewable energy growth.
- **Streamline the process.** There is a need to reduce the complexity of authorisation, including the requirements/number of entities involved, long lead times, expensive connection costs and definition of eligible areas. All agrivoltaics technologies – whether standard in height or vertical – are virtuous and should be given the same recognition in guidelines and legislation.



Recommendations

Creating enabling conditions is crucial to fully harness the benefits of integrating renewable energy in agriculture while managing associated risks. The following recommendations highlight key actions derived from the seven case studies:

The water-energy-food-ecosystems (WEFE) nexus approach

- 1. Governments should adopt a holistic and cross-sector approach to integrating renewable energy into agriculture in Nationally Determined Contributions (NDCs), rural development plans, agricultural policies and strategies, and budgets.** Diverse ministries, such as energy, agriculture, environment, and finance, should work together to align the goals, create coherent strategies for the WEFE nexus and socio-economic development, and allocate funding. Supportive policies and regulatory frameworks, including renewable energy targets and financial incentives (such as subsidies and tax reductions) are effective in encouraging renewables deployment in agriculture. Equally important is to harmonise and streamline permitting processes, reduce administrative burdens, and establish and enforce quality standards for renewable energy equipment.
- 2. Measures should be implemented to leverage synergies across renewable energy and food systems and to protect arable land and food output.** Energy generation can be more profitable than agriculture, so it is important that it does not undermine overall food production and food security at the national and regional level or create unintended trade-offs. Targeted research and pilot projects can identify the most effective design and establish best practices for different conditions and crops. Zoning to protect forests and agricultural land as well as standards for expected production output can be considered in specific cases. Independent impact evaluations are necessary to provide credible evidence on project performances. Baseline data collection at the beginning of the project and regular monitoring can maximise yields and allow a timely identification if it is necessary to modify the design and adjust operations. Comprehensive sustainability assessments must consider environmental, economic and social dimensions. Collected data and analysis can also provide insights on what works and how to effectively scale it up. Incentives and guidelines should encourage project developers to integrate land restoration measures and nature-positive farming.
- 3. International collaboration is essential to enable technology transfer and the exchange of knowledge and best practices.** By fostering partnerships among governments, the private sector, research institutions, and local stakeholders, innovation can be accelerated and successful models more easily replicated. Disseminating proven business models and research on synergies between food and energy production internationally can further enable scaling up of renewable energy in agriculture.



Access to finance and markets

4. It is critical to facilitate access to finance and to increase awareness among financial institutions.

Government support to enable access to affordable funding is critical. Blended finance, low-interest loans, grants and guarantees, and subsidies in early stages can address the barrier of a high upfront cost and perceived risks. Specific financial products adjusted to smallholder farmers and co-operative conditions are needed. Innovative models such as rent-to-own can assist smallholder farmers and marginalised communities. Financial institutions are prepared to lend for renewable energy or agriculture projects. It is important to increase awareness of the specific agri-renewables model, the risks and returns, which would facilitate financial products adapted to a local context and access to climate finance.

5. Project partners should support access to markets and establish viable business models.

An integrated approach facilitating access to technologies and markets will enable income generation that would pay back energy investment, reducing reliance on grant models. Aggregating farmer activities, and co-operative models, can improve the affordability of technologies and reduce logistics costs. Measures to connect food output to potential consumers and energy to off-takers can contribute to project profitability and local economic development. Scaling PURE offers opportunities for sustainable local development.

User-centric design

6. The project must be guided by a thorough diagnosis of the specific context, local needs and gender perspective.

The collection of data, engaging local stakeholders and mapping out capacities and needs will ensure that the most appropriate technology and design are chosen to improve efficiency and financial viability, and to maximise socio-economic benefits. Land rights and tenure security also need to be considered. Participatory, integrated land-use planning must involve all local land users, particularly ensuring the participation of smallholders and vulnerable groups. Developing projects that are responsive to the real needs of farmers will avoid designing inappropriate tools and services that fail to deliver. Gender-specific indicators will ensure that the business model inherently nurtures systems that allow for further inclusion and gender transformative action. In practice, this means designing solutions that address local gender-based power dynamics and structural inequalities and incorporate women's access and use of land and resources, their participation in decision-making processes, and their autonomy in managing income.

7. Farmers and local communities should receive technical assistance and capacity building developed in collaboration with actors on the ground.

Training programmes on installation, operation and maintenance should develop skills, raise awareness and create trust in renewable energy technologies. Technical support, equipment and spare parts for maintenance must be available locally to ensure continuation of operations. Recognising that a potential power imbalance might exist between energy companies/developers and land users (farmers, pastoralists), it is important to strengthen local people's capacity to negotiate. This can be achieved by improving access to unbiased information and legal counsel, and civic education to understand laws and rights. An inclusive, gender-sensitive approach should ensure that diverse needs are met and opportunities are accessible to all.



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