IRENA
International Renewable Energy Agency

Decentralised renewable energy for agriculture in Zimbabwe

ISBN: 978-92-9260-624-4

Citation: IRENA (2025), *Decentralised renewable energy for agriculture in Zimbabwe*, International Renewable Energy Agency, Abu Dhabi.

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Acknowledgements

This report was developed under the guidance of Gürbüz Gönül (Director, IRENA Country Engagement and Partnerships) and Kavita Rai, and authored by Wilson Matekenya (IRENA) and Velenjani Lupankwa (consultant [published posthumously]).

The report benefited from reviews and comments by Babucarr Bittaye, Kamran Siddiqui, Ntsebo Sephelane and Paul Komor (IRENA), and Stephanie Pinnington (consultant). The report also benefited from reviews by Rejoice Lunga (SNV [Foundation of Netherlands Volunteers] Zimbabwe), Daniel Maregedze (Silo Food Industries Ltd) and Courage Taka (Black Puck Water Ltd).

Publication and editorial support were provided by Francis Field and Stephanie Clarke. The report was edited by Justin French-Brooks, with design by Elkanodata.

This report was made possible by the voluntary contributions of the Government of the United Arab Emirates and the Open Society Foundations.

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Abbreviations

AC	alternating current
AENF	Agro-Energy National Facility
ARDA	Agricultural and Rural Development Authority
DC	direct current
DRE	distributed renewable energy
GDP	gross domestic product
ha	hectare
hp	horsepower
IRENA	International Renewable Energy Agency
kg	kilogram
kW	kilowatt
kWh	kilowatt hour
m	metre
MLAFWRD	Ministry of Lands, Agriculture, Fisheries, Water and Rural Development
mm	millimetre
MOEPD	Ministry of Energy and Power Development
MW	megawatt
m^3	cubic metre
PUE	productive use of energy
PV	photovoltaic
R&D	research and development
VBU	Village Business Unit
ZERA	Zimbabwe Energy Regulatory Authority

Executive summary

Agriculture is a critical sector in Zimbabwe, accounting for between 11% and 14% of the country's gross domestic product (GDP) (MOFAIT, 2023). The sector employs 53% of the workforce and supports the livelihoods and food security of 70% of the population (FAO, 2022). Additionally, the agricultural sector is responsible for more than half of total female employment in the country (WFP, 2022). Smallholder agricultural operations, typically managed by a single family or individuals, produce 70% of staple foods (maize, millet and groundnuts) (FAO, 2024a). However, most of these farmers have no access to electricity, with only 12% connected to the grid (ZIMSTAT, 2022). Without energy security, rural communities are increasingly vulnerable to global shocks, climate change and rising fuel prices, severely restricting their economic opportunities. Poor access to electricity leaves millions of people unable to lift themselves out of extreme poverty, which affected 44% of the population in 2022 (Climate Justice Central, 2023). Women and girls are disproportionately impacted by the lack of electricity, with this energy poverty having a greater negative effect on their health, education, time use and access to information. Improving energy access for smallholder farmers has the potential to significantly enhance their productivity, yields and opportunity for value addition, ultimately boosting their incomes. Reliable electricity can also facilitate the adoption of farming equipment, reducing the need for manual labour and freeing up time for other essential social and economic activities. This is particularly beneficial for women, who often bear much of the manual labour.

In light of these challenges and opportunities, the government of Zimbabwe, represented by the Ministry of Lands, Agriculture, Fisheries, Water and Rural Development (MLAFWRD) and the Ministry of Energy and Power Development (MOEPD), in collaboration with the International Renewable Energy Agency (IRENA), initiated this assessment to analyse the potential, and possible entry points, for the use of decentralised renewable energy (DRE) solutions in five agricultural value chains: maize, groundnuts, tomatoes, mangoes and fisheries. These value chains were chosen based on criteria that include their potential impact on economic development, poverty alleviation, food security, and climate adaptation and resilience, as well as their relevance to gender and youth empowerment.

Data were collected "from farm to fork", comprising cultivation, growing and harvesting, post-harvest transport, marketing and distribution, and finally heating and cooking. Surveys were conducted across the three provinces of Mashonaland, a region of northeastern Zimbabwe, which account for approximately half of the country's rural households. The survey targeted 460 individual farmers and 50 farmer members of five farmer groups.

The findings identify critical energy gaps, such as limited access to water pumps, cold storage and post-harvest processing equipment. For example, the lack of access to irrigation pumps was identified by 75% of farmers as the biggest limitation on productivity. Additionally, 75% of farmers lack proper storage facilities, leading to significant post-harvest losses, particularly during the hot season, with some losses reaching as high as 50%. Addressing these issues through solar-powered irrigation, refrigeration and drying solutions could substantially increase productivity and reduce post-harvest losses. The potential addressable market for these commercially ready DRE solutions is estimated at USD 7.1 billion for solar-powered irrigation kits, targeting an upper scenario of 2 million hectares as per government plans. Additionally, there is a potential market of USD 128 million for solar-powered refrigeration and cold storage facilities with a capacity of 1.8 million tonnes per annum, and USD 13 million for solar dryers with a drying capacity of 0.25 million tonnes per annum. The economics of the DRE solutions are positive, with payback periods between one year and six years. In addition, renewable energy-powered water pumps and irrigation systems can increase yields by at least 30% and solar cold storage facilities can reduce post-harvest losses by at least 50% of current levels.

However, significant barriers remain, including high costs, limited access to financing and a lack of awareness about DRE solutions. To fully realise the benefits, a concerted effort is needed to develop accessible business models, expand financing options and strengthen distribution networks, particularly in rural areas.

Recommendations

Multi-stakeholder engagement platforms: Establish or strengthen multi-stakeholder platforms or working groups to facilitate efficient engagement between government entities and ministries, development partners, the private sector, academia and financial institutions who are aligned and focused on the energy transition and adoption of agricultural production technology. These platforms are to be co-ordinated by joint team leaders from MOEPD and MLAFWRD.

National energy policies: Use policy design and promotion to maximise the adoption and impact of DRE solutions. Establish a lead team for developing DRE supportive policies and incorporating them into new and ongoing national agriculture and energy sector goals and plans.

DRE awareness: Implement nationwide awareness campaigns to inform potential users in agricultural value chains about available DRE solutions, coupled with the benefits of productive use of energy (PUE) in agriculture. Engage farmer-led groups, associations, the private sector, the public sector and agricultural development partner programmes.

Business models: Promote renewable energy-driven business models in agricultural value chains, with a focus on DRE solution deployment, ensuring capacity building is available for implementation. The models should increase business viability, adoption and customer confidence as well as improve diversity, equality and inclusivity. This recommendation includes establishment of community-based financing initiatives for farmers and Village Business Units (Appendix A), such as joint ventures and aggregation models with large-scale offtakers.

Financing mechanisms for DRE: Establish customised and dedicated financing mechanisms including value chain finance, contract farming, equipment and agricultural inputs finance, risk management and mitigation measures, climate-indexed insurance products, guarantees, subsidies, grants and tax incentives. The following are proposed mechanisms for specific value chain actors:

- **DRE enterprises** – Implement risk mitigation structures, such as dedicated guarantees, to support early-stage DRE enterprises. These financing mechanisms should facilitate the bulk importation of quality-compliant equipment, enabling discounts and savings through economies of scale, ultimately making these technologies more affordable for hard-to-reach communities.
- **Smallholder farmers** – The government and its development partners can establish guarantee schemes. These de-risking mechanisms help smallholder farmers overcome collateral requirements for working capital, equipment credit facilities and loans, thereby encouraging uptake.
- **Local financial institutions** – Develop and promote financial networks that connect DRE enterprises and financial institutions with smallholder markets, particularly in rural and hard-to-reach areas with growth potential.

Capacity building: Invest in capacity-building programmes to improve technical skills and raise awareness among stakeholders and potential value chain actors.

Customer education and quality assurance: Promote consumer education on quality assurance. Implementation of voluntary quality standard frameworks could increase the quality of DRE solutions. The design and installation of technologies requires monitoring and evaluation. As the local DRE market matures, it will be necessary to establish mandated quality standard frameworks.

Diversity, equality and inclusivity: Design and implement policies, regulations and programmes that support marginalised groups to access DRE solutions.

Research and development (R&D): Increase access to funding for R&D of near-to-market and emerging technologies. Additionally, establishing a funded database for the DRE market is essential to map industry needs, track developments and facilitate knowledge sharing.

Implementation roadmap

- **Short term (2024-2025)** – Carry out feasibility studies and pilot projects, and develop policy and regulatory frameworks. Additionally, establish suitable business models, public–private partnerships and financing mechanisms.
- **Medium term (2025-2027)** – Scale up pilot projects and implement large-scale, high-impact DRE solutions for smallholder farmers. Focus on developing local manufacturing capacity for DRE technologies, expanding early warning systems and climate information services, and progressing towards achieving Vision 2030's goal of renewable energy access for agriculture.
- **Long term (2030-2040)** – Develop climate-resilient agricultural practices and water management strategies, and establish a strong insurance market to address climate-related losses.

1. Country context

Zimbabwe is a landlocked country located in southern Africa with a population of 15.1 million (ZIMSTAT, 2022). It is a member of the Southern African Development Community (SADC). With a total land area of over 39 million hectares, 41.9% is designated for agricultural purposes (FAO, 2024b). While agriculture accounts for about 11-14% of Zimbabwe's gross domestic product (GDP), the sector also supports the livelihoods and food security of 70% of the population and supplies 60% of the raw materials required by the manufacturing sector (ZIMFA, 2024).

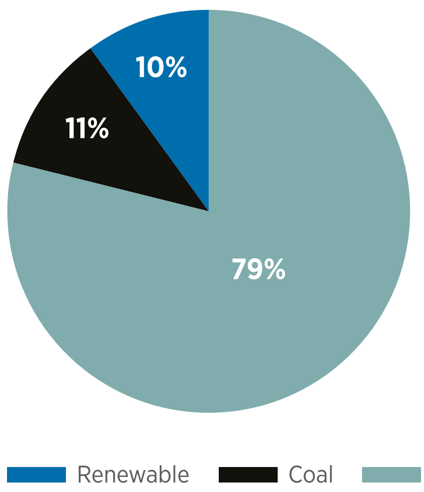
Zimbabwe has established Vision 2030, a strategy that aims to achieve upper middle income country status by 2030 (Republic of Zimbabwe, 2018). The goal of Vision 2030 is also to develop a self-sufficient and food surplus economy that will reposition Zimbabwe as southern Africa's "bread basket". The Vision also prioritises optimal electricity generation from both renewable and non-renewable sources by increasing installed generation capacity, as well as developing new power plants in order to reach 95% urban and 75% rural electrification rates (Tagwireyi *et al.*, 2023).

1.1 Energy sector overview

The country's power supply depends primarily on two main sources: the Kariba Dam hydropower facility, with a capacity of about 1 050 megawatts (MW), and the Hwange thermal coal power plant, which recently increased its capacity by 600 MW (AFRODAD, 2022). Climate challenges have reduced hydropower output from Kariba in recent years. To address this gap, efforts are underway to source renewable energy from independent power producers, with over 2 000 MW of licences already submitted for approval (ZERA, 2024). Biomass accounted for 93% of renewable energy supply in 2020 and hydro 6%.

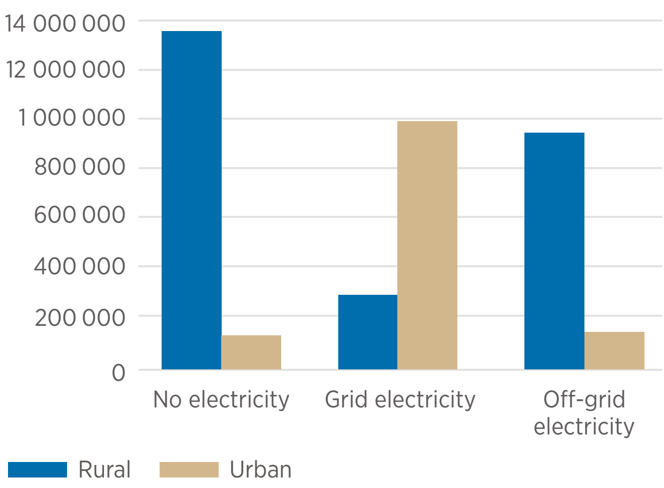
Energy consumption trends differ by sector according to economic activity, population composition in urban and rural settlements and national economic policy initiatives. Statistics on agricultural sector energy consumption are limited, but it is estimated that 84% of rural households, predominantly smallholder farmers, lack electricity (SEforAll, 2023). Only 12% of rural households are connected to the grid, while 93% continue to rely mainly on firewood and fossil fuels for cooking (Amuakwa-Mensah and Surry, 2022).

Figure 1 Zimbabwe total energy supply (2020)



Source: (IRENA, 2023).

Figure 2 Distribution of households by source of electricity in Zimbabwe



Source: (ZIMSTAT, 2022).

Energy policy and regulatory frameworks

Zimbabwe has formulated comprehensive policy and regulatory frameworks to assist energy development (Table 1). These policies also promote rural electrification while also encouraging private sector engagement in renewable energy projects. The National Renewable Energy Policy (NREP) provides strategic guidance and incentives to encourage renewable energy investment, technology deployment and market development. Furthermore, regulatory authorities such as the Zimbabwe Energy Regulatory Authority (ZERA) monitor the licensing, permitting and compliance requirements of renewable energy projects, ensuring openness, accountability and quality assurance in the industry.

Table 1 Overview of energy policies and regulations in Zimbabwe

Year	Policy/Law/Regulation	Description
1998	Water Act of 1998 (Chapter 20:24, No. 31 of 1998)	Regulates the development and utilisation of water resources within Zimbabwe, such as for inland dams with potential for hydropower generation in addition to their primary purpose of irrigation and urban water supply.
2002	Rural Electrification Fund Act (Chapter 13:20, No. 3 of 2002)	Establishes the Rural Electrification Fund (REF) to facilitate the rapid and equitable electrification of rural areas using grid and off-grid technologies.
2002	Environmental Management Act (Chapter 20:27, No. 13 of 2002)	Provides for the sustainable management of natural resources and protection of the environment in accordance with global commitments.
2010	Electricity Act (Chapter 13:19)	Has the objective to establish and maintain efficient industry and market structures for electricity services, optimise resource utilisation, and maximise consumer access to electricity in both rural and urban areas. It aims to ensure a reliable, secure and high-quality electricity supply, while promoting fair and balanced regulation for licensees, consumers, investors and stakeholders in the electricity sector.
	Statutory Instrument (SI 147)	Exempts solar equipment, except batteries, from paying excise duty.
2012	National Energy Policy (NEP)	Provides a framework for the exploitation, distribution and utilisation of the country's energy resources including renewables and outlines the principal strategies for implementing policy.
2011	Energy Regulatory Authority Act (Chapter 13:23, No. 3 of 2011)	Establishes ZERA and defines the regulatory framework for the procurement, production, transport, transmission, distribution, importation and exportation of energy derived from any energy source.
2013	Electricity Licensing Guidelines and Requirements	Provides simple guidelines on the licence application process, including the required documentation. It applies to systems above 100 kW.
2013	Zimbabwe Grid Code	Establishes the basic rules, procedures, requirements and standards that govern the operation, maintenance and development of the electricity distribution systems in Zimbabwe to ensure the safe, reliable and efficient operation of the electricity distribution system.
2015	Statutory Instrument (SI 55)	Electricity (Licensing) (Amendment) Regulations, 2015.
2016	Zimbabwe Climate Policy	Creates a pathway towards a climate-resilient and low-carbon development economy in which the people have enough adaptive capacity to develop in harmony with the environment. The policy is expected to mainstream climate issues in all sectors of the economy, including energy, agriculture, industrial processes, waste, land use, land cover and forestry.
2019	National Renewable Energy Policy	Promotes the development and utilisation of renewable energy resources in Zimbabwe. Provides guidance on the implementation of renewable energy projects, including incentives for investment, regulatory frameworks and capacity building initiatives.
2020	Biofuels Policy	Promotes the production and use of biofuels as alternative sources of energy. The policy aims to enhance energy security, reduce dependence on fossil fuels, and support rural development through the cultivation of biofuel feedstocks such as jatropha, sugarcane and sorghum.

1.2 Agricultural sector overview

In Zimbabwe agriculture plays a pivotal role in the economy, with approximately 45% of the country's exports comprising agricultural products. The sector contributes significantly to the country's foreign exchange earnings, food security and employment. For example, the sector employs 59% of the total female workforce (World Bank, 2024).

Zimbabwe is divided into five agro-ecological zones, primarily based on rainfall patterns: Region I receives more than 1 000 millimetres (mm) annually, Region II receives between 750 mm and 1 000 mm, and Region III receives between 650 mm and 800 mm per year. Regions IV and V are characterised by annual rainfall of 450-650 mm, severe dry spells during the rainy season, and frequent seasonal droughts.

The Ministry of Lands, Agriculture, Fisheries, Water and Rural Development (MLAFWRD) monitors and assesses key agricultural commodities produced by smallholder farmers (Table 2 and Table 3). These farmers engage in diverse agricultural activities, including cultivation of horticultural crops and animal husbandry. Often, smallholder farmers are involved in multiple value chains simultaneously.

The reliance on agricultural exports exposes the economy to external shocks, such as climate change impacts like droughts and erratic rainfall patterns. The smallholder sector, which produces the majority of staple foods (maize, millet and groundnuts), is particularly vulnerable, being almost entirely dependent on rain-fed agriculture. Nationwide, only approximately 220 000 hectares are covered by 460 functional irrigation schemes (MLAFWRD, 2020). To boost productivity, the government aims to expand irrigated land to 450 000 hectares by 2025, with plans to increase this to 2 million hectares in the following years (Ndlovu *et al.*, 2020; UNDP, 2024).

The smallholder sector faces other inherent challenges, including a shortage of inputs, low levels of mechanisation, limited energy access, restricted market access, high post-harvest losses, and poorly structured financing options, such as high interest rates and short-term loans.

Photo: Lorem Ipsum @ shutterstock.com

Table 2 Food crop production in Zimbabwe

		2021/2022			2022/2023			
	COMMODITY	Area (ha)	Overall yield (t/ha)	Production (t)	Area (ha)	Overall yield (t/ha)	Production (t)	
1	Maize	1 900 754	0.76	1 453 031	1 966 177	1.17	2 298 281	FOOD & OIL CROPS
2	Groundnuts	294 918	0.33	98 765	335 840	0.64	214 145	
3	Sorghum	321 216	0.45	144 633	319 789	0.60	191 125	
4	Pearl millet	163 138	0.27	44 143	188 856	0.38	71 221	
5	Sunflowers	31 502	0.35	11 117	146 821	0.62	90 479	
6	Soya beans	51 488	1.59	82 028	55 944	1.66	93 086	
7	Sugar beans	46 531	0.67	31 274	43 568	0.58	25 388	
8	Sesame	18 422	0.29	5 427	37 489	0.62	23 176	
9	Sweet potato	41 082	6.84	276 784	26 306	7.89	207 529	
10	Irish potato	23 241	23.00	534 543	23 982	25.00	599 550	
11	Rice	1 093	0.49	539	2 108	0.26	539	
12	Cabbage	10 479	45.00	471 555	12 654	48.00	607 392	ANNUAL HORTICULTURE CROPS
13	Tomato	10 430	27.00	281 610	11 210	30.00	336 300	
14	Onion	8 825	25.00	220 625	10 764	27.00	290 628	
15	Leafy vegetables	6 934	28.00	194 152	8 732	30.00	261 960	
16	Butternut squash	3 621	15.00	54 315	4 891	20.00	97 820	
17	Carrot	2 637	22.00	58 014	3 274	23.00	75 302	
18	Watermelon	1 941	36.00	69 876	2 152	43.00	92 536	
19	Cucumber	1 256	15.00	18 840	1 873	17.00	31 841	
20	Pepper	1,376	8.00	11 008	1 698	10.00	16 980	
21	Okra	791	5.00	3 955	843	6.00	5 058	
22	Pineapples	689	14.00	9 646	738	15.00	11 070	
23	Peas	568	7.00	3 976	472	6.00	2 832	
24	Tea	5 951	4.20	24 994	5 662	4.00	22 648	PERENNIAL HORTICULTURE CROPS
25	Coffee	681	1.00	681	685	1.00	685	
26	Orange	4 124	41.00	169 084	4 174	43.00	179 482	
27	Lemon	1 691	40.00	67 640	1 706	42.00	71 652	
28	Banana	7 921	38.00	300 998	8 042	39.00	313 638	
29	Apples	214	22.00	4 708	217	28.00	6 076	
30	Peaches and nectarines	347	25.00	8 675	351	27.00	9 477	
31	Macadamia	9 720	5.00	48 600	9 804	5.00	49 020	
32	Avocado	2 294	42.00	96 348	2 304	45.00	103 680	
33	Mango	4 957	26.00	128 882	4 964	29.00	143 956	
34	Sugar cane	74 684	81.00	6 049 404	79 722	82.00	6 537 204	
35	Blueberry	570	6.00	3 420	643	9.00	5 787	
36	Pecan nut	748	0.50	374	762	0.70	533	

Note: ha = hectare; t = tonnes.
Source: (MLAFWRD, 2023).

Table 3 Livestock production in Zimbabwe

	LIVESTOCK	2021	2022
1	**Broiler day old chick production** (million units)	91.6	113.9
2	**Broiler meat production** (tonnes)	143 500	191 813
3	**Cattle population** (head)	5 509 983	5 642 400
4	**Milk production** (litres)	79 607 573	91 396 061
5	**Dairy population** (head)	47 845	53 250
6	**Goat population** (head)	4 344 146	4 865 444
7	**Sheep population** (head)	720 226	728 245
8	**Pig production** (head)	314 335	339 664
9	**Fish production from capture** (tonnes)	9 552	9 836
10	**Fish production from aquaculture** (tonnes)	5 901	5 049

Source: (MLAFWRD, 2023).

Photo: www.gettyimages.com

Photo: www.gettyimages.com

2. Methodology and approach

The assessment methodology followed a structured approach, beginning with a literature review to gather background information and provide context. Relevant value chains within the agricultural sector were selected for focus, targeting smallholder farming regions and based on recommendations from the Zimbabwean government.

Stakeholder engagements were then conducted to identify key lessons, opportunities and barriers in the agriculture and energy landscape. Data were collected through fieldwork, interviews and surveys, and were analysed to identify trends, challenges and opportunities for integrating DRE solutions at critical intervention points.

The DRE market size was then estimated and modelled under various scenarios to develop a viable investment case. Finally, the findings were compiled into a detailed report, which was shared with stakeholders for input and validated to guide decision-making and future programmatic development strategies.

2.1 Value chain selection

The agricultural value chain selection (Table 4) was based on four key criteria: economic considerations, food security considerations, gender and youth considerations, and climate adaptation and resilience considerations.

- **Economic considerations:** Priority was given to value chains with high economic potential, contributing significantly to GDP, employment and local livelihoods. DRE solutions were evaluated for their ability to reduce costs, boost productivity and increase market competitiveness. For example, for the maize value chain, current production stands at only 1.39 tonnes per hectare (FAO, 2024b). Neighbouring countries report significantly higher maize yields, with Zambia averaging around 3 tonnes per hectare and South Africa achieving about 6 tonnes per hectare. With over 3 million farmers involved in maize farming, it is crucial to evaluate how DRE solutions can enhance productivity (Fusillier *et al.*, 2021).
- **Food security considerations:** The assessment prioritised value chains critical to national and local food security. Staple grains like maize, along with protein-rich crops such as groundnuts and soybeans, are essential for both human consumption and livestock systems. Zimbabwe's average annual per-capita cereal consumption is about 110 kilograms (kg) (United States Department of Agriculture, 2021), with grains processed into mealie meal, the staple for the national dish, sadza/isitshwala.
- **Gender and youth considerations:** Emphasis was placed on value chains that engage women and youth, with the goal of enhancing gender equality and youth employment. In Zimbabwe 53% of the population is female (World Bank, 2024), with 61.4% living in rural areas (UNICEF, 2022). Youth make up 67.7% of the country's population. These two demographic groupings have a substantial impact on national performance in a variety of, if not all, economic areas. However, they continue to face numerous limitations and bear the weight of social and economic exclusion and vulnerability, as seen by high unemployment – the youth unemployment rate is 35% (UNICEF, 2022) – and a lack of opportunities (ActionAid, 2022).
- **Climate adaptation and resilience considerations:** Value chains vulnerable to climate impacts were prioritised for renewable energy integration to enhance climate resilience, improve water and energy efficiency, and support sustainable farming practices.

Table 4 Summary of value chains selected

	Value chain	Proxy	Economic considerations	Food security considerations	Climate adaptation and resilience	Gender and youth
1	Cereals	**Maize**	•	•	•	•
2	Oil crops	**Groundnuts**	•	•	•	•
3	Horticulture	**Tomatoes**	•	•	•	•
4	Horticulture	**Mangoes**	•		•	•
5	Livestock	**Fisheries**	•			•

3. Data collection highlights

During the course of data collection 460 individual farmer respondents and 50 members from five farmer groups were interviewed. However, due to the diverse range of farming activities within each household, the questionnaire was tailored to address respondents from each specific value chain.

Farmers assessed	Maize	Groundnuts	Tomatoes	Mangoes	Fish
Number of respondents involved in value chain	448	136	235	40	65

Gender

- 69.13% of the respondents were male.
- 73.91% of the respondents were the head of the household.
- Despite Zimbabwe's census showing more women than men, household agricultural activities remain predominantly male-controlled, reflecting the country's patriarchal marital structure. Among the respondents, 94% were married, aligning with this trend.
- Average household monthly income was USD 60 per month, with a standard deviation of USD 65.44 caused by the high variability of household incomes.
- Household size was about 5.51 on average and on this income, most of the households have members relying on other seasonal jobs.

Agricultural activities

- 98.48% of the interviewed farmers are involved in cropping, with 81.3% in livestock and about 76% in horticulture.

Employment

- Households employed an average of four people for agriculture, with most being family members supplemented by occasional hiring of externals. The employment gender ratio is generally 1:1.

Water access

- 76.6% of the farmers source their water from rivers and are involved in riverside farming during the year, with wells and boreholes used by about 50%. Water transport to agricultural activities is highly dependent on buckets.
- 96.52% of farmers lack access to water pumps or irrigation equipment, primarily due to affordability, energy limitations and limited availability. The few operational pumps use diesel, grid electricity, petrol or solar energy.
- Water access is identified by 75% of respondents as the most critical factor for agricultural success. This limitation has been a significant contributor to poor yields and productivity.

Cold chain

- 95.65% of the farmers do not have access to refrigeration or cold chain infrastructure, with 79.10% of the respondents citing upfront affordability limitations and lack of reliable energy supplies. The existing refrigeration equipment is mostly at growth points[1] and shopping centres using grid electricity and solar power in 1.52% and 1.30% of the respondents.
- 78.91% of the farmers are keen to have access to cold chain facilities.

Drying and shelling equipment

- 97.82% of the respondents do not have access to drying and shelling equipment, and a similar number of interviewees are eager to acquire this technology. The few machines in use rely on electricity either from the grid, diesel-powered generators, or solar PV.
- More than 80% of the vegetable and fruit farmers require more advanced drying equipment. They currently rely solely on low-technology sun drying methods.

1 *A growth point is a designated rural service centre intended to develop into a town or urban area over time.*

Grinding mill

- 98.04% of the assessed farmers do not own their own grinding mills. Instead, most smallholder farmers rely on community mills located at growth points and shopping centres.
- 79% of the respondents' utilise diesel-powered grinding mills.

Current energy uses

- 96.74% of farmers use firewood for heating and cooking, while only 12% have access to renewable energy technology. Firewood use is regulated and discouraged by wildlife authorities, and grid electricity is unreliable due to frequent infrastructure breakdowns.
- 76% of respondents cite heating and lighting as their main energy needs.
- Due to unreliable energy sources, nearly 100% of respondents reported their production is being limited by this constraint. Additionally, 95% of farmers are unaware of the cost of the energy they consume.
- More than 75% of the assessed smallholder farmers do not have appropriate and adequate storage for products before sale.
- These respondents cited significant post-harvest losses due to a lack of appropriate storage facilities for their produce. Losses due to a lack of appropriate storage is more than 10% for crops.
- 70% of the participants mentioned that the losses can be as high as 50% during the hot season.
- Renewable energy enterprises have a very limited presence in rural areas, and farmers are often discouraged by inferior technology from those that do serve rural areas.

Market linkages

- Respondents reported receiving low prices from middlemen due to limited access to efficient markets and inadequate storage and distribution technology. Fish farmers, often organised in community groups, face additional challenges from restricted access to water, aeration equipment and cold storage.
- Many farmers avoid horticulture because of the high perishability of the produce, which presents additional risks without adequate storage and market access.

Access to finance

- There is minimal or no presence of commercial banks and other financial institutions in the assessed areas, leading most farmers to rely on costly capital from lending groups and microfinance institutions.
- Financing costs are high, with microfinance interest rates reaching 10-15% per month, and commercial bank rates at 15% per annum.
- Financing requires collateral, evidence of credit history, and the associated administrative costs, including loan establishment and arrangement fees, which can total up to 7%, making access to debt finance highly prohibitive.
- The majority of farmers express a need for government support in areas such as financing, inputs, technology and training.

4. Mapping energy use patterns along agri-food value chains to identify renewable energy solutions

This section maps the energy needs and usage patterns across the stages of five key agri-food value chains, from production to processing, transport and distribution. These value chains are maize, groundnuts, tomatoes, mangoes and aquaculture. By analysing the energy requirements at each stage, suitable DRE technologies and solutions are identified to enhance efficiency, productivity and sustainability.

4.1 Maize value chain energy needs and renewable energy solutions

Maize is the most widely produced cereal crop in Zimbabwe, grown across all provinces. In 2022/23 approximately 2 million hectares were planted, yielding a total of 2.3 million tonnes, with an average yield of 1.39 tonnes per hectare (FAO, 2023). Figure 3 provides an overview of the value chain activities and energy needs related to maize.

Access to water: This is the most critical and challenging resource in the value chain. Many farmers report yields of less than one tonne per hectare, largely due to poor and unpredictable rainfall patterns that adversely affect yields. False starts to the rainy season or excessive rainfall often disrupt planting schedules.

- **Solar water pumps and irrigation systems:** Water access challenges highlight the need for solar-powered pumps and irrigation systems in maize cultivation. The field study observed that a 1.25 horsepower (hp) solar pump can irrigate one to two hectares, increasing productivity by 114% compared to rain-fed farming. Solar pump kits, starting at USD 300, remain inaccessible to many farmers due to limited availability and financial constraints, with a 1-hectare kit costing around USD 4 500. The USD 300 kit is a smaller, basic solar pump system designed for small-scale or household irrigation, typically suitable for areas smaller than one hectare. In contrast, the USD 4 500 kit is a larger, more powerful system capable of supporting a full one-hectare farm, with higher capacity pumps and additional components for efficient irrigation. The higher cost reflects the system's scale and ability to meet the needs of larger agricultural operations.
- **Wind-powered water pumps:** Wind-powered water pumps are available for use, drawing water from rivers and boreholes. A typical pump with capacity to draw about 20 000-30 000 litres per day was observed to cost about USD 1 500. This technology is available in the country, but manufacturers still require more R&D for optimisation and maturity.

Figure 3 Energy needs at every stage of the maize value chain and the renewable energy solutions

Cultivation	Energy is required for land preparation, water pumping, irrigation and mechanical planting.	Solar-powered irrigation systems, solar water pumps and other solar-powered machinery can be used to meet energy needs during cultivation.
Harvesting	Energy is also needed for harvesting, threshing and transporting maize.	Solar-powered harvesting equipment, biomass briquettes for fuel, and electric vehicles for transport can be utilised.
Post-harvest handling	Drying, cleaning and storage of maize require energy.	Solar dryers, biomass dryers and improved storage facilities with passive ventilation can be deployed.
Processing and value addition	Milling, grinding and processing and value addition activities such as packaging, labelling and branding require energy.	Solar-powered milling machines, biomass boilers for steam generation, and biogas digesters for heat and electricity can be used.
Transport and distribution	Energy is needed for transporting maize products to markets or processing facilities.	Electric vehicles, solar-powered refrigeration units for transport, and biomass-based fuels for vehicles can be utilised.
Cooking and consumption	Cooking and processing maize-based food products for consumption requires energy.	Solar cookers, biogas stoves and improved biomass cooking stoves can be used for cooking purposes.

Harvesting: Smallholder farmers generally harvest maize manually. Existing options for efficient and cost-effective maize harvesting are diesel-powered combine harvesters and tractors. In some cases, the government provides equipment to assist with harvesting. Electric farm implements are not widely available and are also expensive in Zimbabwe, particularly for smallholder farmers. A 40 hp electric-powered tractor costs more than USD 75 000 from overseas manufacturers (Monarch, 2024), compared with a 90 hp diesel-powered tractor, which costs just over USD 24 000 and can be delivered within Zimbabwe.

Post-harvest handling: Farmers manually transport harvested maize using wheelbarrows and animal-drawn carts, occasionally hiring mechanised transport. The maize is sun-dried and shelled manually, primarily by women and youth. Inadequate moisture control, excessive handling and poor storage facilities contribute to significant post-harvest losses, estimated at 20-30% in the maize value chain.

- **Solar-powered maize dryers:** Investment in solar dryers could benefit maize yields through moisture management. In addition to their use for maize, these solar dryers can also be used for drying groundnuts, fruits and vegetables. A 0.4 cubic metre (m^3) dryer costs approximately USD 1 400 in the local market. Moisture testers can be used and charged using solar PV panels. Each tester is about USD 50 and requires a small PV panel for charging, which costs approximately USD 50.
- **Solar-powered maize shellers:** Electric maize shelling machines are available in Zimbabwe, powered by a single- or three-phase electrical supply. Smallholder farmers can purchase a locally built 1.5 tonne per hour sheller that runs on 1.5 kW of single-phase alternating current (AC) for about USD 300. This can be powered by solar PV and a direct current (DC) inverter for around USD 1 500. Additionally, shellers can be used as shared community infrastructure to provide services to multiple farmers.

Processing and value addition: Maize is generally sold to the Grain Marketing Board at a price that is periodically set by the government. Maize marketing regulations are frequently adjusted as maize is considered a strategic commodity for national food security. Additionally, when the government provides inputs for maize production through various schemes, farmers are required to repay their obligations with the harvested maize. Value-added activities in the maize value chain include mealie meal and maize-based snacks, such as maputi and corn puffs. The processing of maize to mealie meal is an important step in the value chain.

- **Solar-powered grinding mill:** The majority of grinding mills in rural areas are diesel-powered and located at growth points or small shopping centres, with farmers paying around USD 1 per 20 kg bucket for grinding services. Some millers are exploring alternative energy options, such as solar and micro-hydro, but the cost for a 20 hp solar-powered grinding machine is about USD 40 000. Solar-powered micro mills, capable of processing 55 kg per hour, are available for small communities but lack the efficiency needed for commercial-scale operations. Further research is needed to develop reliable, cost-effective systems.

Transport and distribution: High initial investment costs for vehicles lead to most farmers hiring transport. There are currently no affordable electric grain transport vehicles in Zimbabwe, with a brand-new electric passenger vehicle costing at least USD 48 000. E-mobility solutions are not yet accessible to the agricultural sector.

Cooking and heating: Rural farmers primarily rely on firewood for cooking and heating, which has a significant negative environmental impact. The introduction of clean-cooking technology is expected to improve household living standards, particularly for women, who are typically responsible for collecting firewood and cooking. Adopting clean-cooking technologies will not only save time, boosting women's productivity, but also have a substantial positive impact on environmental conservation.

- **Biogas digesters:** Digesters are a growing energy solution for cooking and heating in rural areas, with the potential to enhance the livelihoods of most households. A 12 m^3 system for individual residences or shared facilities costs around USD 1 200 and would require low-cost, flexible financing to encourage farmers to transition from the usage of firewood. Blended finance with grant components, rather than pure loan financing, has the potential to make this technology successful in Zimbabwe.

Conclusion: Based on the above entry points, the priority DRE solutions for the maize value chain are solar water pumps and irrigation systems, solar-powered maize shellers, solar dryers, and solar-powered and hydro-powered grinding mills.

4.2 Groundnut value chain energy needs and renewable energy solutions

Approximately 36% of smallholder farmers cultivate groundnuts, primarily relying on rainfall and, in some cases, river water and wells for irrigation. Groundnuts are grown across all five ecological regions, predominantly by women, and serve as a crucial income source for households. Farmers sell groundnuts in various forms, including fresh, unshelled, dried, roasted snacks, and peanut butter. With over 1.5 million smallholder groundnut growers, groundnuts are the second-largest crop by area after maize, often cultivated alongside it (Mango *et al.*, 2023). This versatile crop plays a significant role in both food security and household economies. The groundnut value chain is illustrated in Figure 4.

Figure 4 Energy needs at every stage of the groundnut value chain and the renewable energy solutions

Cultivation	Energy is required for land preparation, water pumping, irrigation and mechanical planting.	Solar-powered irrigation systems, solar water pumps and other solar-powered machinery can be used to meet energy needs during cultivation.
Harvesting	Energy is needed for harvesting, threshing and transport of groundnuts.	Solar-powered harvesting equipment, electric threshers and electric vehicles for transport can be used.
Post-harvest handling	Drying, cleaning and storage of groundnuts require energy.	Solar dryers, biomass dryers and improved storage facilities with passive ventilation can be deployed.
Processing and value addition	Processing groundnuts into oil or other products requires energy. Value addition activities such as roasting, grinding and packaging require energy.	Solar-powered oil presses, biomass boilers for steam generation and biogas digestion for heat can be used. Solar andbiomass-powered roasters and electric grinders can be employed.
Transport and distribution	Energy is needed for transport of groundnut products to markets or processing facilities.	Electric vehicles, solar-powered refrigeration units for transport and biomass-based fuels for vehicles can be utilised.
Cooking and consumption	Cooking groundnut-based food products such as peanut butter and oils for consumption requires energy.	Solar cookers, biogas stoves and improved biomass cooking stoves can be used for cooking purposes.

Despite its importance to the local agro-processing industry, groundnut productivity remains quite low, with yields ranging from 0.33 to 0.64 tonnes per hectare, compared to possible yields of three to four tonnes per hectare (Mofya-Mukuka, 2013; Katema, 2017). This is a result of inconsistent rainfall, low-quality seed varieties typically sourced from prior harvests, poor market structures, and lack of irrigation infrastructure, among other reasons. Although the country has a thriving groundnut processing industry, it relies heavily on imports due to inconsistent quality and supply challenges.

Water access: Reliable water supply is key for smallholder groundnut production.

- **Solar water pumps and irrigation systems:** Water access options for groundnut cultivation are similar to those used for maize.

Harvest and post-harvest handling: Groundnuts are typically harvested manually and then sun-dried in the open for several days, much like the drying process for maize. After drying, groundnuts are either stored in their shells or manually shelled. Storage typically takes place in farm rooms for added protection, or in granaries.

- **Solar-powered groundnut dryers:** Similar to maize, solar dryers can be effectively used for drying groundnuts. Solar dryers increase throughput compared to traditional sun-drying methods.
- **Solar-powered groundnut shellers:** Electric shelling machines provide significant advantages, such as efficient shelling, higher productivity and minimal kernel breakage. A machine with a 1.5-2.2 kW motor, suitable for single-phase AC power, costs approximately USD 3 000. These machines can be powered by solar PV systems with inverters, making them viable for off-grid areas. Configured as shared community infrastructure, these systems can process two to four tonnes of produce per day. However, they require customisation, as they are not readily available as standard off-the-shelf models.

Processing and value addition: Groundnuts can be roasted before being ground into peanut butter, either crunchy or smooth. Roasting is typically done with firewood-powered roasters, which have a detrimental environmental impact. Grinding is usually done manually, or with electric or diesel-powered machinery.

- **Biogas roasting machines:** Peanut roasters require approximately 13.5 kW power systems to run at 50 kg/hr. There is potential to use biogas as an alternative energy source for roasting nuts, or these systems could be powered by a mini-grid or micro-hydro system. This approach could be beneficial for value-addition industries that source peanuts from small-scale farmers. However, these systems require customisation, as they are not readily available in retail form.
- **Solar-powered groundnut grinders:** Groundnut grinding machines are equipped with motors ranging from 0.6 kW to 7.5 kW, which can be powered by a solar PV system connected through a DC inverter. The machines themselves cost between USD 400 and USD 5 000, while the associated energy solutions, depending on the configuration, range from USD 1 000 to USD 10 000.

Transport and distribution: As with maize, transport typically takes place with the use of hired diesel- and petrol-powered vehicles.

Cooking and heating: Firewood is the principal fuel for cooking and heating. The use of clean cooking technologies will increase productivity since women, who are mostly active at this stage, will have more time for agricultural production. The technological solutions are comparable to those for maize.

Conclusion: Based on the above, the priority technologies and energy entry points for the groundnut value chain are solar water pumps and irrigation systems, wind-powered water pumps, solar-powered peanut shellers, solar dryers and peanut grinding machines, for both household and commercial use.

4.3 Tomato value chain energy needs and renewable energy solutions

Tomatoes are consumed in nearly every household throughout the year, making them a staple product. The country produces more than 300 000 tonnes of tomatoes per year, with negligible exports and imports. National average yields are quite low, at 22-30 tonnes per hectare, despite a potential of 40-100 tonnes (Agricura, 2017). This is largely due to the varying quality of cultivars used by farmers and limited access to knowledge and funds needed for optimal fertiliser application. Cyclical and seasonal production causes significant price variations. Excess supply in the fresh market results in unsustainable prices, low revenues and substantial post-harvest losses. As a result, tomato producers in Mashonaland East (Mutoko and Murehwa), Mashonaland West, Mashonaland Central, and the Midlands often end up giving away or throwing away product (Batisayi, 2024). Transport and storage infrastructure is generally unreliable, exacerbating these challenges.

According to the assessment, farmers and wholesalers report post-harvest losses of 30-55%. Local district market places absorb produce, but the most profitable outlet for tomatoes is Mbare Musika in Harare. However, reaching this market is challenging for farmers due to high transport costs, the perishability of the tomatoes and the lack of cold chain infrastructure. The tomato value chain is illustrated below in Figure 5.

Water access: Irrigation is the most effective way to provide appropriate water supply for the tomato value chain for which efficient, consistent and reliable water supplies can boost productivity, especially during droughts. Water is also necessary for cleaning before the tomatoes are sent out to the market.

- **Solar water pumps and irrigation systems:** Solar water pumps and irrigation systems have also been highlighted as the major technology options for water availability.

Figure 5 Energy needs at every stage of the tomato value chain and the renewable energy solutions

Cultivation	Energy is required for land preparation, water pumping, irrigation and mechanised planting.	Solar-powered irrigation systems, solar water pumps and other solar-powered machinery can be used to meet energy needs during cultivation.
Crop maintenance	Energy is needed for pest control, weeding and fertiliser application.	Solar-powered pest control devices, electric weeders and drip irrigation systems can be utilised.
Harvesting and post-harvest handling	Energy is required for harvesting, sorting, drying, packaging and storage of tomatoes.	Solar-powered harvesting equipment, electric sorting machines, packaging equipment, solar dryers and improved storage facilities with passive ventilation can be deployed.
Processing and value addition	Processing tomatoes into paste, sauce, or canned products requires energy. Value addition activities such as cooking, blending and packaging require energy.	Solar-powered processing equipment, biomass boilers for steam generation and biogas digesters for heat and electricity can be used. Solar cookers, electric blenders and biomass-based packaging materials can be employed.
Transport and distribution	Energy is needed for transport of raw and processed tomato products to markets or processing facilities.	Electric vehicles, solar-powered refrigeration units for transport and biomass-based fuels for vehicles can be utilised.
Cooking and consumption	Cooking tomato-based food products such as pastes and juices for consumption requires energy.	Solar cookers, biogas stoves and improved biomass cooking stoves can be used for cooking purposes.

Harvest and post-harvest activities: Temperature management is necessary for this extremely perishable product to prevent deterioration and reduce the significant post-harvest losses. Tomatoes should also be handled with care to prevent surface damage and pathological infestation.

- **Solar grading, packing and cold rooms:** Solar-powered cold storage facilities have been selected as the most suitable technology solution for tomato storage. On-farm cold storage is crucial as farmers report that as much as 20% of their output is wasted owing to the lack of on-farm storage. This can be accomplished with the use of 21 m^3 solar-powered refrigerated containers, which cost approximately USD 5 500. Community-based, market and hub-based 96 m^3 refrigeration, grading and packing facilities are ideal for the farmer groups. These cost approximately USD 45 500 for the entire cold storage equipment and USD 60 000 for the warehouse infrastructure. In general, ripe tomatoes can be cold stored for up to two weeks at a temperature of 12-16°C and a relative humidity of 85-90% (Mulindwa *et al.*, 2018). However, prolonged cold storage can have a detrimental impact on texture, flavour and nutritional value, and the produce may only be useful for processing.
- **Solar dryers:** Dried tomatoes have emerged as a significant export and local product. They can be produced from tomatoes that are no longer suitable for the fresh market. The use of solar dyers is a realistic investment for increasing income diversification and viability in the tomato value chain.

Conclusion: Based on the above, the priority technologies and energy entry points for the tomato value chain are solar water pumps and irrigation systems, on-farm 21 m^3 solar powered refrigerated containers, 96 m^3 solar grading, packing and cold stations, and solar dryers.

4.4 Mango value chain energy needs and renewable energy solutions

Mangoes are widely grown in Zimbabwe's three Mashonaland provinces, with yields ranging from 25 to 29 tonnes per hectare, which can double with improved varieties (Rusenga, 2021). However, farmers face market challenges as mangoes are often harvested simultaneously, leading to oversupply. Without temperature-controlled storage, up to 50% of the fruit rots, causing significant revenue loss. This discourages further production. Introducing better storage and processing infrastructure could reduce spoilage and improve market access. Zimbabwe holds potential to shift from small-scale mango farming to large-scale production of high-quality mango varieties, meeting rising demand. The mango value chain is illustrated below in Figure 6.

Cold storage, value addition, and processing into mango pulp, juices and canned and dried products are all ways that can help local farmers boost their income. There is considerable potential for exports. Farmers, for example, earn approximately USD 3 for a 20-litre bucket of fresh mangoes, while a 100 gram packet of dried mangoes costs the same amount.

Water access: Mango trees require adequate soil moisture throughout the dry season and, if necessary, supplemental irrigation during the rainy season. Lack of irrigation before flowering creates stress, resulting in poorer crop yields and poor tree growth. Proper water management is essential to ensure healthy mango production and maximise yield potential, especially in regions with irregular rainfall patterns.

- **Solar water pumps and irrigation systems:** Solar water pumps and irrigation systems have been selected as the most effective water access technologies.

Harvest and post-harvest activities:

- **Solar grading, packing, and cold rooms:** Mangoes are highly perishable, and therefore on-farm cold storage facilities and community cold storage centres are critical for managing post-harvest losses in the value chain. The cold chain solutions are comparable to those for tomatoes.
- **Solar dryers:** Similarly to tomatoes, solar dryer systems have the potential to produce dried mango for both local and foreign markets.

Figure 6 Energy needs at every stage of the mango value chain and the renewable energy solutions

Stage	Energy needs	Renewable energy solutions
Orchard establishment and maintenance	Energy is required for land preparation, irrigation, and maintenance activities such as pruning and fertilisation.	Solar-powered irrigation systems, solar water pumps, and electric pruning tools can meet energy needs during orchard establishment and maintenance.
Crop management and pest control	Energy is needed for pest control, weed management, and fertiliser application.	Solar-powered pest control devices, electric weeders, and drip irrigation systems can be utilised for efficient crop management.
Harvesting and post-harvest handling	Energy is required for harvesting, sorting, drying, packaging, and storage of mangoes.	Solar-powered harvesting equipment, electric sorting machines, packaging equipment, solar dryers, biomass dryers, and improved storage facilities with passive ventilation can be deployed.
Processing and value addition	Value addition activities such as juicing, pulping, and packaging may require energy.	Solar-powered processing equipment such as electric juicers and pulping machines, and biomass-based packaging materials, can be employed for value addition.
Transport and distribution	Energy is needed for the transport of raw and processed mango products to markets or processing facilities.	Electric vehicles, solar-powered refrigeration units for transport, and biomass-based fuels for vehicles can be utilised.
Cooking and consumption	Preparation of mango-based food products such as pastes and juices for consumption requires energy.	Solar cookers, biogas stoves, refrigeration units for transport, and biomass-based fuels for vehicles can be utilised.

Conclusion: Based on the above, the priority technologies and energy entry points for the mango value chain are solar water pumps and irrigation systems, on-farm 21 m^3 solar powered containers, 96 m^3 solar grading, packing and cold stations, and solar dryers.

4.5 Aquaculture value chain energy needs and renewable energy solutions

The aquaculture value chain in Zimbabwe includes fisheries in national water bodies and man-made facilities. The fish value chain is illustrated below in Figure 7. Traditionally dominated by large-scale corporations for export markets, domestic fish farming in smallholder ponds is a newer value chain facing several challenges. These include inconsistent access to clean water, lack of pumps and electricity, limited production knowledge and insufficient cold storage after harvest. Without cold storage, farmers rely on smoking and drying methods, which are less profitable than selling fresh or frozen fish. To enhance the success of smallholder aquaculture, essential technologies such as well-maintained ponds, efficient feeding systems, aeration and cold storage are required. The technologies that are required for the viability of the fish value chain are:

- **Solar water pump systems:** Ponds require water pumps to introduce fresh water, ensuring the survival of fingerlings. A complete 1.25 hp solar-powered water pumping system costs approximately USD 2 200.
- **PV systems for aeration:** A pond aerator is needed to preserve the health and air balance of the pond environment. Aeration systems employ an air compressor to spread diffused air at the bottom of the fishpond and cause upward water circulation, transporting colder, cleaner, oxygen-rich water to the housed fish. Aeration equipment can be powered by PV systems with a combined system cost of around USD 1 200.
- **Solar grading, packing and cold rooms:** Solar-powered container cold storage is an appropriate technology solution for fishery projects with settable temperatures as low as 3-4 °C. The use of refrigeration containers will increase fish cold chain sustainability. A 21 m^3 solar-powered container refrigerator costs about USD 5 500.

Figure 7 Energy needs at every stage of the fish value chain and the renewable energy solutions

Pond preparation and maintenance	Energy is required for pond preparation, aeration, and water circulation.	Solar-powered aerators, water pumps, and circulation systems can meet energy needs during pond preparation and maintenance.
Fish feeding and management	Energy is needed for fish feeding, monitoring, and water quality management.	Solar-powered automatic feeders, monitoring systems, and water quality sensors can be utilised for efficient fish management.
Harvesting and sorting	Energy is required for harvesting, sorting, and grading of fish.	Solar-powered harvesting equipment, electric sorting machines, freezing cold rooms, and grading systems can be employed for post-harvest handling.
Processing and packaging	Freezing, drying, smoking, and packaging of fish require energy.	Cold rooms, solar dryers, and smokehouses powered by biomass or solar energy, along with packaging equipment, can be deployed for processing and packaging.
Transport and distribution	Energy is needed for the transport of raw and processed fish products to markets or other processing facilities.	Electric vehicles, solar-powered refrigeration units for transport, and biomass-based fuels for vehicles can be utilised.
Cooking and consumption	Cooking fish-based food products for consumption requires energy.	Solar cookers, biogas stoves, and improved biomass cooking stoves can be used for cooking purposes.

Conclusion: Based on the above, the priority technologies and energy entry points for the fish value chain are solar water pumps systems, PV systems for aeration, solar grading, packing and cold rooms, and solar dryers.

5. Socio-economic and environmental implications (scenario planning)

The DRE solutions identified during the mapping of energy and use patterns across various stages of the five agri-food value chains are classified as follows:

- **Full commercial market** DRE solutions that are considered to be available in retail or ready-to-install form as a complete kit. These include PUE (productive use of energy) technologies such as solar-powered water pumps and irrigation systems, on-farm and market-based solar-powered cold storage systems and solar dryers.
- **Near-to-market** DRE solutions adaptable to solar electricity configurations offer promising technologies for agricultural use, though they often require customisation for installation. These include maize and peanut shellers, grain and peanut grinding machines, and pond aeration systems. While micro-hydro systems can power high-energy equipment like grinding mills, they have been rarely utilised in Zimbabwe's agricultural sector. Many of these technologies have been successfully tested in other countries but are not sold as complete kits, requiring adaptation to local conditions for effective use.
- **Emerging-market** DRE solutions such as e-mobility and heavy-duty solar grinding mills see limited sales due to the cost, but are gradually evolving.

In this report, the market size of DRE solutions is determined for the fully commercial market segment, as they are ready to implement under a viable investment case. DRE market size modelling under different scenarios has been prepared as follows:

- **Scenario 1** – Business as usual with continued reliance on firewood and fossil fuels, limited or no renewable energy adoption, increasing energy costs with continued reliance on rainfall for watering. Exorbitant financing mechanisms remain the same.
- **Scenario 2** – Renewable energy transformation is characterised by modest but growing adoption of DRE solutions. This leads to improved energy access and reliability for agricultural activities, along with reduced energy costs and carbon emissions. The transformation is primarily driven by individual adoption of new technologies.
- **Scenario 3** – Rapid market penetration and widespread adoption of DRE solutions, leading to an adaptable energy system tailored to agricultural needs, with significant reductions in energy costs and carbon emissions. This scenario aligns with government irrigation plans for 450 000 hectares, resulting in increased average yields as more farmers receive targeted extension services. Additionally, there is greater participation from women and youth in the agricultural sector.
- **Scenario 4** – An optimistic scenario of market penetration where farmer groups lead the way in owning and operating renewable energy infrastructure. This community-driven approach enhances energy access, empowers gender and youth participation, and fosters economic growth. The initiative aligns with government plans to irrigate 2 000 000 hectares, resulting in increased average yields as more farmers benefit from targeted extension services.

The result of market size modelling for irrigation systems is shown in Table 5.

Table 5 Scenario model – Irrigation systems

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Solar-powered water pump and irrigation		**Business as usual**	**Renewable energy transformation**	**Rapid DRE use**	**Optimistic DRE use**
Target irrigable land	hectares	217 000	250 000	450 000	2 000 000
Existing irrigable land	hectares	217 000	217 000	217 000	217 000
New irrigable land	hectares	-	33 000	233 000	1 783 000
Market potential – 1 hectare irrigation kits	units	-	33 000	233 000	1 783 000
	USD 4 034 each	-	133 122 000	939 922 000	7 192 622 000
Irrigation impact/ increase on total yields – using maize as a proxy (1 season production)	Increase in tonnes	-	60 390	659 390	6 828 890
	USD 368 per tonne	-	22 223 520	242 655 520	2 513 031 520
Maize	tonnes per hectare	1.83	1.83	2.83	3.83
Current	tonnes per hectare	1.17	1.17	1.17	1.17
New	tonnes per hectare	3.00	3.00	4.00	5.00
Payback period, based on 1 season use (using maize proxy)	years	0	5.99	3.87	2.86
Payback period, based on 2 seasons use (using maize proxy)	years	0	3.00	1.94	1.43

The result of market size modelling for on-farm cold storage systems is shown in Table 6.

Table 6 Scenario model – On-farm cold storage systems

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
On-farm refrigeration unit		**Business as usual**	**Renewable energy transformation**	**Rapid DRE use**	**Optimistic DRE use**
Land under horticulture	hectares	81 702	81 702	102 128	122 553
Total fresh produce, all local produce	tonnes per annum	2 663 467	3 329 334	4 161 667	5 493 401
Average yield per hectare	tonnes per hectare	33	41	41	45
21 m³ on-farm solar-powered refrigeration container	average density, kg per m³	-	835	835	835
Solar refrigeration capacity	tonnes	-	17.54	17.54	17.54
Total annual refrigeration capacity, on a 3-day cycle per unit	tonnes	-	2 133	2 133	2 133
Number of units required per annum	units	-	1 561	1 951	2 575
Average cost of a refrigeration unit	USD	-	10 256	10 256	10 256
Market potential - refrigeration units	USD	-	16 005 022	20 006 277	26 408 286
On-farm cold storage impact/reduction of on-farm post-harvest losses, using tomatoes as proxy	tonnes	-	416 167	624 250	1 030 013
Approximate on-farm losses	%	0%	25%	25%	25%
Reduction of on-farm losses	%	0%	50%	60%	75%
Value of reduction of on-farm post-harvest losses, using tomatoes as a proxy	USD 500 per tonne	-	208 083 359	312 125 039	515 006 314
Payback period	years	-	0.08	0.06	0.05

Note: The scenario model assumes an optimistic 3-day residence time per load of tomatoes, while extending storage to 5–7 days could further optimise shelf life. It also assumes 100% cold storage utilisation, which may vary in practice, though effective management can ensure high efficiency based on fluctuating harvest schedules and market demand.

The result of market size modelling for market cold storage facilities is shown in Table 7.

Table 7 Scenario model – Market cold storage facilities

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Market or hub refrigeration unit (hybrid system – solar power and grid)		**Business as usual**	**Renewable energy transformation**	**Rapid DRE use**	**Optimistic DRE use**
Total fresh produce, all local produce	tonnes per annum	2 663 467	3 329 334	4 161 667	5 493 401
96 m³ market or hub solar-powered refrigeration cold room	average density, kg/m³	-	835	835	835
Solar refrigeration capacity	tonnes	-	80.16	80.16	80.16
Total annual refrigeration capacity, on a 5-day cycle per unit	tonnes	-	5 852	5 852	5 852
Number of units required per annum	units	-	569	711	939
Average cost of a refrigeration unit	USD	-	108 898	108 898	108 898
Market potential – refrigeration units	USD	-	61 957 897	77 447 371	102 230 530
On-farm cold storage impact/reduction of on-farm post-harvest losses, using tomatoes as proxy	tonnes	-	332 933	499 400	824 010
Approximate on-farm losses	%	0%	20%	20%	20%
Reduction in losses	%	0%	50%	60%	75%
Value of reduction of on-farm post-harvest losses, using tomatoes as proxy	USD 500 per tonne	-	166 466 688	249 700 031	412 005 052
Payback period	years	-	0.37	0.31	0.25

Note: In Scenarios 2, 3 and 4, the 20% initial loss reflects the impact of no refrigeration. As refrigeration is introduced and optimised in each scenario, it progressively reduces these losses, with greater effectiveness in each successive scenario.

Nearly all agricultural produce can be dried as part of value addition. The capacity of the solar dryer is identified as 0.4 m^3. Using tomatoes as a proxy for the analysis at 0.47 tonnes per m^3, the result of market size modelling for solar dryers is shown in Table 8.

Table 8 Scenario model – Solar dryers

Solar dryer			Business as usual	Low market penetration	High market penetration	Optimistic market penetration
Tomato production	tonnes	336 300	Very low investment			
Increase in production due to irrigation	tonnes	493 685	0%	25%	40%	50%
Tomatoes for drying	tonnes		-	123 421	197 474	246 842
Drying capacity per unit			0.19	0.19	0.19	0.19
Drying cycle	days		2	2	2	2
Annual capacity at 75% capacity			25.94	25.94	25.94	25.94
Number of units required			-	4 758	7 613	9 516
Investment cost per unit	USD		1 400	1 400	1 400	1 400
Total investment potential – market size	USD		-	6 661 129	10 657 806	13 322 258

In conclusion, the addressable market for solar-powered irrigation is between USD 133 million and USD 7.1 billion. The market for on-farm cold storage is between USD 16 million and USD 26.4 million. The magnitude for market- and hub-based refrigeration is expected to be between USD 62 million and USD 102 million. The solar dryer market is estimated to be between USD 6.6 million and USD 13 million. This shows that the potential for use of DRE solutions in agriculture is vast.

Near-to-market technologies are generally not yet readily available off the shelf from local technological enterprises and may require customisation rather than being retail solutions. Market size determination for these technologies still requires design and planning for optimisation and cost-effectiveness first.

6. Options for delivery – technology solutions and cost-benefit analyses

6.1 Solar dryers

The cost-benefit analysis for solar dryers was performed using tomatoes as the proxy. The results are shown in Table 9.

Table 9 Cost-benefit analysis for solar dryers

Solar dryer specifications, using tomatoes as proxy				
		0.8 m x 0.6 m x 0.16 m	2.08 m x 0.875 m x 0.16 m	2.1 m x 1.2 m x 0.16 m
Volume	m^3	0.08	0.29	0.40
Tomato density	kg/m^3	0.47	0.47	0.47
Drying capacity	tonnes	0.04	0.14	0.19
Drying cycle	days per drying cycle	2.00	2.00	2.00
Annual drying capacity, at 75% efficiency		4.94	18.73	25.94
Solar dryer purchase price	USD	150	1170	1400
useful life	in years	3	3	3
Annual operating costs	USD			
Annual depreciation		50.00	390.00	466.67
Maintenance		7.50	58.50	70.00
Interest cost	USD at 15%/ annum	22.50	175.50	210.00
Total annual operating costs		80.00	624.00	746.67
Potential savings from post-harvest losses through drying	tonnes/ annum	4.94	18.73	25.94
Value of tomatoes	tonne	500	500	500
Value of potential savings from post-harvest losses	USD	2 470.32	9 366.63	12 969.18
Net savings from investment in solar dryer per annum	USD	2 390.32	8 742.63	12 222.51
Implied payback period	years	0.06	0.13	0.11

Note: m = metre.

Besides the reduction of post-harvest losses, the value addition to tomatoes through drying is highly profitable. Global demand for dried fruits and vegetables is growing, outstripping supply. The international retail prices for dried tomatoes and mangoes are between USD 10 and USD 15 per kg. On drying, cherry tomatoes will lose 88-93% of their fresh weight. As a result, it takes anywhere from 8 kg to 14 kg of fresh tomatoes to make a single kilogram of sun-dried tomatoes. Also, 100 kg of fresh mangoes can be dried to about 17 kg of dried slices. A simulation for tomato and mango value addition is shown in Table 10.

Table 10 Value addition simulation for drying selected highly perishable produce

Product	Weight required to produce 1kg of dried product	Value per kg (USD)	Produce value per kg of dried product	Export mark-up	FOB value (USD)	Freight	Commissions & fees	Export landed value (USD)	International retail price per kg (USD)
Tomatoes	11.00	0.50	5.50	30%	7.15	12.5%	12.5%	8.94	12.50
Mangoes	5.88	0.50	2.94	30%	3.82	12.5%	12.5%	4.78	12.50

6.2 Solar water pumps and irrigation

A cost simulation for a 1-hectare solar pump and irrigation system is shown in Table 11.

Table 11 Cost analysis for a 1 hectare pump

1-hectare solar pump and irrigation system	
Component description	**Purchase cost (USD)**
1.25 hp AC pump with external control box + 143 m for a head dam to tank (VSD) 100 m to tank complete with accessories	1394.00
Panel frame	350.00
Labour and concrete	490.00
5 000 litre tank and stand fitted	1000.00
1 hectare drip kit with 100 m x 100 lines	800.00
Total cost of 1 hectare solar pump and irrigation system	**4 034.00**

Operating costs	Cost (USD)
Depreciation, 10 years useful life	403.40
Initial year interest cost, 15% per annum	605.10
Maintenance	100.85
Total operating costs of 1 hectare solar pump & irrigation system	**1109.35**

Note: VSD = variable speed driven.

The use of solar pumps and irrigation systems significantly boosts productivity for crops like maize, groundnuts, tomatoes and mangoes. In practice, the 1-hectare irrigation kit is not limited to a single season; it can be used year-round, enhancing production diversity and, consequently, increasing smallholder farmer revenues. Table 12 is a simulation illustrating the potential impact of irrigation water across different value chains.

Table 12 Yield increase scenario model

		Maize	Tomatoes	Groundnuts	Mangoes
2022/23 national average yield	tonnes per hectare	1.17	30.00	0.64	29.00
Seed company optimal yield/performance, under commercial management	tonnes	10.00	60.00	4.00	60.00
Expected performance, under smallholder conditions	tonnes	3.00	50.00	1.47	40.00
Expected yield increase due to irrigation	tonnes	1.83	20.00	0.83	11.00
Increase	%	156	67	130	38
Market selling price	USD	368.00	500.00	800.00	500.00
Value of yield increase	/hectare	**673.44**	**10 000.00**	**664.00**	**5 500.00**

The profitability of an investment in a solar pump and irrigation system can be calculated based on all-year use of the system, with a minimum of two crops in different scenarios (Table 13). Farmers are assumed to want to maximise their returns.

Table 13 Cost-benefit analysis for solar water pump and irrigation system

Maize	USD 673	**Groundnuts**	USD 664	**Maize**	USD 673
Tomatoes	USD 10 000	**Tomatoes**	USD 5 500	**Groundnuts**	USD 664
Operating costs	(USD 1109)	**Operating costs**	(USD 1109)	**Operating costs**	(USD 1109)
Net profit	**USD 9 564**	**Net profit**	**USD 5 055**	**Net profit**	**USD 228**
Payback	0.42 years	**Payback**	0.75 years	**Payback**	Not viable

6.3 Solar-powered packing and cold storage facilities

On-farm cold chain infrastructure is essential for reducing post-harvest losses and preserving the quality of fresh produce from the farm to the market or processing hubs. With on-farm losses reaching as high as 25%, relying solely on market storage systems is insufficient. Implementing on-farm cold storage facilities enables better quality control, allowing farmers to manage harvest timing and storage conditions more effectively, ensuring fresher, higher-quality produce.

Table 14 Solar-powered cold storage container simulation and investment analysis

21 m³ mobile solar-powered cold container facility **Component description**		**Purchase cost (USD)**	**Useful life, years**	**Annual cost of operation (USD)**
Refrigeration and machinery		8 476.00	10	847.60
Transporting		847.60	10	84.76
Civil works		932.36	10	93.24
Total cost of cold storage equipment	USD	**10 255.96**		**1 025.60**
Interest on total project finance cost, at 15% per annum	USD			1 538.39
Maintenance costs	USD			512.80
Operating costs per annum	USD			**3 076.79**
Dimensions of the container (3 m x 3 m x 2.4 m)	m^3			21.60
Season 1 – Mangoes (1 hectare production – 27 tonnes)				
Mango density	kg / m^3			1 200.00
Capacity of container	tonnes			25.92
Number of storage cycles from 1 hectare production				1.04
Potential saving, 25% on farm-loss reduction	tonnes			7.03
Value of saving at USD 500 per tonne, in season	USD			3 515.63
Season 2 – Tomatoes (1 hectare production – 50 tonnes)				
Tomatoes density,	kg per m^3			470.00
Capacity of container	tonnes			10.15
Number of storage cycles from 1 hectare production				4.93
Potential saving, 25% on-farm loss reduction in tonnes	tonnes			12.50
Value of saving at USD 500 per tonne, in season	USD			**6 250.00**
Net saving per annum	USD			**6 688.84**
Implied payback period	years			**1.53**

The payback period based on reduction of post-harvest losses is very short and therefore attractive, illustrating the viability of the investment.

Market-based cold storage facilities: The on-farm cold chain should be complemented by investment in cold storage facilities at the markets or processing centres/hubs. These are needed to manage losses at the markets or prior to processing at the value addition hubs, which can be as high as 20%, especially during the hot season. The following is an evaluation of an investment in a larger market-based or community-serving cold storage facility, using tomatoes as the proxy product.

It is important that facilities are managed to achieve maximum utilisation by promoting high turnover. However, even at an average of two weeks' storage per load, the payback period is attractive at 2.21 years. Assuming each farmer produces one tonne of tomatoes, the facility can support a minimum of 26 farmers per annum storing product for an average two weeks at a time.

Table 15 Packing and cold storage facility simulation and investment analysis

96.3 m^3 **Component description**	**Purchase cost (USD)**	**Useful life, years**	**Annual cost of operation (USD)**
Refrigeration and machinery, 96.3 m^3	12 500.00	10	1 250.00
Insulation panels and doors	13 241.00	10	1 324.10
Solar panels	6 000.00	15	400.00
Solar panel frame	840.00	10	84.00
Lithium solar batteries (5-year warranty)	6 530.00	5	1 306.00
Inverter	2 390.00	5	478.00
Installation costs	4 000.00	5	800.00
Total cost of cold storage equipment	**45 501.00**		**5 642.10**
Civil works	63 397.56	20	3 169.88
Total project cost, 96.3 m^3 packing and cold storage facility	**108 898.56**		**11 479.98**
Interest on total project finance cost, at 15% per annum			16 334.78
Operating costs per annum			**27 814.76**
However, for 3 months of the year there is limited sunshine, so the grid electricity is used as backup.			
Power used per day by the cold room is an average of 8.628 kW per hour x 24 hours x 3 months			18 636.48
Cost of grid electricity per kWh, budgeted			0.12
Total cost of grid electricity			2 236.38
Total operating cost of the facility per annum			**30 051.14**

Capacity utilisation		24-hour storage	48-hour storage	5-days' storage	7-days' storage	14-days' storage
Facility storage capacity	m^3	96.3	96.3	96.3	96.3	96.3
Annual storage	m^3	35 150	17 575	7 030	5 021	2 511
Tomatoes density	kg/m^3	470	470	470	470	470
Tomatoes storage capacity at a time	tonnes	45.26	45.26	45.26	45.26	45.26
Tomatoes per annum	tonnes	16 520	8 260	3 304	2 360	1 180
Turnover cycles per year (of 45.26 tonnes each)		365	183	73	52	26
Potential saving, 20% loss reduction		3,304	1,652	661	472	236
Value of saving at USD 500 per tonne	USD	**1 652 027**	**826 013**	**330 405**	**236 004**	**118 002**
Cold station – depreciation cost	USD	11 480	11 480	11 480	11 480	11 480
Grid electricity cost	USD	2 236	2 236	2 236	2 236	2 236
Interest cost	USD	16 335	16 335	16 335	16 335	16 335
Maintenance costs	USD	2 722	2 722	2 722	2 722	2 722
Factory labour – 10 employees	USD	18 000	18 000	18 000	18 000	18 000
Management – 3 employees	USD	18 000	18 000	18 000	18 000	18 000
Total fixed costs	USD	**68 774**	**68 774**	**68 774**	**68 774**	**68 774**
Net saving from investment in packing and cold storage facility	USD	1 583 253	757 240	261 632	167 230	49 228
Implied payback period	years	0.07	0.14	0.42	0.65	2.21

Note: kWh = kilowatt hour.

7. Investment strategies and flow of funds

Surveyed smallholder farmers expressed a strong need to adopt DRE solutions to reduce their reliance on fossil fuels. However, barriers such as limited knowledge, access to technology, and financial constraints hinder adoption. Farmers often lack reliable income due to post-harvest losses, poor market connections and droughts. Access to DRE distributors remains restricted, and financial resources primarily come from government and donor programmes or local savings co-operatives, which provide small loans averaging USD 100 with interest rates as high as 15% per month, limiting investment in DRE solutions.

7.1 Possible financial viability scenarios

- **Scenario 1** – Current business as usual: Commercial banks and microfinance institutions require collateral for agricultural loans, typically capped at USD 5 000. Collateral often includes moveable assets like livestock or farm equipment, or salary-based guarantees, with cover requirements reaching 200% of the loan's value. Loan terms are usually limited to 360 days. Interest rates vary, with commercial banks offering rates between 12% and 18% per annum, while microfinance rates range from 10% to 15% per month. Many borrowers opt for microfinance institutions due to the stricter requirements of commercial banks. Overall, lending capacity is limited due to liquidity challenges and scarce credit lines for agricultural finance.
- **Scenario 2** – Slow structured deployment: Interest is charged at 15% per annum. The loan terms are a maximum of 24 months. For solar-powered irrigation, this reduces interest payments to USD 607 per annum. Loan establishment fees are 3-4% of the loan amount at drawdown. Collateral requirements can be reduced to 100% of loan value. Loan amounts are limited to 50% of cost, with the farmer contributing 50% as well. This increases borrowers' participation, but the collateral requirements can act as a limitation on offtake.
- **Scenario 3** – Interest is charged at 15% per annum: The loan terms are between 12 months and 60 months. Cheaper finance made possible with the introduction of the MLAFWRD Agro Energy Fund loan guarantee structure as collateral. Loan establishment and guarantee fees are 5-6% of loan amount at drawdown. Loan amounts are 90% of purchase amount. Uptake and participation by borrowers, especially farmer-led community projects including women and youth, increase as the guarantee offer eases collateral requirements.

Farmers expressed interest in accessing finance for technology, provided it is available, affordable and of guaranteed quality. They showed a preference for hybrid financing options such as pay-as-you-go schemes, as well as value chain finance and customised financing plans that can be repaid by offsetting harvests. The majority of capital is accessible for short-term trading contracts rather than long-term value chain financing.

Sustainable and profitable business models with strong market linkages are important for the farmers. The following are some of the funding requirements for various value chain actors:

- Short-term working capital for inventory, operating expenses, energy and inputs.
- Mid- and long-term financing for equipment, livestock, storage facilities, vehicles and infrastructure.
- The use of technology and services for transactions (payment and receipt of money).

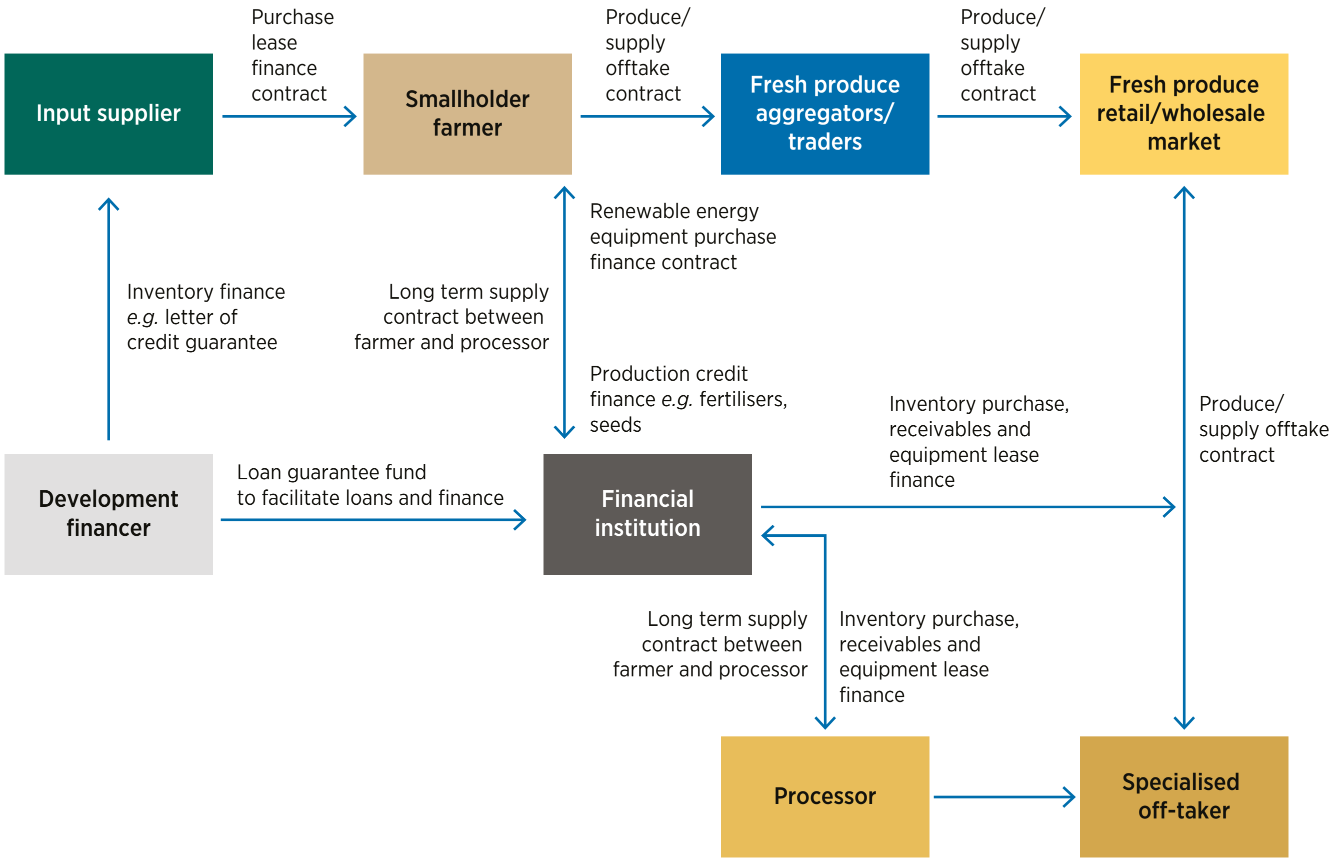
The following are the investment strategies that can work for financing agriculture and renewable energy deployment in Zimbabwe.

7.2 Value chain finance

Traditional finance involves financial institutions lending to individual or stand-alone value chain actors with little to no co-ordination or integration of services and knowledge. Value chain finance brings increases in efficiencies through the collaboration of different but linked financing mechanisms and services that feed along the chain. It can also increase credit access to smallholder producers by leveraging value chain capacities. Investment opportunities are also covered according to value chain actors' funding requirements.

Value chain finance involves forming strategic partnerships and collaborations between financial institutions, agricultural input suppliers, equipment and technology suppliers, aggregators/traders, processors, wholesalers, retailers and development organisations. These partnerships may include joint venture initiatives and supply chain finance programmes to leverage expertise, resources and networks. It may also include providing working capital loans, asset financing, trade finance, insurance products and risk management solutions. Risk management financial products such as weather-indexed insurance, warehouse receipt financing and integrated contract farming arrangements are also necessary to hedge against price volatility, production risks and market uncertainties, together with climate related risks. Figure 8 shows the range of actors involved in value chain finance and the relationships between them.

Figure 8 Value chain finance interrelationships

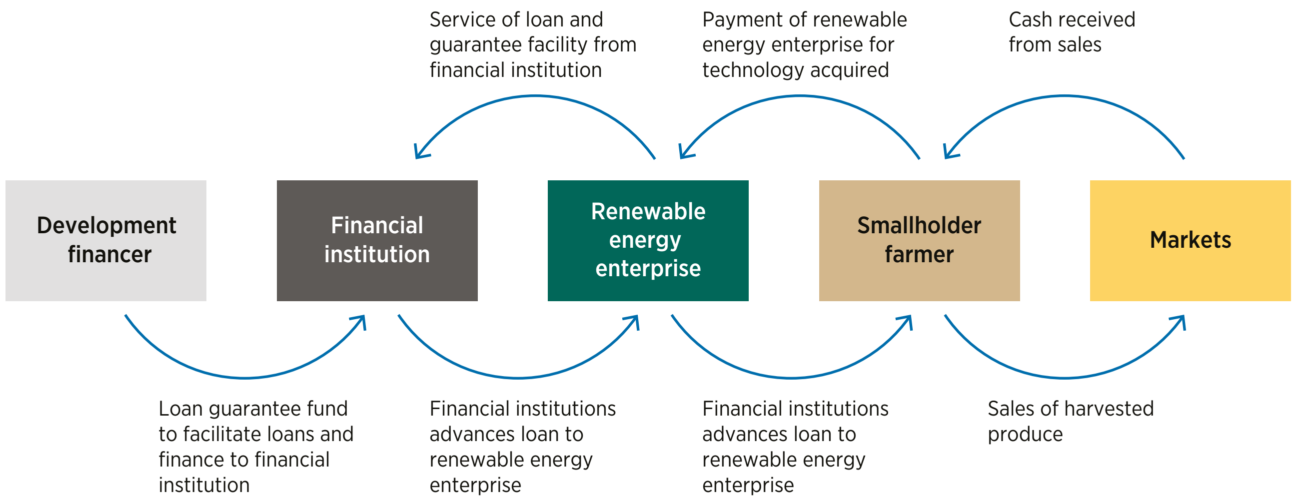


Specific funds can flow in the following manner:

- **A basic equipment finance contract**

Renewable energy enterprises can significantly grow their businesses and expand into rural areas by partnering with financial institutions through tailored financing mechanisms. In this model, the renewable energy enterprise sells DRE solutions to farmers on credit, leveraging their understanding of the farmers' practices and creditworthiness. This approach minimises the risk of fund misallocation that could occur if funds were advanced directly to the farmers, as in Figure 9.

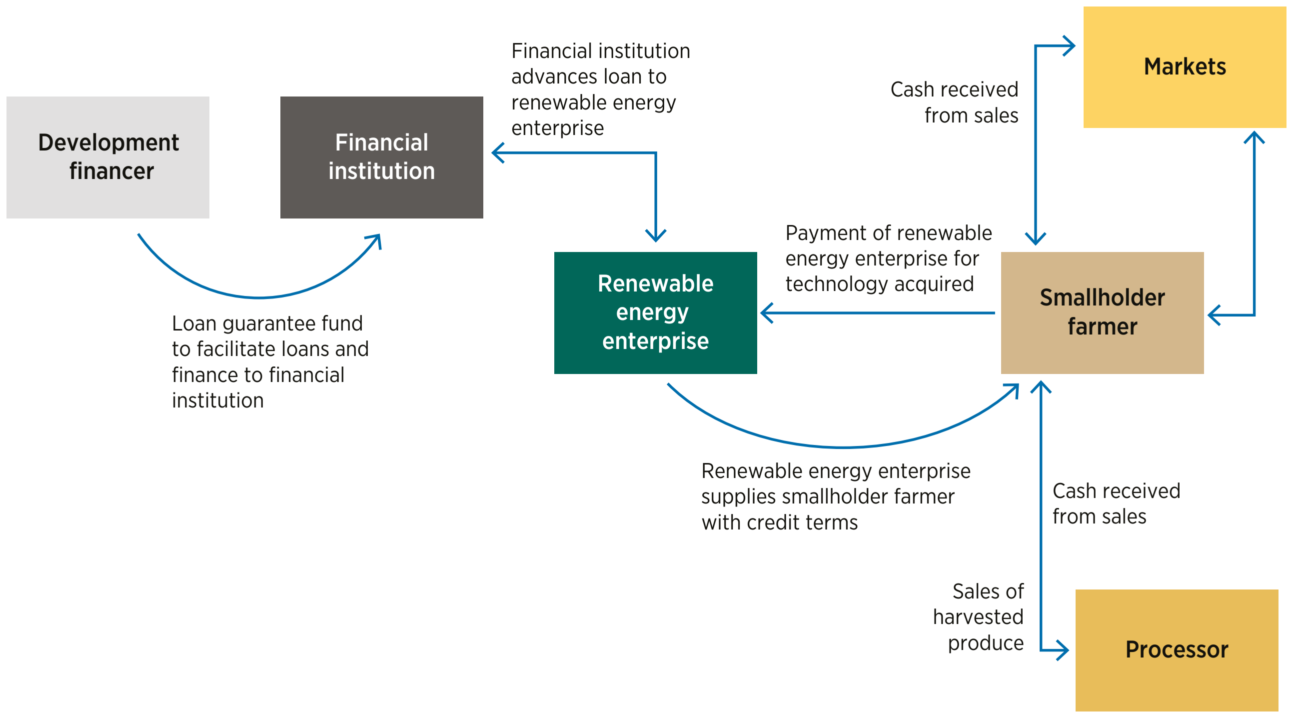
Figure 9 Renewable energy equipment finance directly to smallholder farmers



- **An equipment finance arrangement involving a Village Business Unit**

This arrangement involves an agro-processor and a Village Business Unit. A development financier incentivises a local financial institution to provide loans to the Village Business Unit under a formal contract (Figure 10). The loan is utilised to purchase DRE technologies, such as irrigation kits and cold storage facilities, which enhance product quality and reduce post-harvest losses.

Figure 10 Equipment finance arrangement involving a Village Business Unit



The viability of these investment strategies is heavily influenced by the pricing structures that determine interest rates and bank charges. Excessive costs can undermine the sustainability of both the farmers and the financial models. It is crucial that loan repayment terms align with the business life cycles to ensure long-term success.

8. Programmatic strategies

To effectively integrate DRE solutions into smallholder farms, a holistic and collaborative approach will be vital, with various steps running simultaneously (Table 16). First, there is a need to roll out awareness and education initiatives that inform farmers about the benefits of DRE solutions. This can involve hosting workshops and information sessions, and setting up demonstration sites to showcase successful projects. After that, providing technical assistance will be essential to help farmers with the design, installation, operation and maintenance of DRE systems, ensuring they are not only effective but also user-friendly.

To make the transition more feasible, there is a need to establish financial assistance options, including access to microfinance, government subsidies and grants to ease the initial financial burden of adopting these technologies. It is equally important to focus on technology adaptation, tailoring DRE solutions to fit local contexts. This could mean developing affordable, locally sourced technologies like cold storage and irrigation systems that meet the specific needs of farmers.

Engaging farmers in community-based approaches is crucial. By involving them in decision-making processes, we can foster a sense of ownership and empowerment. Additionally, creating market linkages will connect farmers with DRE enterprises and open up new market opportunities. It is also important to advocate policy and regulatory support that encourages DRE adoption and offers the necessary incentives. Lastly, investing in research and innovation will help develop efficient DRE technologies, while robust monitoring and evaluation systems will ensure that progress is tracked and adapted as needed. Together, these steps will pave the way for a sustainable future in smallholder agriculture, empowering farmers and their communities.

Table 16 Steps to integrate renewable energy in smallholder farms

Awareness and education through awareness raising, education campaigns, workshops, demonstration sites and information sessions.
Technical assistance for design, installation, operation and maintenance of DRE systems.
Financial assistance to promote access to finance options, including microfinance programmes, government subsidies, grants and tax incentives.
Technology adaptation to adapt DRE technologies to be suitable for Zimbabwe, including creating low-cost, locally derived solutions such as cold storage and irrigation systems.
Community-based approaches by including farmers in decision-making processes.
Market linkages by connecting farmers with DRE enterprises and markets.
Policy and regulatory support advocating legislation and regulations that encourage the use of DRE on smallholder farms. Includes incentives, subsidies and tax breaks.
Research and innovation investment to create new DRE solutions to improve efficiencies, reduce cost and increase dependability of existing technology.
Monitoring and evaluation by introducing tools to evaluate energy savings, productivity increases, revenue creation, social benefits and environmental consequences.
Scaling up and replication through the creation and documentation of stakeholder networks for knowledge sharing to replicate agricultural best practices.

8.1 Collaboration and support networks

The establishment of collaboration and support networks is crucial for facilitating the integration of DRE on smallholder farms. These networks bring together farmers, local governments and development and private sector partners, fostering a collaborative environment where knowledge can be exchanged, resources can be shared and best practices can be disseminated. Such partnerships enhance implementation efficiency and eliminate duplication of resources, maximising the impact of initiatives aimed at promoting renewable energy adoption.

Interministerial collaboration is particularly vital in this context, as it encourages various government departments to align their policies and programmes to support the integration of renewable energy in agriculture. This collaboration ensures that smallholder farmers have access to the necessary technical assistance, financial resources and innovative solutions tailored to their specific needs. By amplifying the voices of farmers within these networks, stakeholders can advocate policies that create a conducive environment for renewable energy adoption. Overall, these collaborative efforts not only strengthen the resilience of smallholder farms, but also contribute to sustainable agricultural practices, ultimately improving the livelihoods of farming communities and promoting a sustainable future.

Table 17 Strategies and processes for collaboration and support networks

Strategy	Process
Stakeholder mapping	Understanding responsibilities, interests and capacities should inform collaboration and networking initiatives as well as their alignment.
Multi-stakeholder platforms	There is an urgent need for the establishment of multi-stakeholder platforms or working groups aligned with and focused on the energy transition and the adoption of technology in agriculture. These platforms should provide a space for stakeholders to share knowledge, co-ordinate actions, address challenges and leverage resources collectively.
Capacity-building workshops	In addition to the multi-stakeholder platforms, the organisation of capacity-building workshops and training programmes are imperative to enhance the knowledge and skills of stakeholders involved in renewable energy solutions for agriculture. This includes training on technology selection, project management, financing options, energy economics, policy advocacy and monitoring and evaluation.
Demonstration projects	The implementation of demonstration projects to showcase the feasibility and benefits of renewable energy solutions, especially PUE for agriculture in a route which can enhance greater collaboration in the ecosystem. These demonstrations should serve as learning hubs where stakeholders can explore and understand the feasibility of the technologies in action and operation, exchange experiences and build confidence in renewable energy adoption.

9. Conclusion

The powering of agriculture through DRE solutions is a critical step for the success of the sector, and Zimbabwe's economy as a whole. The government is determined to achieve its Vision 2030 to achieve 95% urban and 75% rural electrification rates. The agricultural industry has great potential for expansion, but agro-value chains remain constrained by energy availability.

The five value chains chosen from Zimbabwe's agricultural sector revealed that farmers have a high demand for energy and equipment for agricultural production. However, these farmers are primarily constrained by a lack of access to DRE solutions and financing methods. Those that are available have unfavourable pricing and payment terms and conditions. The deployment of DRE solutions to power agriculture in Zimbabwe is a crucial step towards achieving energy and food security, improving agricultural productivity and enhancing climate resilience. Solar-powered equipment and solar-based electricity are examples of adoption-ready solutions that are available on the market. DRE options, such as solar-powered irrigation systems, cold storage facilities and solar dryers, are feasible alternatives to traditional energy sources and could enable the transition to a viable green energy smallholder agricultural production system. This can reduce reliance on fossil fuels.

Zimbabwe's market potential for renewable energy technologies is around USD 7.1 billion for irrigation solutions, USD 128 million for cold storage solutions, and USD 13 million for sun drying equipment. According to the cost-benefit evaluations conducted for irrigation, the adoption of these technologies is feasible and viable if the funding mechanisms and production systems are favourable. This includes interest at 15% per annum total cost, long-term loans, the use of risk mitigation insurance policies and access to guarantees.

The options under consideration have payback periods ranging from one to six years. They can help improve farmers' profitability by increasing yields by at least 30% and reducing post-harvest losses by 50%. Furthermore, there is vast potential for production diversification, such as producing and marketing sun-dried tomatoes. These untapped opportunities would also lead to new employment creation. The impact on households from revenue generation, especially export proceeds, is substantial. These solutions can assist in alleviating the effects of climate change by lowering greenhouse gas emissions and encouraging climate-resilient agricultural practices.

In the long run, localised DRE solutions can help Zimbabwe's economic growth, food security and sustainable development. These efforts can help the government accomplish its aim of a USD 13.75 billion farm industry. As a result, it is critical to prioritise the deployment of these solutions and establish a conducive climate for their adoption and scaling up.

Photo: www.gettyimages.com

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Appendix

A. Rural Development Programme

i. The Presidential Rural Development Programme is the flagship of the Rural Development 8.0 interventions, which have a target to drill one borehole in each of the 35 000 rural villages in the country and establish a commercial one-hectare garden in each of the 35 000 villages, giving 10 fruit trees per household to the 3 million households, and giving 50 sweet potato vines to each of the 3 million households. This is set to benefit households by alleviating rural poverty in line with National Development Strategy 1 (NDS1).

ii. In line with the government's rural industrialisation agenda, the Agricultural and Rural Development Authority (ARDA) is set to establish across the country:

- 35 000 Village Business Units
- 9 600 School Business Units
- 450 Irrigation Schemes.

iii. Village Business Units (VBUs) are registered rural development enterprises meant to boost economic activity and improve livelihoods in rural communities. The VBUs will be managed under the ARDA V30 Accelerator Model, which guarantees profitability, viability and sustainability. The VBUs are being rolled out in a whole-of-government approach to establish 35 000 one-hectare self-sustaining VBUs powered by solar-driven boreholes for drip irrigation of horticultural gardens in the rural communities.

iv. Over 37 VBUs have been registered and operationalised, benefiting about 2 775 households. The VBUs are supported by aggregation centres at ward level for processing, grading and consolidation to build economies of scale, dispatch and distribution to offtake markets.

v. The main objective of this project is to enhance agricultural production and productivity and increase sector competitiveness by increasing access to renewable energy equipment and machinery for creditworthy smallholder farmers in Zimbabwe, which includes those under VBUs. This will include providing rural smallholder farmers with renewable energy infrastructure and equipment, setting up at least 16 decentralised solar agro-processing plants in eight rural provinces and creating revolving funding that allows 100% loan recovery from beneficiaries.

Source: MLAFWRD (2020).

B. The Agro-Energy National Facility

i. The Agro-Energy National Facility (AENF) is a programme proposed by the Department of Agricultural Engineering, Mechanisation and Farm Infrastructure Development to provide a facility for farmers to acquire alternative energy assets to alleviate the impact of load shedding on farming operations and the agricultural sector.

ii. The facility seeks to provide reliable energy supply for continuity of production on farms, focusing on energy-intensive agricultural activities, which include intensive agricultural production systems, irrigation and on-farm cold chain related activities. In addition to mitigating an urgent demand for additional sustainable energy generation, the facility is expected to support long-term strategic ambitions for the economic, industrial and social development of Zimbabwe.

iii. Sector focus is (1) farm households and offices, i.e. poultry, piggeries, (2) dairy farming, (3) all irrigated commodities, i.e. water pumping stations, boreholes, centre pivots, and (4) on-farm processing such as cold storage facilities.

iv. The programme objectives are (1) promotion of renewable energy adoption, (2) enhancing energy efficiency, (3) fostering sustainable rural development, (4) mitigating climate change impacts, and (5) strengthening collaboration and knowledge sharing.

v. Programme structure. The AENF will be implemented through a structured facility that leverages the existing banking system. The facility will serve as a central hub for providing financial and technical support to eligible agricultural entities for renewable energy projects.

a. Financial support

- The facility will offer a range of financial instruments to support renewable projects in agriculture.
- Loans: Eligible agricultural entities can apply for loans to finance the installation, construction and implementation of renewable energy systems. The loans are to have favourable interest rates and flexible repayment terms tailored to the specific needs of the agricultural sector.
- Grants: In addition to loans, the facility will provide grants to incentivise and subsidise renewable projects that demonstrate exceptional environmental benefits, technological innovation, or socio-economic impact. The grants will be awarded through a competitive selection process.

b. Eligible agricultural entities

- The programme will define the eligibility criteria for agricultural entities to participate in the facility.
- Eligible entities may include individual farmers, farmer co-operatives, agricultural associations, agribusinesses and other relevant stakeholders in the agricultural sector that are involved in primary and secondary agricultural activities.
- Entities will be required to demonstrate their commitment to sustainable agricultural practices and their ability to implement renewable energy projects effectively.

Source: MLAFWRD (2024), Concept Note – Agro-Energy National Facility.

C. Zimbabwe Irrigation Investment

i. The government of Zimbabwe has intensified its bid to promote investment in irrigation development to promote agriculture and economic growth in the midst of climate change and the current El Niño phenomenon, which has struck the country and the region at large. To court potential investors, MLAFWRD organised a high-level Zimbabwe Irrigation Investment Conference on 5 July 2024, endorsed and graced by the country's Presidium and widely attended by potential investors, farmers, development partners, the diplomatic community, finance institutions, the central bank, the private sector and members of the Irrigation Development Alliance in Zimbabwe.

ii. The government is therefore prioritising irrigation development to decisively move away from overreliance on rain-fed agriculture through various initiatives. These include the Public Sector Investment Programme and interventions by development partners and the private sector. The projected national irrigation potential is 2.2 million hectares from the more than 10 600 dams and water bodies.

iii. Agricultural production that is anchored to irrigation is both reliable and highly productive. It offers a real opportunity for year-round production on the land, thereby optimising the utilisation of the land itself, labour and machinery, resulting in improved farmer cashflows and income.

iv. The projected area to be developed is 492 000 ha made up of the currently developed and functional 217 000 ha, and 275 000 ha additional area required during summer. This is intended to increase the area available for maize production from the current average of 75 000 ha to 350 000 ha, which is the minimum irrigated area needed to ensure the nation achieves food self-sufficiency.

v. Estimated production of 1.8 million tonnes of maize is anticipated from this targeted 350 000 ha during summer, and an additional minimum of 1.4 million tonnes of wheat will be produced in winter, making Zimbabwe a net exporter of wheat with production that is adequate to feed the whole nation.

vi. The national functional area under irrigation increased from 175 000 ha prior to 2020 to the current figure of 217 000 ha. Out of the 217 000 ha about 141 000 ha is available for cereals, tobacco and other crops, while 75 000 ha was availed for maize production during the 2023/24 summer season.

vii. There are four classes of land to be developed:

- Land with existing infrastructure (quick-fix rehabilitation) is 21 000 ha.
- Land to be developed around existing dams (completed dams without irrigation or underutilised dams) is 124 150 ha.
- New land to be developed (dams under construction or planned future major dams) is 92 000 ha.
- Land to be developed under Rural Development 8.0 is 45 000 ha.

viii. Only 10% of the country's potential irrigable land is equipped with irrigation infrastructure and only 5% of the potential irrigable land is currently available for cereals.

Source: MLAFWRD (2020).

D. Key DRE market size determination assumptions

i. Maize: According to the Crop and Livestock Report for the 2022/23 summer season, the yield by smallholder farmers under irrigation was 2.44 tonnes per hectare. A1 smallholder farmers under irrigation achieved 3.18 tonnes per hectare. The market size determination uses a rounded up figure of 3 tonnes per hectare.

ii. Tomatoes: A good commercial yield of tomatoes with subsurface drip irrigation and best management practices (BMP) would produce 120-140 tonnes/ha. Other irrigation methods would yield 80-100 tonnes/ha. In sub-Saharan Africa, yields reach 50-60 tonnes/ha (NETAFIM, 2025).

iii. Groundnuts – The maximum yield attained by rural farmers in Chegutu per study by Katema (Katema, 2017).

iv. Mangoes – Production figures based on the report by the Commercial Farmers Union (CFU, 2022).

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