International Renewable Energy Agency

Decentralised renewable energy for agriculture in Malawi

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Abbreviations

DRE	decentralised renewable energy
EGENCO	Electricity Generation Company
ESCOM	Electricity Supply Commission of Malawi
HPS	High Penetration Scenario
IRENA	International Renewable Energy Agency
kW	kilowatt
kWh	kilowatt hour
LPS	Low Penetration Scenario
MBG	milk bulking group
MMPA	Malawi Milk Producers Association
MPS	Moderate Penetration Scenario
MW	megawatt
PAYG	pay-as-you-go
PU	productive use
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
NASFAM	National Smallholder Farmers Association of Malawi

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Executive summary

Access to energy remains a critical challenge in Malawi, particularly in rural areas where limited access to reliable power significantly constrains agricultural productivity and overall economic development. Recognising this, the government of Malawi has implemented the National Energy Policy, prioritising renewable energy as a means to diversify energy sources and drive rural electrification. In parallel, the Malawi Rural Electrification Programme aims to extend electricity to underserved rural regions.

Supporting these efforts, the International Renewable Energy Agency (IRENA) is working to promote decentralised renewable energy (DRE) solutions, particularly in the agricultural sector. This sector holds immense potential to boost Malawi's economy, enhance food security and support inclusive growth.

This report presents the findings of a feasibility study focused on deploying DRE technologies across selected agricultural value chains. Drawing from desk reviews, stakeholder consultations, focus group discussions and interviews with farmers, the study provides critical insights and actionable recommendations to align DRE investments with the national aspirations of Malawi Vision 2063.

Key findings

The study identified high demand for DRE solutions across selected agricultural value chains, namely, olericulture, dairy, rice, legumes (groundnuts and soybeans) and aquaculture. For instance, dairy farmers face severe challenges due to energy insecurity, with 52% of surveyed farmers lacking access to electricity. Even among those who have access, 44% rely on the national grid, where power outages pose a significant challenge. In both instances, the lack of reliable electricity and cold chain infrastructure results in over 41% of the milk produced by farmers spoiling before reaching the market. These losses, compounded by transport and infrastructure issues, reduce farmers' incomes and undermine the profitability of the dairy value chain.

In the rice value chain, the study revealed that high electricity tariffs pose a significant barrier to irrigation. On average, rice farmers reported spending nearly USD 576 monthly on electricity to power their irrigation systems. As a result, irrigation schemes like the Lifuwu Rice Irrigation Scheme are underutilised. Despite its capacity to irrigate 180 hectares, the scheme currently irrigates only 30 hectares, representing just 18% utilisation. This inefficiency leads to substantial production losses, underutilisation of infrastructure and reduced income for smallholder farmers.

The assessment findings also show that most of the surveyed smallholder farmers are willing to pay for DRE solutions if the economic benefits of the solutions are clearly explained. The majority of the farmers are motivated to increase productivity and reduce energy costs, and are thus willing to invest in technologies to achieve this. Farmers appreciate the increase in profitability that results from energy access leading to a reduction in post-harvest losses. By implementing DRE solutions, farmers foresee increased yields and reduced waste, which eventually contribute to higher incomes. Therefore, creating financial models that align with farmers' capacity to pay can facilitate the adoption of these technologies, ensuring that they are both accessible and economically viable for smallholder farmers.

Financial viability of DRE solutions

Analysis conducted during the study demonstrates the need to deploy DRE solutions in these value chains, although systems that have already been implemented in the sector struggle to highlight a strong business case. For example, in the legume sector, Jesca Enterprises, a small-scale processor, invested USD 125 520 in a 30 kilowatt (kW) DRE system. Over five years, this investment resulted in an unattractive internal rate of return (IRR) of 4%. Similarly, in the dairy sector, Kalimbuka Milk Bulking Group (MBG) invested in DRE-powered milk storage and processing solutions with an IRR of 2%, again a low return investment. These examples also indicate that, despite their importance, DRE investments have high investment cost and low return. However, because of the potential for positive impacts, there is a need for policy intervention such as tax exemptions to drive their costs down and increase their attractiveness.

DRE technologies also offer transformative potential in aquaculture. Energy is essential for heating, water circulation and hatchery operations. The adoption of DRE for pond irrigation and processing can enable year-round fish production and significantly increase yields. In the olericulture sector, the use of DRE for irrigation and cooling can increase yields and extend the shelf life of high-value crops, improving marketability and reducing post-harvest losses. For instance, using solar-powered cold storage systems in markets and production hubs could reduce vegetable spoilage by over 30%, leading to increased farmer incomes and improved food security.

Investment and scaling potential

An estimated USD 183.85 million investment is required to integrate DRE solutions across five priority agricultural value chains in Malawi: olericulture, dairy, rice, legumes and aquaculture. This catalytic investment would help reduce perceived risk whilst boosting the commercial viability of DRE rollout in the country. The funding would be used to support and deploy solar-powered irrigation, cold storage solutions and custom processing units across the value chains. It would further be used to provide liquidity to microfinancing institutions that provide smallholder farmers with access to finance through concessional credit lines. This multipronged approach would help kickstart and accelerate the uptake of DRE technologies and help reduce post-harvest losses, boost productivity, and improve food and nutrition security, whilst empowering smallholder farmers to conduct and scale their farming operations sustainably. The following is an overview of the funding spread across the value chains:

- **Olericulture value chain (tomatoes, onions, leafy green vegetables, green beans) (USD 12.24 million):** DRE solutions targeting the cold chain, processing and irrigation would help increase productivity and reduce both yield losses and dependence on rain-fed farming. These solutions would increase farmers' earnings whilst enhancing the supply of fresh produce.
- **Dairy value chain (USD 22.88 million):** Cold chain solutions are needed to reduce the milk losses experienced across the values chain. These solutions would have the greatest impact on remote rural farmers with limited access to energy and located far from milk aggregation centres.
- **Rice value chain (USD 32 million):** Capital would enable the use of solar dryers and water management systems to improve yield quality, enhance double-cropping capabilities and reduce reliance on rain-fed irrigation, bolstering resilience to water scarcity.
- **Legume value chain (USD 82.93 million):** Investments would target solar-powered water pumps, storage and drying technologies to minimise post-harvest losses and improve processing efficiency, supporting the productivity and profitability of legume farmers.
- **Aquaculture value chain (USD 33.80 million):** Funding would enable the installation of solar-powered refrigeration, aerators and water pumps, enhancing fish stock health, reducing losses and ensuring supply stability.

Beyond increasing productivity, investment would generate employment in DRE installation and maintenance, strengthening local economies. DRE solutions can further enhance climate resilience by reducing fossil fuel dependence, stabilising yields during droughts and improving supply chains through robust infrastructure. Establishing mini-grids to serve multiple value chains, farmer co-operatives and rural businesses can enhance cost-effectiveness and economies of scale, while targeted renewable enterprises should be prioritised according to their scalability, profitability and impact potential for smallholder farmers.

High electricity tariffs, unreliable grid supply, and limited access in rural and remote areas drive the demand for DRE in Malawi's agricultural sector. However, realising the full potential of DRE solutions requires financing and capacity-building challenges to be addressed. Access to credit remains a significant barrier, with most financial products either costly or incompatible with the needs of rural smallholder farmers. Flexible financing options, such as low-interest loans with repayment plans linked to agricultural production cycles, are important to scale up DRE adoption. This assessment aims to stimulate a self-sustaining DRE ecosystem that supports smallholder farmers, strengthens market linkages, and enhances Malawi's agricultural resilience and productivity.

Recommendations

To boost DRE implementation in Malawi's agricultural sector, a co-ordinated approach is needed with actionable recommendations targeting key stakeholder groups.

Government and policy makers should implement tax incentives and subsidies, such as providing tax exemptions for importing DRE solutions used in smallholder agriculture, including solar-driven water pumps and refrigeration units. Reforming import procedures and enhancing access to foreign currency for DRE solutions would ease access for smallholder farmers. Furthermore, developing a national agricultural DRE policy under the Ministry of Agriculture can help integrate DRE technologies into agricultural development plans, with detailed targets for solar water pumps and cooling facilities in rural areas by 2030. Establishing a "Green Finance Facility" in partnership with local banks can support DRE purchases by providing low-interest loans for DRE solutions. Additionally, improving the capacity of agricultural extension officers to manage DRE maintenance and operation would enable them to support farmers in integrating solutions like solar dryers for olericulture and solar aerators for aquaculture. Finally, increasing interministerial co-ordination through a task force across relevant ministries would align suitable policies and resources to be developed for DRE implementation.

Development partners and donors should support DRE demonstration projects to showcase the benefits of DRE technologies, such as a solar cooling project for dairy co-operatives in Mzuzu. Providing farmers with capacity building and training on DRE solutions, and operational and basic maintenance techniques is important. Allying projects and programmes with national energy goals in partnership with the Ministry of Energy should help guarantee effective implementation.

Financial institutions are encouraged to create tailored financial products for DRE solutions, offering finance with flexible settlement terms suited to the extended production cycles in agricultural sectors such as aquaculture and dairy. Instituting pay-as-you-go (PAYG) financing models can allow smallholder farmers to buy DRE solutions incrementally, reducing the financial burden. Local institutions can also collaborate with regional development banks to develop risk-sharing and reduction mechanisms such as risk mitigation facilities that will lower the cost of capital for smallholder farmers.

DRE technology providers and suppliers are encouraged to develop DRE solutions suited to Malawian smallholder farmers' needs. A wider network of service and repair centres is needed to service farmers in remote locations. This would enhance the reliability of the solutions and subsequently uptake across the value chains. Technology suppliers can also increase business volumes by implementing targeted outreach and awareness campaigns that make the farmers aware of available solutions, thus stimulating demand.

Agricultural co-operatives and farmer groups can set up shared DRE solution centres to make solutions available to their membership. For example, co-operative operated cold chain solutions at aggregation centres could increase energy access and throughputs, enhancing resource utilisation efficiency as opposed to locking capital in on-farm cold storage. The co-operatives and groups can also be instrumental in negotiating bulk purchases and loan agreements for their members.

Research institutions and academia can lead evidence-based work demonstrating the benefits of DRE solutions for the livelihoods of smallholder farmers in Malawi. Developing appropriate, cost-effective innovations specifically for smallholder needs can address local challenges effectively. Likewise, transferring research findings into practical application through partnerships with extension services and renewable energy enterprises could enhance farmers' understanding of DRE technologies.

Local communities and farmers should form co-operatives to combine resources for buying DRE equipment and participate in maintenance and operation training sessions to ensure the reliability of technologies being utilised. Encouraging community-level DRE projects fosters shared infrastructure, such as solar-powered cold storage facilities that benefit multiple farmers from different value chains. Entrepreneurs and farmers are urged to leverage DRE technologies to improve production cycles and improve post-harvest processing. This includes using DRE for irrigation and cooling, particularly in the dairy and aquaculture sectors. Finally, following best practices for crop and animal management maximises the benefits of DRE integration.

In conclusion, by implementing these recommendations across government, the private sector, financial institutions and donor communities, Malawi can fast-track the integration of DRE solutions into smallholder agricultural value chains. This should increase yields, decrease waste and increase farmers' earnings, eventually contributing to the nation's development goals as defined in Vision 2063.

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1. Country context

1.1 Background

Agriculture is a cornerstone of Malawi's economy, supporting livelihoods and contributing significantly to the country's development agenda. However, the sector faces persistent challenges, including low productivity, limited mechanisation and vulnerability to climate-related impacts. These issues are compounded by insufficient access to reliable energy, which is critical for modernising farming practices, improving value addition and reducing post-harvest losses. Energy plays a pivotal role in transforming agricultural systems by powering essential activities such as irrigation, processing and storage. Yet, many rural communities in Malawi rely on manual labour or traditional fuels, which limits their ability to increase productivity and improve the quality of agricultural outputs.

Decentralised renewable energy (DRE) solutions offer a practical and sustainable alternative to meeting the energy needs of agriculture, particularly in off-grid and underserved areas. Technologies such as solar-powered irrigation systems, biomass-based drying units and geothermal energy systems provide opportunities to enhance productivity, reduce energy costs and support environmentally sustainable practices.

In response to a request from the government of Malawi, the International Renewable Energy Agency (IRENA) has conducted an assessment to explore the integration of DRE solutions in the country's agricultural value chains. This study identifies energy entry points, evaluates the suitability of DRE technologies for key agricultural activities and provides recommendations to support sustainable development in the sector. This initiative aligns with IRENA's mission to accelerate the global energy transition and demonstrates its commitment to supporting developing states in addressing critical energy challenges while fostering economic growth and environmental resilience.

Socio-economics

The government of Malawi values the importance of the energy sector as a key driver for the country's socio-economic development, as charted in its strategic plan, Malawi 2063. This long-term development plan aims to move Malawi up to an industrialised lower-middle-income country by 2030, focusing on pillars such as agricultural output and commercialisation, industrialisation and mining (NPC, 2020). The transformation of the agricultural sector is important for achieving these goals. Shifting from low-productivity subsistence farming to a highly productive and commercialised system with manufacturing linkages requires increased mechanisation and technology adoption, leading to a surge in energy demand within the agricultural sector.

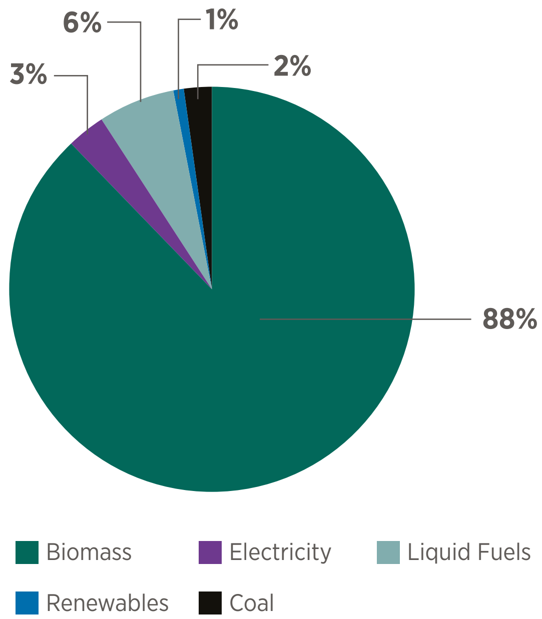
The government of Malawi acknowledges that industrial progress has been hindered by high production costs stemming from energy and transport inefficiencies (NPC, 2018a, 2020). To address this, the government is committed to invest in alternative energy sources, including solar, wind and others, with a focus on minimising environmental impact. This strategy aligns with the objectives of the National Energy Policy of 2019, emphasising the diversification of energy sources, the development of an efficient energy sector and modernised, sustainable energy services, and increased access to clean and affordable energy for all citizens (NPC, 2018a).

Energy consumption patterns

Malawi's yearly energy demand is about 5 million tonnes of oil equivalent, with per-capita primary energy use standing at a low 45 kilowatt hours (kWh) in 2021, notably lower than the sub-Saharan median of 180 kWh (Ministry of Energy, 2020). The country's energy supply depends heavily on petroleum, coal and renewables (mainly large hydro and biomass), with households using 81% of the total energy (Ministry of Energy, 2024). Biomass predominates, contributing 88% of the energy used by households in the form of firewood, charcoal and crop residues. Other energy sources, such as petroleum, grid electricity and coal, contribute minor portions.

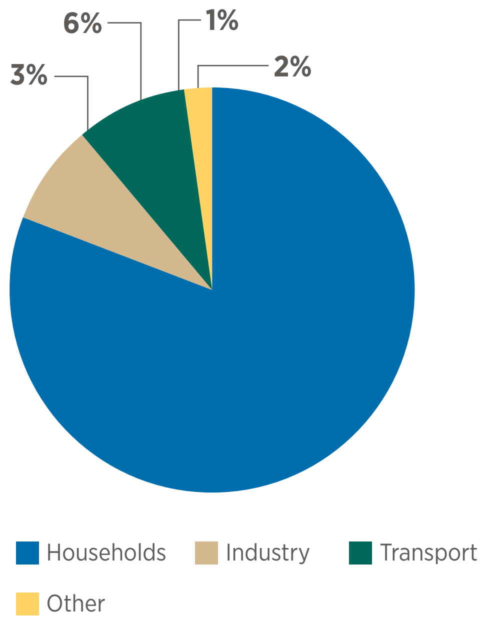
The Electricity Generation Company (EGENCO) is Malawi's primary energy producer, with an installed capacity of 442 megawatts (MW) mainly from hydropower, recently supplemented by 80 MW of solar energy through independent power producers (EGENCO, 2024). Only 18% of the population has access to electricity, leaving nearly 3.7 million households lacking modern forms of energy (CESET, 2020). Realising universal electricity access by 2030 will imply an access expansion rate of above 600 000 additional connections per year (SEforAll, 2022), with investment in both grid and off-grid solutions being decisive. The country also confronts challenges with power reliability, infrastructure and financing, restricting access and quality of energy services.

Figure 1 Malawi energy supply mix



Source: (NPC, 2018a).

Figure 2 Malawi energy demand mix



Source: (NPC, 2018a).

Agricultural sector overview

The agricultural sector is important to Malawi as it accounts for 23% of the country's GDP and employs about 77% of its workforce (FAO, 2023). About 90% of those employed in the agricultural sector are smallholder farmers cultivating less than one hectare each, with the per-capita availability of arable land decreasing owing to a growing population (JICA, 2024). Women and youth comprise about 60% of the country's agricultural workforce, playing a central role in national crop production and household food and nutrition security (UN Women, 2016). They participate in several primary and secondary agriculture activities, from planting to post-harvest processing. Regardless of their important role in the sector, women and youth encounter challenges, such as restricted access to financial resources, which hold back their productivity and decision-making capability.

Agriculture in Malawi largely depends on rain-fed systems, as irrigation has been slow to develop compared with demand. As a result, crop yields are dependent on erratic rain and weather conditions. This reliance on rains often leads to food shortages at both national and household level. Most smallholder farmers cultivate important staple crops, such as maize, beans, rice and groundnuts, which are important to guarantee food security and raise export earnings (NPC, 2020).

Use of modern forms of energy in the agricultural sector continues to be a challenge, as many smallholder farmers depend on traditional biomass for cooking and other energy needs. This reliance emphasises the potential for DRE solutions to increase productivity and sustainability in agriculture. Additionally, attracting youth into agricultural practices could further innovation and increase productivity, as they are a growing demographic in both rural and urban communities.

1.2 Climate change, mitigation and adaptation

Similar to many developing countries, Malawi faces substantial effects from climate change, mainly manifested in rising temperatures, irregular rainfall, and extreme weather events such as droughts and floods. These impacts harshly affect the country's agricultural sector, which is the central pillar of the economy and sustains the livelihoods of about 80% of the population. The irregularity of weather patterns worsens food insecurity, leading to reduced crop yields and heightened exposure among smallholder farmers (Word Bank, 2022). Likewise, rising temperatures put pressure on water resources, adversely disturbing both irrigation and drinking water supplies, hence adding to health issues and decreasing agricultural productivity (NPC, 2018b).

In reaction to these challenges, the government has developed and actioned numerous strategies targeted at climate adaptation and building resilience. The National Climate Change Adaptation Strategy stresses sustainable land management practices and increased use of irrigation systems, and advocates climate-resilient crops. Also, the government is working to strengthen the regulatory framework for, and foster investment in, renewable energy sources to reduce fossil fuel use and dependency in climate-sensitive sectors (NPC, 2018b). These practical measures demonstrate the government's pledge to mitigate climate impacts while advancing sustainable development.

DRE solutions for adaptation

DRE solutions play an important role in adapting to climate change. As climate change worsens energy insecurity and environmental degradation, adopting DRE solutions is key to increasing resilience. These solutions present sustainable alternatives to fossil fuels, thereby easing carbon emissions and dependence on unreliable grid power, which are important for agricultural value chains such as rice, legumes and aquaculture. For example, solar-driven irrigation can ease the effects of erratic rainfall and lingering droughts, guaranteeing a steady water supply for rice fields and fishponds. Also, renewables-driven processing and storage facilities, like milling machines and solar-powered cold rooms, can increase the shelf life and quality of yields, lower post-harvest losses and improve food security.

1.3 Policy and regulatory frameworks

The impacts of climate change are affecting Malawi's ability to improve its citizens' quality of life, particularly vulnerable smallholder farmers with limited access to energy and a heavy reliance on rain-fed agriculture. Malawi's Nationally Determined Contribution (NDC) stated the country's ambition and commitment to increase both adaptation and mitigation efforts in line with the Sustainable Development Goals (SDGs). The pledges made by the country include increasing the use of renewable energy to address the country's energy access gap and growing energy demand. By promulgating the Malawi Growth and Development Strategy (MGDS III) and Vision 2063, the country has integrated both renewables and climate change management into its development agenda. These instruments are strengthened by policies that include the National Climate Change Response Framework, the National Adaptation Plan, and the National Climate Change Management Policy of 2016.

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2. Methodology

The main objective of this assessment is to establish how to increase the uptake of DRE solutions by smallholder farmers in Malawi. It does this by identifying opportunities and recommendations for key DRE intervention points across selected agricultural value chains. The assessment was conducted through a consultative multi-stakeholder process to gain a thorough understanding of the current situation and map a way forward for the adoption of DRE solutions by providing the necessary support for the ecosystem as set out in the recommendations. The following sections provide more detail on the steps taken during the assessment.

2.1 Desktop review

The assessment started with a detailed desktop review of relevant policies and donor programmes, with a strong focus on both the energy and agricultural sectors in Malawi. This literature review served multiple purposes:

- **Policy frameworks:** Analysing existing policy frameworks, such as the National Agricultural Policy and the National Energy Policy, allowed the assessment team to identify priorities set by the government regarding agricultural development and energy access. This understanding is critical for aligning DRE solutions with national goals and initiatives.
- **Donor programmes:** The review encompassed the plotting of donor programmes currently running in Malawi. By recognising the focus areas and funding instruments of different donors, the assessment could identify potential partnerships and areas where DRE solutions could be integrated into ongoing programmes.
- **Energy sector landscape:** An assessment of the energy sector highlighted existing energy sources, use patterns and gaps in energy access, specifically in rural areas where agricultural activities mainly take place. Understanding the energy scene is necessary for proposing appropriate DRE technologies that can meet the specific needs of farmers and agribusinesses.
- **Agricultural sector insights:** The review provided insight into key agricultural value chains such as rice, legumes, fish, olericulture and dairy. Information about production levels, challenges confronted by farmers, and underlying market forces helped to spot value chains with noteworthy potential for DRE integration.

Overall, the desktop review instituted a base for understanding the existing environment and identifying opportunities for integrating DRE solutions in the agricultural sector.

2.2 Stakeholder consultations

Following the desktop review, stakeholder consultations were conducted to collect qualitative evidence and confirm findings. These consultations involved diverse players in the agricultural and energy sectors:

- **Policy makers:** Engagements with delegates from the Ministry of Agriculture and the Ministry of Energy provided vital understand of government priorities and policies that might affect DRE acceptance. These dialogues uncovered the government's pledge to increase agricultural productivity, food security and energy access.
- **Community-based organisations:** Engagement with community-based organisations on agro-energy permitted the assessment team to appreciate the grassroots challenges confronted by farmers, including inadequate access to energy, information gaps and monetary limitations. These organisations frequently act as agents, enabling the spreading of technology and information to rural smallholder farmers.
- **Farmer groups:** Meetings with farmer groups elicited valuable views on the practical challenges they face, such as the need for reliable energy sources, the impact of climate variability, and the desire for capacity-building programmes. Comprehension of the needs and ambitions of farmers is important for making sure that DRE solutions are appropriate and beneficial.
- **Aggregators and offtakers:** Discussions with aggregators (*e.g.* milk bulking groups) and offtakers (*e.g.* processors, supermarket chains) provided insights into underlying market forces and demand for different agricultural products. This evidence is needed to identify practical routes for integrating DRE solutions that can increase the effectiveness of both processing and distribution.

- **Renewable energy enterprises:** Engaging with renewable energy enterprises allowed the assessment team to identify the existing DRE technologies, funding models and implementation challenges. These companies can play an important role in scaling up DRE solutions in the agricultural sector.
- **Donors and development partners:** Sessions with donors and development partners shed light on funding prospects and areas of interest, ensuring that the assessment fits within broader development objectives.

Through these consultations, the assessment team collected qualitative data that augmented the understanding of the agricultural and energy environments, helping to identify the main challenges and opportunities for DRE integration.

2.3 Value chain selection

The criteria used to select the value chain reflected the following attributes: government priorities, food security considerations, economic capability, climate resilience, and enablement of women and youth (Table 1). These criteria reflect the Malawian government priorities as detailed in Vision 2063 and other shorter-term development goals on agricultural transformation, economic diversification, climate resilience and increasing the reach of financial services. DRE solutions have the potential to change the agricultural sector and positively contribute to Malawi's climate ambitions whilst empowering vulnerable populations. Five agricultural value chains were selected for analysis: olericulture, dairy, rice, legumes and aquaculture. The selection criteria comprised:

- **Government priorities:** The government of Malawi has established policy instruments such as the Malawi Implementation Plan (MIP 1) and the National Agricultural Policy to drive sustainable agricultural practices, promote the farming of nutrition-rich food security crops and increase processing and value addition across agricultural value chains. In particular, the government emphasises the need to increase productivity along the legume and fish value chains to improve access to protein at the household level. Under the Coalition for African Rice Development (CARD) the Malawian government has classified rice as a priority export crop, with a target of increasing production by 500 000 tonnes per year since 2018. However, in 2021 Malawi's rice production only achieved about 184 000 tonnes, showing sizable disparity with the targeted growth. Furthermore, the government aims to increase annual soybean production from 300 000 tonnes to 869 000 tonnes and annual groundnut production from 400 000 tonnes to 1 million tonnes by 2030 as part of Pillar 1 of Malawi 2063, which emphasises agricultural productivity and commercialisation. Integrating DRE solutions – such as solar-powered processing facilities and efficient irrigation systems –can significantly bolster the productivity of these value chains. By curtailing post-harvest losses and advancing processing efficacy, DRE technologies can promote a more sustainable agricultural environment, supporting the government's vision for economic diversification and increased food security.
- **Food security considerations:** Malawi's dependence on rain-fed food production results in considerable yield variations, contributing to erratic food shortages. In 2022 poor weather conditions lowered the production of various key crops, such as legumes and fish, which are important sources of protein for many households. The Affordable Inputs Programme (AIP) targets the improvement of agricultural yields, specifically for staple crops, while incorporating DRE solutions such as solar irrigation systems, which can provide a reliable water supply. The rice and aquaculture value chains, which heavily depend on access to water, are the greatest beneficiaries of improved all-year sustainable access to water. The selection targeted value chains that add to food and nutrition security, such as legumes, rice, fish and dairy, which play central roles in improving protein availability for households and tackling malnutrition.
- **Economic viability:** Given that agriculture accounts for 23% of Malawi's GDP and employs 77% of its labour force, the sector is a key driver of the economy. This study prioritised the selection of value chains that are economically feasible for smallholder farmers and with the highest potential to impact livelihoods. The selected value chains – olericulture, dairy, rice, legumes and aquaculture – all have potential for economic growth. In particular, legumes improve soil fertility with their nitrogen fixing properties whilst enhancing protein availability for smallholder farmers. The olericulture value chain sets itself apart for its ability to provide large revenues, allowing farmers to access profitable markets and broaden their revenue streams. The dairy sector is key to government initiatives targeting the commercialisation of agriculture. By integrating DRE solutions, such as biogas production from cow dung and dairy waste, smallholder farmers can increase their profitability while generating energy for on-farm processing of milk. This eases dependence on fossil fuel sources and also lessens production costs. Finally, choosing value chains according to their economic importance can enhance production, sustainability and resilience in Malawi's agricultural environment.

- **Climatic resilience:** Malawi is struggling with advancing climate variability, which presents major challenges to agricultural production across several value chains, including those selected for this study. The addition of DRE solutions offers an effective approach to boosting resilience against climate risks. For instance, solar energy can power irrigation systems that support rice farming and olericulture, guaranteeing reliable water supply even in dry seasons. This stability not only improves production, but also helps mitigate the negative effects of unpredictable weather patterns. In the aquaculture sector, solar-powered systems can increase fish farming sustainability by improving water quality and maintaining ideal growing conditions, eventually leading to higher yields and decreased dependence on fossil fuels. DRE solutions have the potential to reduce climate-related post-harvest losses. For example, high ambient temperature-related losses can be reduced by enhancing storage through cold chain solutions and enabling processing. DRE solutions can be instrumental in building climate-smart and resilient agri-food systems in Malawi. Considering the effects of climate change on agricultural output, the assessment centred on value chains that are more resilient to climate-related distress and where DRE solutions can strengthen adaptability and alleviate risks.
- **Empowerment of women and youth:** At about 60%, women and youth make up the majority of the labour force in the agricultural sector in Malawi. DRE solutions are key to promoting gender balance and equality. The mechanisation of the sector through DRE solutions reduces drudgery for women whilst attracting more youth and enhancing productivity per hectare. For example, the use of a solar thresher reduces the physical effort required and increases throughput whilst lowering breakages, resulting in higher quality rice for the market. Likewise, in the dairy sector, mechanised milking and processing can lead to higher production levels, eventually benefiting households and communities. By placing the emphasis on mechanisation coupled with DRE solutions, Malawi can empower women and youth, advance gender balance and promote inclusivity in the agricultural sector. This approach not only supports both economic independence and resilience for these demographics, but also contributes to improved agricultural productivity and sustainability across value chains. The selected value chains present prospects for the involvement and empowerment of women and youth, who make up a significant subdivision of the agricultural labour force in Malawi.

These criteria steered the selection procedure and ensured that the selected value chains align with national priorities while exploiting the potential impact of DRE solutions.

Table 1 Mapping of selected value chains

Value chain	Criteria				
	Government priorities	Food and nutrition security	Economic considerations	Climate considerations	Women and youth
Olericulture	●	●	●		●
Dairy	●	●	●		
Rice	●	●	●		●
Legumes	●	●	●	●	●
Aquaculture	●	●	●		●

Note: ● implies that the value chain meets the criterion.

2.4 Data collection and analysis

Data collection comprised both quantitative and qualitative methodologies to evaluate the following value chain aspects systematically:

- **Profitability of value chains:** Financial analysis was conducted to assess the profitability of each value chain, including cost compositions, revenue potential and investment needs.
- **Potential market size for DRE:** The assessment identified the potential market size for DRE within the value chains. The absolute market potential for DRE in agriculture was projected to be worth around USD 185 million in Malawi, covering equipment such as solar irrigation, biogas systems and solar-driven processing machinery. This inference was grounded on the magnitude of each value chain, possible energy demand, and the readiness or willingness of farmers to implement DRE solutions. The analysis was carried out using four scenarios linked to progressive uptake of DRE solutions. The baseline scenario is the business as usual with a 100% adoption rate and the largest market size of USD 185 million. The other three, more realistic, scenarios assume a 5% incremental increase in uptake from 5% to 10% and 15%. These scenarios are estimated to have market potential of USD 9.25 million, USD 18.5 million and USD 27.75 million respectively. These scenarios assume a growing business case for the DRE

solutions. As more systems are deployed, a reinforcing effect is triggered attracting more ecosystem players: more farmers demanding the solutions lead to reduced perception of risk, thus more access to finance to invest in DRE solutions at a lower cost of capital.

- **Productivity assessments:** Smallholder farmer-level data were collected on the harvest per hectare under the current energy use scenario (baseline, or business as usual) in order to establish the impact of integrating DRE solutions.
- **Post-harvest losses:** High post-harvest loss points in the value chain were assessed to identify key entry points for DRE solutions, for example, post-harvest losses experienced during storage of produce at markets and transport. Losses linked to poor processing methods due to a lack of energy also provide a strong basis for DRE solution integration.
- **Energy demand and usage:** The current energy use patterns were studied to understand smallholder farmers' willingness to pay, access to technology and reliance on fossil fuels to power the selected value chains.
- **Availability of equipment:** The assessment engaged renewable energy enterprises to scope the available solutions in the market and also appreciate their costs. This activity further aimed to identify the gaps in the available solutions and expose the enterprises to solutions available in other markets outside Malawi.
- **Access to funding:** Data were gathered from smallholder farmers and renewable energy enterprises on sources and accessible levels of funding and the cost. Financial institutions were engaged to collect information on available products for DRE solutions, interest rates, tenure and accessibility to smallholder farmers and enterprises.

This comprehensive data collection and analysis process delivered a vigorous evidence base to back the development of a programme targeted at stimulating the adoption of DRE across the selected value chains.

2.5 Data synthesis and validation

The collected date were analysed and processed to offer articulate insights that could be shared with stakeholders. This procedure included:

- **Synthesis of findings:** The collected data were collated into targeted key messages and recommendations for smallholder farmers, financial institutions, development partners, government, renewable energy enterprises and other key ecosystem players supporting smallholder farmers.
- **Stakeholder engagement:** The analysed findings were shared with key stakeholders to collect feedback and validate the insights. This action was important to establish that the assessment confirmed experiences on the ground and resounded with the experiences of farmers and other players in the agricultural value chains.
- **Validation workshop:** The validation workshop was held in Lilongwe in July 2024, bringing together stakeholders from several sectors, including government, civil society, entrepreneurs, the private sector and academia. During the validation workshop, participants systematically assessed the findings and action plans and reflected on methods to deploy DRE solutions within the value chains.

The validation workshop served as an instrument for shared dialogue, reassuring support and collective ownership of the assessment outcomes. The comments received in this workshop also refined the study's comprehensions and recommendations, making certain that they are in sync with the needs and ambitions of stakeholders.

This thorough approach allowed the assessment to successfully recognise prospects for integrating DRE solutions into the selected agricultural value chains in Malawi. The comprehensive approach followed in this study enabled an understanding of the key interventions needed to unleash the rich potential that DRE solutions have to offer smallholder farmers in Malawi.

3. Mapping energy needs with a value chain approach

Mapping energy needs for the integration of DRE solutions requires an understanding of the critical stages in agricultural value chains. This comprehensive approach identifies specific energy demands at each stage, permitting targeted interventions that improve production, efficiency and sustainability. The value chain procedure highlights energy requirements and also identifies blockages, market links and opportunities for value addition. By focusing on specific value chains – olericulture, legumes, aquaculture, dairy and rice – DRE interventions can be better adapted for maximum impact. The value chain approach allows interrogation of the key DRE solution intervention points, from production at smallholder farms to the markets where the produce is sold. This approach also provides detailed understanding of the current energy use patterns among smallholder farmers and identifies gaps in the uptake of DRE solutions and barriers to increasing their uptake. The value chain approach has strength in ensuring that the proposed DRE solutions are coupled to the relevant energy needs and are tailored to address the co-benefits of gender equality and youth empowerment, generating inclusive opportunities for economic involvement and technological innovation.

3.1 Key stages in agricultural value chains

Knowledge of the stages in each of the selected value chains enables the right DRE solutions to be mapped. Broadly, the stages in the selected value chains are:

- **Production:** This phase concerns planting, growing and caring for crops or livestock. The energy needs at this point frequently concern irrigation, mechanisation and inputs such as fertilisers. Solar-powered water pumps, wind-powered solutions for irrigation and other renewable energy-driven tools and machinery can raise productivity, lower input costs and guarantee consistent water supply, specifically in drought-prone areas.
- **Post-harvest handling:** After harvesting, produce requires cleaning, grading and initial processing to prepare it for storage or sale. This is a key phase where high post-harvest losses often occur due to a lack of energy access.
- **Processing:** Adding value to agricultural products via milling, drying, packaging or pasteurisation needs energy. DRE solutions such as solar-powered milling equipment or biogas systems for dairy pasteurisation can improve processing effectiveness, decrease operational costs and present sustainable energy alternatives to traditional fossil fuel resources. Notably, this phase is key in dairy, where pasteurisation and refrigeration are important for maintaining milk quality.
- **Storage:** Perishable goods, especially those in olericulture and dairy, need cold storage to avoid damage. Solar-powered cold storage solutions can perform a progressive role here, extending the shelf life of produce and lowering post-harvest losses, markedly in remote and rural areas where grid access is unpredictable. The dairy, aquaculture and olericulture chains require cold storage solutions as they yield highly perishable produce.
- **Marketing and distribution:** This last stage of the value chains includes moving the produce to markets and aggregation centres. To maintain product quality, cold chain solutions are an integral part of marketing and distribution.

3.2 Targeted DRE entry points to catalyse integration

The uptake of DRE solutions remains low in Malawi. Smallholder farmers often lack access to affordable finance. There are also awareness challenges regarding the DRE solutions that are available in the country. Analysis of the key DRE intervention points across the value chain provides a means to prioritise DRE adoption with a focus on high-impact points. These key points have the ability to trigger systemic adoption of DRE across the agri-food value chains, providing a foundation for long-term sustainable development in the sector. The potential addressable market for DRE is huge, starting from smallholder farmers through to produce aggregators and on to processors. A deliberate focus on key points has the potential to lower the entry barriers through demonstration of the utility and financial viability of DRE solutions. For example, financial solution providers are likely to develop products to support DRE solutions if they see a proven case for them at key intervention points. Likewise renewable energy enterprises are more inclined to import and produce solutions if the intended markets – smallholder farmers, aggregators, processers etc. – have access to finance to buy the equipment. A summary of the priority DRE intervention points across the selected value chains is provided in Table 2.

Table 2 Summary of the priority DRE technologies and price range

Agricultural value chain	Value chain stage	DRE solution	Indicative pricing per unit USD
Olericulture	**Production**	Solar-powered water pump	750-1500
	Processing and storage	Drying system	500-1000
		Solar refrigerator	750-1500
		Solar walk-in cooler	15 000-60 000
Diary	**Production**	Solar milking machine	750-1500
	Processing and storage	Solar refrigerator	750-1500
		Solar walk-in cooler	15 000-60 000
Rice	**Production**	Solar-powered water pump	750-1500
	Post-harvest handling	Solar dryer	500-1000
		Solar thresher	1000-2 000
	Processing and storage	Solar-powered milling	2 000-5 000
Legume	**Production**	Solar water pumping	750-1500
	Post-harvest handling	Solar dryer	500-1000
	Processing and storage	Solar milling	2 000-5 000
Aquaculture	**Production**	Solar water pumping	750-1500
		Solar aerators	500-1500
	Processing and storage	Solar refrigerator	750-1500

3.3 Olericulture value chain analysis

In this study, olericulture includes crops such as tomatoes, onions, leafy vegetables, fruits and spices. Each phase of the value chain offers opportunities for integrating DRE solutions, which can improve productivity, reduce losses and advance sustainability.

- **Production:** The production stage involves planting, growing and nurturing crops, with energy needs centred around irrigation. High-value horticultural crops like tomatoes and leafy vegetables are water-intensive and require frequent irrigation. Over the past five years there has been a significant increase in the use of solar-powered submersible water pumps, allowing farmers to reduce reliance on diesel. However, 20% of farmers still use diesel-powered pumps, with many expressing a willingness to transition to solar-powered pumps. About 50% of farmers surveyed for this study are willing to pay between USD 175 and USD 525 for these solar systems, while only 13% are prepared to spend more than USD 525.
- **Post-harvest handling:** This stage, relating to cleaning, grading and sorting, and basic processing, is energy-demanding, especially for drying produce. Lack of access to energy results in considerable losses. Solar-powered dryers present a viable solution, lowering moisture content in produce and extending shelf life. This is valuable, as horticultural produce is highly perishable.
- **Processing:** Value addition through activities such as drying, juicing and packaging is important for horticultural crops. Solar-powered milling and processing equipment reduces reliance on fossil fuels and cuts operational costs. DRE solutions such as small biogas systems can also provide power for processing units, making these activities more cost-effective and sustainable.
- **Storage:** The storage stage is vital for maintaining product freshness and minimising spoilage. For instance, 30% of farmers report losing over 40% of their crops during transport due to lack of cold storage facilities. Solar-powered cold storage facilities are key to extending the shelf life of perishable horticultural crops. In Malawi 33.3% of horticultural traders lack access to storage and are willing to pay for renewable energy solutions. For example, traders are willing to pay USD 1 per day for storing 1 to 3 bags of produce in energy-efficient storage systems. However, existing storage facilities are often inadequate, contributing to significant losses of up to 40% at major markets in Lilongwe and Blantyre.
- **Marketing and distribution:** Efficient transport and distribution are essential for maintaining the quality of perishable produce. Most of the energy in this stage is used to cool produce during transit, extending its shelf life.

However, due to inadequate access to cold chain logistics, 98% of traders experience spoilage at open markets, with 70% reporting losses of up to 10% and another 10% facing spoilage rates as high as 40%. Establishing solar-powered cold storage systems at distribution points offers a critical solution to reducing these losses and improving profitability.

This analysis highlights critical stages – particularly production, storage and transport – where DRE solutions can significantly reduce post-harvest losses and improve productivity. Prioritising **solar-powered water pumps, cold storage** and **drying systems** offers a path to sustainable and resilient olericulture value chains in Malawi.

3.4 Dairy value chain analysis

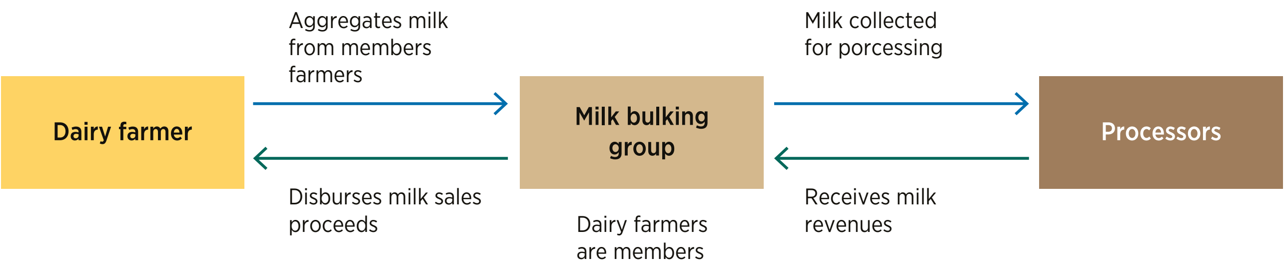
The dairy value chain in Malawi encompasses production, collection, processing, storage and distribution of milk and other dairy products. Integrating DRE solutions at critical stages can significantly improve productivity, reduce losses and promote sustainability. This is particularly important as dairy farming is energy-intensive due to high energy demands for milk storage, transport and value addition. The dairy sector is crucial for household income, especially in the Shire Highlands of Southern Malawi, with a notable untapped potential for pasteurised and processed milk. The following are the critical stages where DRE solutions can be integrated effectively:

- **Production:** Dairy farming at the production stage involves livestock management, feed preparation and ensuring optimal milk yields. Key energy needs include water pumps, lighting and equipment for preparing feed. At 52%, over half of dairy farmers in Malawi lack access to energy, which directly impacts their ability to store milk effectively before sending it to milk bulking groups (MBGs) for cooling (Box 1). Among those with energy access, 44% rely on the national grid, and 56% use solar home systems, though mostly for lighting rather than cooling. Solar-powered water pumps offer reliable water for livestock, particularly in off-grid areas. Additionally, solar lighting systems can extend work hours, aiding livestock care during early mornings and late evenings.
- **Post-harvest handling and milk aggregation:** Post-harvest handling of milk involves collecting raw milk, ensuring its quality, and aggregating it at MBGs. Due to milk's perishable nature, 45.5 litres of milk are lost per farmer monthly, representing 41% of total production and resulting in average losses of USD 24 per farmer per month. Solar-powered milk cooling units at aggregation centres can immediately chill milk, significantly reducing spoilage during transport. At these collection points, 93% of farmers expressed interest in investing in solar fridges, which could improve milk quality, lower transport needs and boost profits by up to 8%.
- **Processing:** The dairy processing phase, in which raw milk is converted into food products such as pasteurised milk, cheese, butter and yogurt, is dominated by a small group of commercial bulk milk processors, which include Katete Dairy Farm, Lilongwe Dairy, Suncrest, and Sable Farming. These large processors rely on MBGs for fresh milk supply, with the exception of Katete, which uses fresh milk directly produced from its dairy farms. Small and medium-sized dairy processing operations, such as Dwale Milk Bulking Group, MAFE Farms, Kombeza Dairy (a women-owned enterprise), and Mach Milk Company, use small milk processing units. These small-scale milk processors, while mainly being local and thus closer to smallholder farmers and MBGs, confront challenges in competing with the large processors because of limited access to reliable and affordable energy. DRE solutions such as solar-powered milk pasteurisers have the potential to enable small-scale processors to add value more effectively, reducing operational costs whilst supporting local dairy markets and smallholder farmers.
- **Storage:** Storage is an important consideration in the dairy value chain as fresh milk and dairy products need refrigeration to stay fresh and avoid spoilage. Cold storage, especially solar-powered systems, can lengthen the shelf life of milk, allowing farmers to store their produce longer and sell it at better market prices. Limited cold chain infrastructure remains a major issue, causing milk spoilage, mainly during rainy seasons when roads may be inaccessible and the resulting transport delays aggravate losses. Farmers, who in general lose 41% of their production due to ineffective pre-storage, stand to see major improvements with DRE-powered refrigeration solutions.
- **Marketing and distribution:** Maintaining the prime quality of dairy products throughout distribution requires a consistent cold chain. Solar-powered refrigeration units installed on transport vehicles can keep milk and other products fresh during distribution, lowering spoilage and ensuring high-quality products reach the market. This is particularly valuable for smallholder farmers in rural areas, who transport their milk to urban markets or processing centres. Solar-powered solutions can preserve the freshness of dairy products, creating opportunities for expanded market access and improved profitability for smallholder farmers.

Box 1 Milk bulking groups

MBGs for processing and storage: MBGs serve as central aggregation points for milk collection from smallholder farmers, providing a crucial link to dairy processors. Each MBG handles an average of 2 191 litres of milk daily during peak periods and 963 litres during off-peak periods, with the stored milk valued at USD 403 (MWK 698 583) during peak periods and USD 175 during off-peak periods. However, MBGs face significant challenges, including milk spoilage, due to frequent power outages. On average, 4 830 litres of milk are lost per month, amounting to USD 891 in losses. Furthermore, MBGs incur high electricity bills, averaging USD 173 monthly. While 80% of MBGs are connected to the national grid, power reliability is a major issue, leading to reliance on diesel generators, which increases operational costs. The implementation of solar-powered cooling tanks could significantly reduce these losses and operational expenses, improving overall profitability for farmers.

Figure 3 The role of MBGs



Malawi's dairy sector has the potential for considerable growth through the incorporation of DRE solutions. At present, the diffusion of DRE continues to be low. Measures such as the use of solar milking machines, **solar-powered milk coolers** at MBGs, **solar refrigeration** for storage at smallholder farmer level, and **biogas systems** for processing can trigger extensive adoption of DRE in the sector. By giving consideration to the key points and phases in the value chain, DRE technologies can lessen post-harvest losses, boost dairy product quality and increase profitability for smallholder farmers, while contributing to the long-term sustainability of the industry.

3.5 Rice value chain analysis

The rice value chain in Malawi comprises production, post-harvest handling, processing, storage and distribution. Undertaking these tasks requires a lot of energy. Embracing DRE solutions can significantly boost efficiency while cutting losses after harvesting and enhancing the sustainability of small-scale rice farming practices. Rice is key a crop for promoting integrative development in Malawi, with women participating in central roles in both production and marketing. Efficient energy use across the rice value chain is important for meeting domestic consumption needs and export targets.

- **Production:** The cultivation of rice in Malawi occurs during two main seasons: the rainy season, which utilises floodplains, and the winter season, which depends heavily on irrigation. Key agricultural operations for the sector include land preparation, irrigation, weeding, fertilisation and harvesting. Due to low levels of mechanisation, most tasks are performed manually, with irrigation being the most energy-intensive activity. Water for irrigation is usually pumped from reservoirs to fields using diesel, solar or hydroelectric-powered pumps. For example, the Lifuwu Irrigation Scheme, powered by the Electricity Supply Commission of Malawi (ESCOM), incurs high electricity costs, averaging USD 1 093 per month for only water pumping. Equally the Lifantchema Rice Co-operative has electricity bills that average about USD 73 per month, mainly for water pumping. DRE solutions can be an affordable substitute for grid-supplied electricity, which often has reliability issues. Despite their high upfront costs, DRE solutions are more reliable and provide farmers with energy independence, particularly when the sun's intensity is at its peak during the dry hot season when crop water needs are highest. Beyond water pumping, DRE solutions can increase productivity via farm mechanisation, with equipment such as solar-powered ploughs for tilling.
- **Post-harvest handling:** This phase of the rice value chain has activities that include drying, threshing or hulling, and storage. Drying in particular is a point of potentially high losses as farmers rely on traditional method of sun drying, which exposes their produce to contamination and weather risks that affect quality. Solar dryers are a

proven DRE solution that can efficiently dry rice in a hygienic environment, leading to high-quality products that can generate more income for smallholder farmers. Similarly, threshing is often done manually by striking the produce with sticks, which leads to high breakage levels that lower the value of the rice. Solar threshers offer a faster, labour-saving solution that has minimal breakage. Compared to hand threshing with sticks, machine-threshed grains are less likely to be damaged, which improves the quality of the rice and reduces post-harvest losses.

- **Processing:** Rice processing in Malawi comprises both large-scale and small-scale processors. Large-scale processors, including companies such as Mulli Brothers, Rab Processors, Agora Ltd, NASFAM and TransGlobe, are situated in urban centres such as Blantyre and Lilongwe, where they take advantage of access to the national electricity grid. In contrast, small-scale processors in remote rice-growing districts like Salima, Karonga, Nkhotakota and Chikwawa, often face challenges due to unreliable or limited grid connectivity. At the farm gate level, only 45.7% of farmers engage in value addition activities like polishing and packaging, largely due to energy limitations. Scaling up small-scale processing operations requires investment in expensive energy-demanding machinery. Mini-grids offer a prospective solution for powering such equipment, with the projected energy requirement for rice processing machines ranging from 37 kW to 40 kW. Addressing these energy access challenges is necessary to improve the productivity and output of small-scale processors. Including solar-powered rice mills and huskers in the sector's operations can help reduce operational costs and emissions whilst making processing more accessible, especially for off-grid areas. These DRE solutions can enhance profitability and create value addition opportunities for co-operatives and smallholder farmers.
- **Storage:** Appropriate storage is needed for rice because of its vulnerability to pests, moisture and spoilage, especially in Malawi's humid climate. Without access to appropriate storage, large quantities of rice are lost. Solar cold chain solutions offer a proven solution to control the temperature, minimising mould and pest growth in storage facilities and enhancing the shelf life of rice. These improved storage management methods enable the smallholder farmers to service the premium market that demands and pays well for quality rice.
- **Marketing and distribution:** Marketing and distribution involve moving the rice from smallholder farmers and food processors to markets and buyers. Temperature-controlled transport units are required to maintain the quality of rice during transport, reduce heat stress-related spoilage and ensuring the rice reaches the market in good condition. For export markets that demand higher product standards, maintaining a high quality is key. Solar-driven cold chain guarantees that rice remains in good condition throughout the distribution process, which is necessary for competing in regional and global markets.

The analysis of energy needs along the rice value chain shows that DRE solutions have the potential to meet energy demand at key intervention points along the whole value chain, at production, post-harvest handling, processing, marketing and distribution. These key points include **solar-powered irrigation systems** during production, **solar dryers and threshers** during post-harvest handling, and **solar-powered milling equipment** during processing. Integrating DRE solutions along the rice value chain has the potential to increase productivity, reduce post-harvest losses, raise the quality of rice delivered to market and increase the sector's profitability.

3.6 Legume value chain analysis

Legumes, such as soybeans and groundnuts, play a key role in adding to food security, raising nutrition levels and diversifying diets in Malawi. The value chain for these grain legumes includes several phases, from production to marketing, each requiring substantial energy inputs. With government efforts to annually increase the planted hectares of grain legumes, the sector is becoming progressively more energy-intensive, meaning that incorporating DRE solutions can speed up processes, decrease post-harvest losses and increase product quality.

- **Production:** The production stage for legumes includes planting, growing and crop management. This phase has considerable energy demands, principally related to irrigation, mechanisation and the use of agricultural inputs such as fertilisers. Using solar-powered water pumps and wind-powered irrigation systems can significantly boost efficacy, lower operational costs and ensure a reliable water supply, especially in regions susceptible to drought. This study showed that diesel-powered irrigation for rain-fed systems costs about USD 7.88 per hectare, using about five litres of diesel. Solar-powered water pumps offer a promising alternative, especially for farmers without reservoirs, as they can pump water effectively from sources such as rivers or wells, presenting sizable benefits for grain legume production. By tapping into renewable energy solutions, farmers can increase their production and resilience against climate variability.
- **Post-harvest handling:** Following the harvest, legumes require careful handling, including cleaning, sorting and preliminary processing, to prepare them for storage or sale. This stage also demands energy for drying and basic

processing activities. Using solar-powered dryers can successfully decrease the moisture content of soybeans and groundnuts, notably lowering post-harvest losses while increasing product quality. This phase is markedly important, as insufficient energy access often results in extensive waste, making it important to address energy needs effectively to preserve these valuable crops. Approximately 40% of farmers engage in value addition, primarily through drying and milling their produce. At the farmer organisation level, NASFAM stands out for its industrial-scale value addition, such as producing roasted peanuts. Small groups like Kasekese in Lilongwe also add value by processing soybeans into soymilk and yogurt, requiring energy for heating, cooling and machine operation.

- **Processing:** Processing is an important stage, with value addition to grain legumes by activities such as milling, drying and packaging. This step needs energy inputs, which can be improved through DRE solutions such as solar-powered milling equipment. Also, renewable energy systems can power effective processing methods, lowering operational costs and presenting sustainable substitutes to conventional fossil fuel sources. On the large or industrial scale, major processors such as Central Poultry, Rab Processors, Mount Meru, Seba Foods, Sunseed Oil Limited and Cori Limited produce numerous products from groundnuts and soybeans, such as cooking oils, peanut butter and animal feed. These processors are generally dependent on the national grid supplied by ESCOM to power their machinery and run operations. A striking case is JESCA Enterprise, a women-owned business in Lilongwe, which raised its peanut butter processing capacity but failed to use its new equipment due to inadequate grid power supply from ESCOM. This case reflects the challenges faced by small-scale processors in accessing connections to the grid. DRE presents solutions that can alleviate these challenges whilst also addressing power quality and reliability challenges that the grid presents.
- **Storage:** Legumes require appropriate storage to retain their quality and lengthen shelf-life. Solar-powered cold chain at aggregation centres can assist remote smallholder farmers store their produce prior to delivery to urban and export markets. Availability of storage can also allow the farmers to store their produce during times of oversupply when market prices are low.
- **Marketing and distribution:** This stage involves transporting the produce from farmers and aggregators to markets. Solar-powered cold chain solutions can help keep the produce fresh. These solutions also enable smallholder famers and aggregators to reach distant and export markets and achieve a good price. This enables farmers to deliver premium products that serve higher end markets, raising profitability.

Integration of DRE solutions across the various stages of the legume value chain, from production to marketing, has the potential to increase productivity, lower post-harvest losses and improve profitability by allowing premium products to be sold to both local and export markets. In the production stage, **solar-powered water pumps** are key to optimising irrigation and boosting yields. During the post-harvest handling stage, **solar drying** systems can provide substantial benefits by improving the preservation of legumes and reducing spoilage. At the processing stage, **solar milling** technology offers the greatest advantages, enhancing efficiency and lowering energy costs. **Solar cooling** technologies at the storage and marketing stages help minimise losses, ensuring better quality products reach the market. Leveraging DRE technologies across the legume sector not only strengthens economic resilience, but also contributes to sustainable agricultural practices, promoting food security and rural development in the long term.

3.7 Aquaculture value chain analysis

The aquaculture value chain in Malawi involves various phases, which include the production, harvesting, processing, storage and distribution of fresh fish. This substantially energy-intensive value chain performs a key role in providing food and income, serving as an important source of white animal protein and source of employment, particularly for women and youth. Recognising its importance, the government has integrated aquaculture into its strategic investment plans, such as the Aqua Mega Parks. The analysis highlights the energy demands associated with fish marketing, in both aquaculture and capture fisheries, particularly the need for refrigeration and preservation during trading. This report focuses on identifying energy requirements for processes where DRE solutions could be effectively utilised.

- **Production:** In the production phase, aquaculture involves managing and feeding fish stock, and ensuring ideal fish growing conditions. Energy needs include powering aeration systems, water pumps and feeding equipment. The majority of smallholder farmers use gravity-driven flow to fill up their fishponds. The use of solar water pumps can increase the availability of water and also allow farmers to pump water from deep wells, rivers and other sources. Farmers can also increase the amount of oxygen in their ponds by using solar aerators. These solutions directly increase the viability and productivity of fish farming.

- **Harvesting and post-harvest handling:** This stage involves preparing the fish for market and is often associated with high post-harvest losses and deterioration of quality. Once harvested, fish is highly perishable and demands hygienic conditions. DRE solutions such solar-powered washing systems can ensure that high standards of hygiene are maintained. The use of DRE-powered cold chain and ice-making solutions to temporarily store harvested fish can help preserve freshness and reduce post-harvest losses.
- **Processing and storage:** During processing, raw fish is transformed into value-added products such as fillets, nuggets, smoked fish and fishmeal. Value addition offers farmers and processors higher profitability than selling raw fish. However, as identified in focus group discussions, appropriate cold-chain chilled processing facilities are necessary to preserve quality. Cold rooms can be constructed in market areas or by co-operatives – farmer organisations comprising groups of fish farmers who conduct business together. This collective approach enables individual farmers to access extension services, credit and inputs at affordable prices due to bulk procurement and bargaining for better prices for their produce. At the individual farmer level, the majority indicated a preference for solar-powered technologies to support cooling or drying. Other forms of fish processing include open sun drying, smoking, deep frying, parboiling, solar tent drying, and salting and brining. However, open sun drying – a common method in Malawi – is fraught with fish contamination issues, posing health risks to consumers. Other methods like smoking, deep frying and parboiling often rely on firewood, contributing to deforestation and environmental degradation. Thus, fish processing provides a strategic entry point for DRE solutions in Malawi's fish value chain. These DRE solutions can be integrated with other sustainable drying methods, such as solar tent drying, parboiling and electric smoking kilns, which are safer to use.
- **Distribution:** Maldeco distributes fish via refrigerated vans to chain stores like Food Lovers, Shoprite and Chipiku, and through prequalified sales agents in major cities. In comparison, small-scale traders buy fish from those with small boats and sell to households and restaurants, transporting the fish in cooler boxes on bicycles, motorcycles and minibuses. This stresses the urgent need for DRE solutions in fish distribution networks. Focus group discussions showed that nearly all fish in Malawi is sold either fresh or processed by sun drying or parboiling, with nominal value addition, such as filleting or canning, due to low production volumes and small fish sizes.

High-priority interventions, such as **solar-powered cold storage** at processing facilities and fish bulking centres, offer strategic entry points to steer the extensive implementation of DRE in aquaculture. Key impact technologies include **solar-powered pumps**, which improve water circulation and oxygen levels in fishponds; **solar-powered aerators**, important for maintaining fish health; and solar-powered cold storage, which conserves harvested fish and reduces spoilage. Also, biogas systems turn organic waste from fish farms into energy, powering equipment or heating systems, while solar heating provides a renewable source for temperature control. As DRE dissemination in Malawi's aquaculture sector remains low, targeted interventions can reveal substantial gains in production, decrease post-harvest losses and improve profitability across the value chain. By concentrating efforts on critical stages with the highest potential for impact, DRE technologies can change aquaculture into a more sustainable, resilient and economically viable industry.

Photo: Riccardo Mayer @ shutterstock.com

4. Estimated value chain market potential

4.1 Introduction

The integration of DRE solutions across Malawi's smallholder farmer value chains presents a significant opportunity to enhance productivity, reduce post-harvest losses and improve economic resilience. This chapter estimates the market potential across the five assessed value chains: olericulture, dairy, rice, legumes and aquaculture. Despite been unique, the value chains face similar challenges and most DRE solutions are transferrable across the value chains. Targeting interventions at key intervention points has the potential to catalyse broad uptake of DRE solutions in the agri-food sector in Malawi. Chapter 3 presented the key stages at which DRE solutions can be integrated for each of the value chains. For example in olericulture, solar water pumping and cooling can increase productivity and storage respectively. In the dairy sector, solar-powered milk coolers have the potential to drastically reduce milk loss and enhance profitability for both smallholder farmers and processors. Likewise, solar-powered irrigation and processing technologies in the rice and legume sectors can increase productivity and lower energy costs, while solar-powered cold storage systems in aquaculture can maintain fish quality and rise marketability. By assessing the market potential for these technologies, this chapter delivers a roadmap for ramping up DRE implementation in Malawi's agricultural sector, driving long-term sustainability, economic resilience and improved livelihoods for smallholder farmers.

Data on the number of farmers involved in each value chain are currently absent, so the figures used here are estimations drawn from several sources, which include government strategies and donor programmes. Malawi's smallholder farmers comprise about 3.1 million farming families who jointly manage 6.5 million hectares, around 69% of the country's total 9.4 million hectares assigned for agriculture under customary land tenure. With an average farm size of about 0.7 hectares, nearly 60% of smallholder farmers farm less than one hectare (CCARDESA, 2024). Notably, these farmers are not a homogeneous group, as many participate in multiple value chains, indicating potential duplication of equipment needs. Suitable business models are thus needed to fully realise the market potential. For example, renting equipment might be a more viable option for smallholders than individual ownership, as it minimises operational and maintenance costs. Consequently, this market potential estimate presented serves as a high-level calculation to guide policy and business decisions. Accurate system sizing tailored to individual farmers' needs will be required for more precise figures.

4.2 Methodology

The market potential for DRE solutions in the value chains is informed by farmers' willingness to pay, as determined through the assessment. This willingness to pay establishes the Baseline Scenario, which indicates the proportion of the total number of farmers within each value chain that are likely to adopt DRE solutions. Building on this foundation, we have developed three additional scenarios that reflect not the willingness to pay (as reflected in the Baseline Scenario), but the ability of farmers to pay for DRE solutions. The Low Penetration Scenario (LPS, 5%) assumes that 5% of the baseline population will implement DRE solutions, representing a cautious level of uptake. The Moderate Penetration Scenario (MPS, 10%) is built on a 10% implementation rate, indicating rising interest in DRE solutions. Lastly, the High Penetration Scenario (HPS, 15%) is centred on a substantial level of implementation, where 15% of the baseline population implements DRE solutions, in so doing highlighting large market potential. These scenarios enable market size estimations by multiplying the unit price of DRE solutions by the total population in each value chain and the baseline willingness to pay, with adjustments made for each penetration level.

4.3 DRE market potential in the olericulture value chain

The olericulture value chain in Malawi exhibits substantial prospects for DRE technologies to improve production, lower losses and expand market access for smallholder farmers. Fundamental DRE solutions assessed include solar refrigerators, solar water pumping systems, walk-in coolers and solar dryers. Solar refrigerators, costing about USD 1 000 each, are key to providing cold storage to reduce post-harvest losses and preserve the quality of perishable horticultural products at smallholder farmer level. With a projected 50% of the target population (10 000 people) willing to pay, the baseline market potential for solar refrigerators is rated at USD 5 000 000. On the basis of ability to pay, this potential could reach an estimated USD 750 000 in the HPS (15%) (Table 3).

Solar water pumping systems, with a mean cost of USD 750, allow efficient irrigation, which is necessary for guaranteeing a steady water supply and improving crop yields. Assuming 60% willingness to pay among the target group, the baseline market potential for solar water pumps stands at USD 4 500 000, possibly exploitable up to USD 675 000 under the HPS (15%). Walk-in coolers, while notably higher in cost at USD 40 000, offer large-scale cold storage solutions appropriate for co-operatives or central hubs. With 100% of the target population of six entities (central hubs) willing to pay, the baseline market potential for walk-in coolers is USD 240 000, with projected market potential value of USD 36 000 under the HPS. Solar dryers, averaging USD 500, help preserve produce quality by reducing moisture, increasing marketability and shelf life. With a 50% willingness to pay among 10 000 potential users, the baseline market for solar dryers is USD 2 500 000, with a potential of up to USD 375 000 in the HPS.

In total, these DRE solutions offer a baseline market potential of about USD 12 240 000 for the olericulture value chain. Based on the assumed scenarios, and thus the ability to pay, this could range from USD 612 000 in the LPS (5%) to USD 1 836 000 in the HPS (15%), demonstrating the substantial demand and economic opportunity for DRE adoption in Malawi's horticultural sector

Table 3 Estimated market potential – olericulture value chain

DRE technology	Average cost USD	Population	Willingness to pay – baseline %	Market potential USD			
				Baseline	LPS 5	MPS 10	HPS 15
Solar refrigerators	1 000	10 000 *	50	5 000 000	250 000	500 000	750 000
Solar water pumping	750	10 000	60	4 500 000	225 000	450 000	675 000
Walk-in coolers	40 000	6	100	240 000	12 000	24 000	36 000
Solar dryers	500	10 000	50	2 500 000	125 000	250 000	375 000
				12 240 000	612 000	1 224 000	1 836 000

* The Horticultural Cooperative Union in Malawi has approximately 10 000 members. However, the total number of horticulture farmers in the country is estimated to be between 1 million and 1.5 million smallholder horticulture farmers. This figure suggests that the total number of horticulture farmers is significantly higher than the membership of the union, indicating a broader network of farmers engaged in horticultural activities beyond those formally associated with the organisation.

4.4 DRE market potential in the dairy value chain

The dairy value chain in Malawi also demonstrates encouraging market potential for DRE solutions to power milk preservation, cooling and processing. The essential DRE solutions recognised for this sector consist of solar refrigerators, walk-in milk coolers and solar-powered milking solutions. Solar refrigerators, costed at around USD 1 000 per unit, perform the purpose of cooling and storing dairy products to reduce spoilage at farm gate level. With a target population of 11 832 smallholder farmers and a high willingness to pay of 93%, the baseline market potential for solar refrigerators is projected at USD 11 003 760. In the LPS (5%), this potential is valued at USD 550 188, building up to USD 1 100 376 and USD 1 650 564 in the MPS (10%) and HPS (15%), respectively (Table 4).

Walk-in milk coolers, with an average cost of USD 40 000, are suitable for bulking storage solutions, mostly at MBGs. For this technology, 50% of the population (150 MBGs) are inclined to invest, establishing a baseline market potential of USD 3 000 000. Reflecting ability to pay, this value can range between USD 150 000 in the LPS and USD 450 000 in the HPS. Solar-powered milking systems, which cost around USD 1 000 each, provide an effective solution for smallholder dairy farmers to increase milk production and quality. With a 75% willingness to pay within the same population of 11 832 potential users, the baseline market potential for solar milking systems is projected at USD 8 874 000. This estimated amount scales from USD 443 700 in the LPS to USD 1 331 100 in the HPS.

In total, the dairy value chain has a baseline market potential of about USD 22 877 760 for these DRE technologies. This market potential ranges between USD 1 143 888 in the LPS and USD 3 431 664 in the HPS, demonstrating the significant demand and economic prospects for DRE solutions in Malawi's dairy sector.

Table 4 Estimated market potential – dairy value chain

DRE technology	Average cost USD	Population	Willingness to pay – baseline%	Market potential USD			
				Baseline	LPS 5	MPS 10	HPS 15
Solar refrigerators	1000	11832	93	11003760	550188	1100376	1650564
Walk-in milk coolers	40000	150	50	3000000	150000	300000	450000
Solar milking	1000	11832	75	8874000	443700	887400	1331100
				22877760	1143888	2287776	3431664

4.5 DRE market potential in the rice value chain

The rice value chain in Malawi presents a considerable market potential for DRE technologies, particularly in supporting key energy needs such as water pumping, drying, threshing and milling. Solar water pumping solutions, which are fundamental for irrigation, are costed at about USD 1000 per unit. With a target population of 10000 smallholder farmers and a 40% willingness to pay, the baseline market potential for solar water pumps is USD 4000000. On the basis of ability to pay, in the LPS this figure stands at USD 200000, scaling up to USD 400000 in the MPS and USD 600000 in the HPS (Table 5).

Smallholder farmers can reduce post-harvest losses by drying their rice crops using solar dryers, which have the dual benefit of being efficient and hygienic compared to open sun drying. About 30% of the surveyed farmers indicated a willingness to pay for solar dryers, which are marketed at USD 500 per unit. Under the Baseline Scenario this is equivalent to a potential market of USD 500000. Regarding the penetration scenarios ranging from 5% to 15%, the addressable market ranges from USD 75000 to USD 225000, respectively. With regards to solar threshers, costed at USD 2000 per unit, 65% of the farmers have indicated that they would be willing to invest. This represents a higher market baseline value of USD 13000000 and penetration scenario values ranging from USD 65000 to USD 1950000. For milling machines the willingness to invest was 45% at USD 3000 per unit. This presents a baseline market potential of USD 13500000. This potential adjusts to USD 675000 in the LPS and USD 2025000 in the HPS, reflecting the ability to pay.

In total, the rice value chain confirms a solid baseline market potential of USD 32000000 for these DRE solutions. Dependent on the market penetration scenario, this potential varies from USD 1600000 in the LPS to USD 4800000 in the HPS, representing a substantial demand for renewable energy technologies to enhance rice production and processing in Malawi.

Table 5 Estimated market potential – rice value chain

DRE technology	Average cost USD	Population	Willingness to pay – baseline %	Market potential USD			
				Baseline	LPS 5	MPS 10	HPS 15
Solar water pumping	1000	10 000	40	4 000 000	200 000	400 000	600 000
Solar dryers	500	10 000	30	1 500 000	75 000	150 000	225 000
Solar threshers	2 000	10 000	65	13 000 000	650 000	1 300 000	1 950 000
Solar milling	3 000	10 000	45	13 500 000	675 000	1 350 000	2 025 000

4.6 DRE market potential in the legume value chain

The market for DRE solutions in the legume value chain exhibits sizable prospects. Key technologies assessed for this chain include solar water pumping, solar dryers and walk-in coolers. Solar water pumping has an estimated cost of USD 1 000 and focuses on 103 367 smallholder farmers with a baseline motivation to pay of 60%, leading to a total market potential of about USD 62 020 200. This splits down to USD 3 101 010 for the LPS, USD 6 202 020 for the MPS and USD 9 303 030 for the HPS, each of these reflecting an ability to pay rather than a willingness to pay. Solar dryers, cited as costing USD 500 each and aimed at the same population with a lower willingness to pay of 40%, have a market potential of USD 20 673 400, with USD 1 033 670 (LPS), USD 2 067 340 (MPS), and USD 3 101 010 (HPS), respectively. Walk-in coolers, valued at USD 40 000, are practical for only six units but have a 100% willingness to pay, commanding a total market potential of USD 240 000, with USD 12 000 (LPS), USD 24 000 (MPS) and USD 36 000 (HPS), respectively (Table 6).

In total, the aggregate market potential for these DRE technologies in the legume value chain is assessed at around USD 82 933 600, split into USD 4 146 680 (LPS), USD 8 293 360 (MPS), and USD 12 440 040 (HPS), respectively. This analysis highlights the material prospect to boost production and sustainability in the legume sector through targeted DRE investments.

Table 6 Estimated market potential – legumes value chain

DRE technology	Average cost USD	Population	Willingness to pay – baseline %	Market potential USD			
				Baseline	LPS 5	MPS 10	HPS 15
Solar water pumping	1000	103 367	60	62 020 200	3 101 010	6 202 020	9 303 030
Solar dryers	500	103 367	40	20 673 400	1 033 670	2 067 340	3 101 010
Walk-in coolers	40 000	6	100	240 000	12 000	24 000	36 000
				82 933 600	4 146 680	8 293 360	12 440 040

4.7 DRE market potential in the aquaculture value chain

The market potential for incorporating DRE solutions in the aquaculture value chain is substantial, driven by different technologies. Solar refrigerators, with a typical cost of USD 1 000, can serve 15 465 smallholder farmers, displaying a high baseline willingness to pay of 80%. This results in a total market potential of about USD 12 372 000, which converts to USD 618 600 in the LPS, USD 1 237 200 in the MPS and USD 1 855 800 in the HPS (Table 7), reflecting three different levels of ability to pay.

Walk-in coolers, valued at USD 40 000 each and relevant to only nine units, show a 100% willingness to pay, pointing to a market potential of USD 360 000, with USD 18 000 (LPS), USD 36 000 (MPS), and USD 54 000 (HPS), respectively. Solar water pumps, costing USD 750 each and also aimed at the same farmer group with a 75% willingness to pay, have an estimated market potential of USD 8 699 063, broken down into USD 434 953 (LPS), USD 869 906 (MPS), and USD 1 304 859 (HPS), respectively. In addition, solar aerators, estimated equally to solar refrigerators at USD 1 000, assist the same population with an 80% willingness to pay, resulting in market potential of USD 12 372 000, which mirrors the refrigerator scenario in terms of penetration estimates.

Collectively, the aggregate market potential for these DRE technologies in aquaculture is assessed at USD 33 803 063, with possible revenue of USD 1 690 153 (LPS), USD 3 380 306 (MPS), and USD 5 070 459 (HPS), respectively. This analysis stresses the sizable opportunities for advancing production and sustainability in the aquaculture sector through targeted DRE investments.

Table 7 Estimated market potential – aquaculture value chain

DRE technology	Average cost USD	Population	Willingness to pay – baseline %	Market potential USD			
				Baseline	LPS 5	MPS 10	HPS 15
Solar refrigerators	1 000	15 465	80	12 372 000	618 600	1 237 200	1 855 800
Walk-in coolers	40 000	9	100	360 000	18 000	36 000	54 000
Solar water pumps	750	15 465	75	8 699 063	434 953	869 906	1 304 859
Solar aerators	1 000	15 465	80	12 372 000	618 600	1 237 200	1 855 800
				33 803 063	1 690 153	3 380 306	5 070 459

Table 8 Summary of market potential

	Baseline USD	LPS 5 USD	MPS 10 USD	HPS 15 USD
Olericulture	12 240 000	612 000	1 224 000	1 836 000
Dairy	22 877 760	1 143 888	2 287 776	3 431 664
Rice	32 000 000	1 600 000	3 200 000	4 800 000
Legumes	82 933 600	4 146 680	8 293 360	12 440 040
Aquaculture	33 803 063	1 690 153	3 380 306	5 070 459
Estimated market size	183 854 423	9 192 721	18 385 442	27 578 163

In conclusion, the market potential for adding DRE solutions within the five value chains – olericulture, dairy, rice, legumes and aquaculture – reveals major openings for increasing production and sustainability. The combined baseline market size across all the five value chains is estimated at USD 183 854 423, with adjustable potential revenue centred on distinct penetration scenarios (Table 8). For the low penetration scenario (LPS), the added market potential is around USD 9 192 721, while the moderate penetration scenario (MPS) improves this sum to about USD 18 385 442. In a high penetration scenario (HPS), the total market potential increases to a probable USD 27 578 163.

Each assessed value chain offers unique opportunities, with legumes having the highest baseline market potential at USD 82 933 600, driven by the high population of smallholder farmers in the sector and their high willingness to pay, followed by rice and dairy at USD 32 000 000 and USD 22 877 760, respectively. Olericulture and aquaculture also show reassuring market potential, with baseline makings of USD 12 240 000 and USD 33 803 063, respectively. These outcomes stress the key role that DRE technologies can play in meeting energy needs, advancing efficiency and cutting post-harvest losses within several agricultural sectors. By deliberately investing in these technologies, stakeholders can accelerate a more sustainable and productive agricultural environment, eventually adding to nutrition, food security and economic growth. The figures presented above stress the potential to accelerate the integration of DRE solutions in agriculture and food value chains in Malawi. These envisioned catalytic investments are projected to unlock an extensively larger total market potential, allowing the widespread implementation of DRE solutions. The impact of this is expected to reach across the five assessed value chains and beyond, pushing transformational benefits for the country's agricultural sector and related industries.

5. Recommendations

To accelerate the adoption of DRE solutions across Malawi's agricultural value chains, the following targeted recommendations are provided for each stakeholder group with specific actionable examples.

A. Government and policy makers

- **Implement tax incentives and subsidies:** Implementing incentives and subsidies targeting DRE solutions used in the agri-food sector should lower cost prices and make the solutions more affordable and accessible to smallholder farmers. Renewable energy enterprises would import more DRE solutions were demand to increase.
- **Develop a national agricultural DRE programme:** Setting up policy instruments with targets for the deployment of DRE solutions would demonstrate government commitment to supporting smallholder farmers. This may have the positive impact of lowering risk and attracting investment in the sector.
- **Set up a green finance facility:** Limited access to affordable financial solutions is among the biggest deterrents to wider adoption of DRE solutions. Th government may consider partnering with local and development banks to establish facilities that offer finance to farmers at affordable interest rates. The government may even go further by guaranteeing the loans taken by smallholders to access DRE solutions.
- **Expand DRE training for extension officers:** Equipping agricultural extension workers with knowledge of DRE solutions would enable them to support smallholder farmers better and also raise awareness of solutions available for their integration at the various stages of value chains.
- **Enhance interministerial co-ordination:** Scaling up the deployment of DRE solutions will require co-ordination across several government ministries: ministries of energy, agriculture, trade, finance and environment. This can be achieved by establishing an interministerial task force. Such a task force would also help optimise resource allocation and co-ordinate development partner activities aimed at the deployment of DRE solutions.

B. Development partners and donors

- **Pilot DRE demonstration projects in key value chains:** Smallholder farmers and at times renewable energy enterprises are not aware of the DRE solutions available for the value chains. Establishing demonstration projects has the effect of raising awareness and subsequently demand. Exposure to viable DRE solutions may entice financial services providers to develop financial products targeting DRE and smallholder farmers.
- **Provide capacity building for farmers and co-operatives:** This would raise awareness of and demonstrate a business case for DRE solutions. Rising demand for DRE solutions may trigger the provision of both technology and financial solutions from services providers. Co-operatives and smallholder farmers could also benefit from basic knowledge on the operation and maintenance of DRE solutions to enhance the reliability of the solutions and reduce downtime.
- **Fund research on energy needs by value chain:** There is need for evidence-based information on the positive effect of DRE solutions across the various value chains. Development partners and government could support studies that further reveal priority areas for DRE dissemination across the major value chains. Such research could support financial product development for small institutions who often lack the capacity and financial resources to develop tailored-made products.
- **Align donor projects with national policy:** There is a need for co-ordination of donor-funded projects to ensure efficient resource allocation. Close co-ordination with relevant government ministries would ensure that there is less duplication of donor efforts across the farming sector. Donor projects should be implemented in a manner that aligns with national goals, for example co-ordinating projects that contribute to Malawi's National Energy Policy target of increased rural electrification and agricultural productivity.

C. Financial institutions

- **Develop DRE-specific loan products for farmers:** Financial institutions should develop innovative products that offer affordable finance to smallholder farmers. These financial products may involve aspects of asset-based financing, reduced interest rates and also appropriate tenure that aligns with farming seasons.
- **Promote pay-as-you-go (PAYG) financing for solar equipment:** PAYG systems have the potential to make DRE solutions more affordable and accessible to smallholder farmers since they lower the upfront cost of procuring the solutions and also enable gradual payment.
- **Introduce risk-sharing mechanisms with donors:** Local financial institutions my enter into partnerships with larger regional development banks to set up credit guarantees for DRE loans, reducing risk for banks.

D. DRE technology providers and suppliers

- **Design affordable, durable equipment for local use:** Local DRE solution providers should be encouraged to develop appropriate local DRE solutions to reduce reliance on expensive imports. Appropriate local solutions are not only cheaper, but may also be easier to maintain and operate, enhancing accessibility and reliability.
- **Establish local service centres for after-sales support:** DRE solution providers tend to be concentrated in the big cities. There is a need to open maintenance and service hubs in more remote locations to provide after-sales support, particularly in established agricultural districts.
- **Implement co-operative leasing models:** Renewable energy enterprises could offer DRE solutions to farmers through leasing models that use co-operatives. Despite the willingness of farmers to buy DRE solutions, it may be more viable to have centralised equipment for hire at co-operatives that the farmers can access at times of need. This avoids the locking in of capital in equipment that may not be used throughout the year.
- **Run awareness campaigns on DRE benefits:** There is need to raise awareness of the DRE solutions that are available. Renewable energy enterprises can set up demonstration facilities and organise field days at which they expose farmers to available solutions in action.

E. Agricultural co-operatives and farmer groups

- **Establish shared DRE facilities for members:** Co-operatives and similar groups could establish shared DRE solution centres to increase accessibility for their members. Shared cold storage facilities at aggregation centres and co-operatives would service more members whilst reducing the cost per individual farmer. Shared infrastructure also avoids duplication of solutions across the value chain. Not every farmer needs to own a thresher or a cold room if the services are accessible at co-operatives, freeing up capital for other uses. The facilities could also serve as maintenance and repair hubs in remote districts.
- **Implement bulk purchasing of DRE solutions:** Co-operatives can be instrumental in aggregating demand and negotiating discounts and favourable purchase agreements, reducing individual purchase prices for their members. Demand aggregation can also enable co-operatives to collaborate with financial institutions in structuring affordable finance solutions.
- **Peer learning and demonstration programmes:** Co-operatives could organise peer-to-peer capacity-building sessions where members who have successfully integrated DRE solutions into their operations share their experiences.

F. Research institutions and academia

- **Conduct field studies to quantify DRE benefits:** Research institutes should support the adoption of DRE solutions with evidence-based research that demonstrates the benefits for smallholder farmers and other value chain actors. There is need for further information on the effects of DRE solutions on productivity and loss reduction in Malawi.
- **Develop cost-effective DRE innovations for agriculture:** There is a need for appropriate DRE solutions that optimally fit the context of Malawi. Such context-tailored solutions, when produced locally, are likely to be more affordable and accessible.
- **Offer technical training in DRE to students:** Academic institutes could collaborate with renewable energy enterprises and co-operatives to offer capacity-building programmes on the operation and maintenance of DRE solutions. This would bridge the skills and support gaps in agricultural districts that are far from major cities.

Scaling up the adoption of DRE solutions in Malawi's agri-food value chain requires multi-stakeholder efforts. The implementation of the above recommendations would potentially support wider access to DRE solutions, helping increase productivity and reducing post-harvest losses and reliance on fossil fuels. while contributing to a more sustainable and resilient agricultural economy.

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