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GREEN JOBS FOR RURAL YOUTH: UNLOCKING RENEWABLE ENERGY'S POTENTIAL IN AGRICULTURE

Credit: Futurepump

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Efficiency for Access Coalition

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This report seeks to provide EforA stakeholders with insights into the employment opportunities arising from the adoption of Decentralized Renewable Energy technologies (DRE) in the agriculture sector. Specifically, this study shows the channels through which DRE technologies contribute to local job creation (both direct and indirect) and overall productivity in agriculture. It provides the first comprehensive country-level estimates to date of employment levels and trends. To achieve this, the report focuses on four value chains—rice, dairy, French beans, and cassava—in India, Kenya, Nigeria, and Uganda.

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ABBREVIATIONS

CBU	Completely built units
CCI	Cold chain infrastructure
CEEW	Council on Energy, Environment and Water
CNC	Computer numerical control machine
DRE	Decentralized renewable energy technology
FGD	Focus group discussion
GDP	Gross domestic product
HQCF	High-quality cassava flour
IRENA	International Renewable Energy Agency
MNRE	Ministry of New and Renewable Energy (India)
PM KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiya
PUE	Productive use of energy
PV	Photovoltaic
SHFs	Smallholder farmers
SWP	Solar water pump
TVET	Technical and vocational education and training
UK	United Kingdom
US	United States
USD	United States Dollar

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EXECUTIVE SUMMARY

Youth unemployment is at an all-time high in sub-Saharan Africa and South Asia. At the same time, populations are growing rapidly in these regions, increasing the need for meaningful employment opportunities. Decentralized renewable energy (DRE) technologies offer a promising solution by creating sustainable growth and green jobs.

DRE technologies generate green electricity near the point of use, reducing reliance on centralized power plants, increasing productivity, and improving sustainability. This creates new and enhanced employment opportunities in rural communities, particularly in agriculture, the largest employer in these regions, with 50% to 85% of the labor force working in the sector. However, high upfront costs, limited product availability, lack of awareness of the benefits, and shortage of local talent hinder the widespread adoption of DRE technologies in emerging economies.

This new research fills many of the data gaps in this sector by analyzing four countries, and quantifying the jobs created by DRE technologies in agriculture. It also provides the first comprehensive estimate of employment levels and trends at the country level.


Photo credit: CLASP

KEY FINDINGS

- The solar irrigation sector in India and Kenya alone has the potential to create more than **115,000 jobs by 2030**, offering higher incomes for graduates from DRE courses.
- DRE creates opportunities for farm workers to transition into less physically demanding roles, **avoiding long-term job displacement and improving life quality.**
- DRE innovations significantly **reduce labor-intensive tasks for women**. In India, mechanized roti-rolling can save women up to 1,800 labor hours per year.

RECOMMENDATIONS

- Investors, financiers, philanthropies, and governments should **improve financial support and market incentives to increase the demand for DRE equipment** in the agriculture sector to address consumer affordability — the biggest challenge for the growth of DRE markets. This includes creating better financing options to make it easier for farmers to adopt these technologies.
- Governments and stakeholders need to **strengthen the manufacturing sector for solar equipment** to create thousands of skilled jobs in the DRE industry. For example, India could see up to 5,500 manufacturing jobs created in the solar water pump sector by 2030.
- Educational institutions, government bodies, DRE companies, and development programs need to **collaborate to strengthen the DRE workforce**. Technical and Vocational Education and Training Institutes (TVETs) can play a key role in **rural skill development** but face challenges like outdated curricula and high tuition costs. To support labor transitions in the DRE sector, integrating short-term internships, apprenticeships, and job training programs is essential.
- **Improving coordination between agricultural and energy stakeholders** is critical to improve the adoption of DRE products. Uganda has successfully integrated renewable energy into its agricultural development plans by assigning responsible parties to establish key performance indicators (KPIs) for implementing renewable energy targets. This approach has stimulated growth in the DRE market and attracted business investment in the sector.

Table 1: Summary of DRE sector job creation in the focus countries

COUNTRY	INDIA	KENYA	NIGERIA	UGANDA
Value chain selected	Rice Dairy	French bean (green bean)	Cassava	Dairy
DRE technology prioritized	**Rice** Solar Water Pumps (SWP) Solar rice mills **Dairy** Solar milk chillers Solar fodder grower units Solar milking machinery	SWPs Cold storage	Cassava graters Cassava millers	Solar milk chillers
Jobs created	Up to 77,000 jobs can be created in 2030 due to adoption of the SWP Up to 2,300 workers can be employed by the solar mill sector by end of 2030	Up to 38,000 jobs can be created in Kenya due to the use of SWP	Few jobs created due to adoption of cassava graters or miller as the market is in infant stage	Limited job creation as very few solar milk chillers have been installed

INTRODUCTION

1.1. Background and context

This study provides insights into the job creation potential within four agricultural value chains—rice, dairy, French beans, and cassava—in India, Kenya, Nigeria, and Uganda; and how DRE technologies affect employment levels on and off the farm. Specifically, this study shows the channels by which DRE technologies contribute to local job creation (both direct and indirect) and overall productivity in agriculture. It provides the first comprehensive country-level estimates to date of employment levels and trends within the four value chains. The findings will inform a balanced mix of policy and market-oriented solutions to maximize employment and sector growth.

Agriculture is the largest employer in most sub-Saharan African and South Asian countries, with over 50%—and as high as 85%—of the labor force working in the sector.[1] It is also a major contributor to these economies, accounting for 35% of Africa's Gross Domestic Product (GDP) and 18% of India's GDP.[2,3] Smallholder farming[i] dominates the agricultural landscape in many developing economies, accounting for over 80% of total farming in Africa and South Asia, and with a global population of 500 million smallholder farmers (SHFs) worldwide.[4]

However, farming faces the twin challenge of increasing food production and productivity while mitigating, and adapting to, negative climate impacts. On the other hand, the current farming system is a direct contributor to accelerating climate change due to its dependence on fossil fuels, in the case of diesel water pumps.[5]

DRE powered agricultural technologies—which include solar-powered milling, drying, irrigation, cold storage, and cold chains—have a great potential to boost incomes, improve livelihoods, and expand energy access in energy-poor regions. Solar machinery and equipment help farmers to cope with extreme weather conditions such as droughts, while also expediting agricultural processing, and even increasing working hours through lighting. In addition, DRE has proven to be a major driver of employment in emerging economies. According to Power for All's latest Powering Jobs Census, the DRE sector created 374,000 direct jobs in Africa in 2022—as many, if not more, than the fossil fuel industry.[6]

Across the African agricultural sector, there is significant latent job creation and food security potential that can be unlocked through fast, affordable access to key productivity inputs, including electricity. Decentralized energy systems play a vital role in achieving universal energy access and fostering inclusive growth in underserved areas. However, despite growing demand for DRE technologies over the past decade, recent studies suggest a shortage of local talent needed to scale the sector in energy-poor countries.[7] In addition, the lack of data on direct and indirect jobs at the farm level has been a limiting factor in developing the necessary human capital pipeline—with skills and job training at the center—that meets the sector's growing needs.

1.2. Literature review: past studies on DRE employment

A review of past studies reveals the significant impact of DRE technologies on job creation in emerging markets. Reports from IRENA, Power for All, and EforA highlight the current and potential employment benefits of DRE, particularly in rural areas. Key insights include:

- **IRENA** estimates 13.7 million jobs in the global renewable energy sector, with nearly five million in solar PV. DRE investments create substantial employment opportunities, with 58 full-time jobs per $1 million USD invested in mini-grids.[8]
- **Power for All** shows that the off-grid solar sector is a major employment driver, resilient to economic shocks, and growing rapidly post-pandemic.[9]
- **EforA** indicates significant job opportunities in Kenya's solar irrigation sector, estimating 7,000 to 10,000 direct jobs by 2027.[10]

i Smallholder agriculture typically includes both farming, usually on land sizes of less than two hectares, and pastoralism.

This report builds on these studies and expands the knowledge base in two significant ways. First, it examines the impact of DRE technologies on indirect employment. While most current literature focuses on direct job creation, there is a lack of studies estimating the impact of DRE technologies on indirect and productive use employment. This report seeks to fill this research gap. Second, it demonstrates the unique impact of DRE technologies on the agricultural labor force. The widespread adoption of DRE technologies, or any type of agricultural machinery, is expected to bring about a seismic shift in rural employment, enabling underemployed and unemployed youth to transition into more productive sectors of the economy. However, this process may also involve short- and long-term job displacement. There is limited existing research to understand these dynamics, which this report aims to address.

1.3. Approach

Employment type scope: This report classifies jobs into the following three categories.

1. **Direct jobs:** Jobs created directly by the economic activity of a DRE company. Some of the typical roles in this category include installation technician, solar installer, or salesperson.
2. **Indirect upstream jobs:** Jobs created because of the backward linkage in the DRE value chain. These jobs are associated with the manufacturing, assembly, and importing of components required in the production of DRE equipment. For example, an increase in demand for pumps will result in an increase in solar PV manufacturing. This will be counted under indirect upstream jobs. Unlike direct jobs, these jobs are not necessarily new jobs. They can be a reallocation of labor into producing DRE agricultural equipment. This might result in overestimation of indirect upstream jobs.
3. **Indirect downstream jobs:** This refers to both existing and new jobs that have been created or enhanced due to the use of DRE applications. These are further divided into two subcategories:
    a. **Onsite farm jobs:** These are farm-level jobs created to operate the machinery. The type of jobs here includes rice miller operator, cassava grater operator, etc.
    b. **Agricultural value chain jobs:** These are jobs created through increased productivity and production resulting from the adoption of DRE equipment. For example, in some instances, adoption of SWPs can double rice farmers' production. On the other hand, DRE technologies can make agriculture more efficient, increasing the reliability of produce and thereby increasing yield or production.

Figure 1: DRE technologies selected for each value chain

India

Rice

- Solar water pump
- Solar rice mill

Dairy

- Solar milk chiller
- Solar milking machinery
- Solar fodder grower unit

Kenya

French Beans

- Solar water pump
- Cold storage

Nigeria

Cassava

- Cassava grater
- Cassava miller

Uganda

Dairy

- Solar milk chillers/ refrigeration

This will inevitably increase the demand for workers who will harvest, transport, or process the rice.

Country and value chain scope: The study focusses on India, Kenya, Nigeria, and Uganda, prioritizing one key agricultural value chain per country based on market size (export and local market) and other social factors, such as women's share of employment, the role of the crop in the country's dietary consumption, and the number of SHFs engaged in the value chain.[ii]

India: Rice and dairy value chains
Kenya: French bean value chain
Nigeria: Cassava value chain
Uganda: Dairy value chain

Technology scope: After exhaustively mapping all DRE technologies available in the market for each value chain, technologies with a high current level of adoption and better prospects for near-term adoption were prioritized. The list of DRE technologies considered for each value chain is discussed in each value chain chapter. The figure below contains the list of DRE technologies selected for each value chain.

A detailed methodology of this report is presented in the appendix section.

ii See the Methodology appendix for details on value chain analysis and prioritization

Photo credit: CLASP

KEY FINDINGS

The impact of DRE technologies on employment is country-specific and value chain-specific. However, we have identified some common patterns discussed below. A more detailed assessment of each value chain by country can be found in chapters 4—8, while the table below contains the headline job figures for each country and value chain.

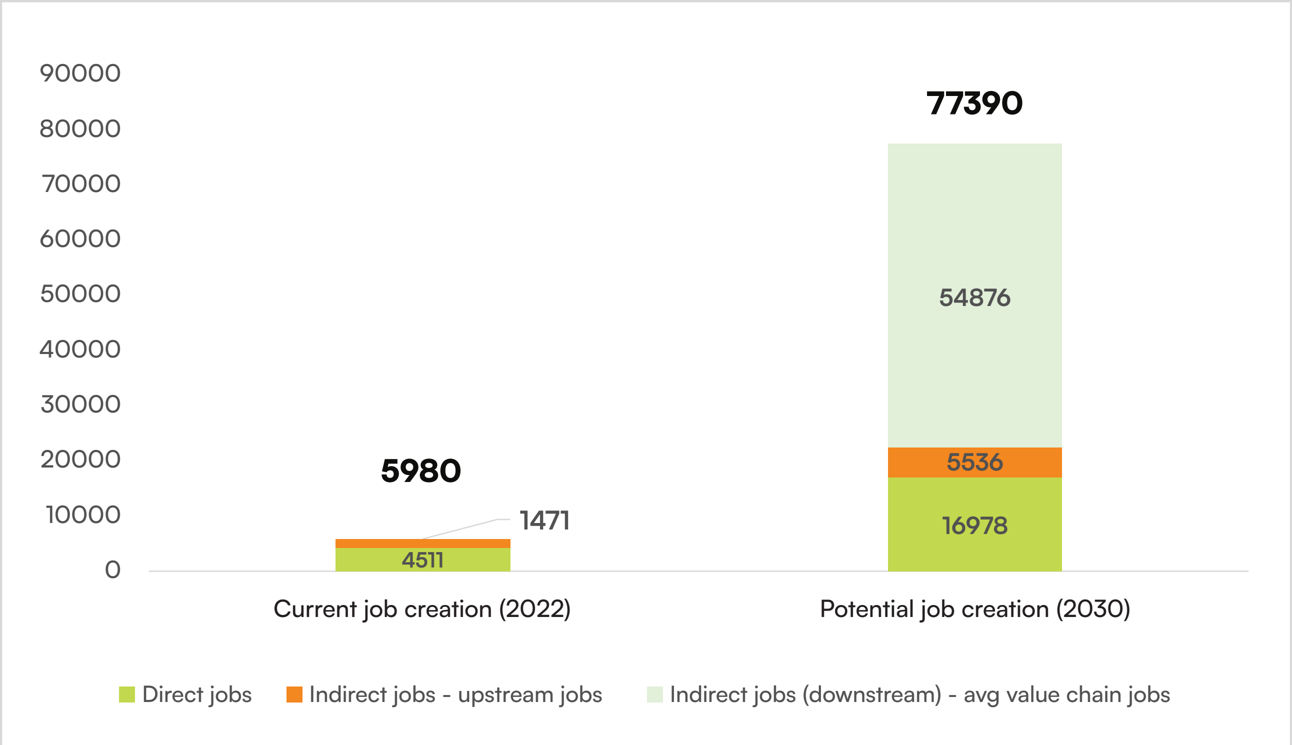
2.1. Significant job opportunity exists in the solar irrigation sector in India and Kenya

In India, the SWP sector currently employs 6,000 people directly and indirectly. By 2030, the SWP sector in India could create up to 77,000 jobs.

Meanwhile, in Kenya, the sale of pumps is currently providing close to 500 direct jobs and is projected to reach 5,000 jobs by the end of 2030. This presents a major job opportunity for underemployed or unemployed rural youth.

Currently, other technologies discussed in this report create much fewer jobs as most of them are in the early stages of product development. Users and private retail companies that were interviewed indicated that they expect the demand for these technologies to increase in the near future. Similar to SWPs, this could result in thousands of new jobs over time. These opportunities can arise from either the bulk deployment of new technologies or the retrofitting of diesel-powered machinery.

Figure 2: Total number of jobs created due to the use of SWP (India)



Source: author's analysis

Table 2: Total serviceable market and resulting jobs in the SWP market by 2030[11,12]

COUNTRY	TOTAL SERVICEABLE MARKET FOR SWP BY 2030 (IN UNITS)	PROJECTED JOBS BY 2030 (NUMBER OF PEOPLE EMPLOYED)
Kenya	470,400	38,000
India	568,000	77,000

2.2. DRE could support more job creation if countries strengthened their solar manufacturing sector

Among the four focus countries, India has the most developed manufacturing sector for solar modules and solar appliances. Except for electronic components, all parts for DRE technologies are locally sourced in India. The Indian SWP sector is projected to support 5500 manufacturing jobs by the end of 2030. These workers hold highly technical positions such as welders, CNC operators, laser cutting operators, and more.

Nigeria also has a growing manufacturing sector.[13] Most parts of graters or millers are manufactured locally. As owners of diesel-powered equipment decide to replace their machinery, this will create more manufacturing jobs. However, although there is a growing solar module assembly in Nigeria, the country largely relies on imports for its solar module needs.[14] Hence, jobs for standalone solar equipment manufacturing will be created outside the country's borders unless Nigeria ramps up production of solar modules in the coming years.

Uganda and Kenya largely import completely built units (CBU) of SWPs and other DRE equipment.[15] Local assemblers in Uganda, Kenya, and Nigeria face challenges such as unattractive import tariff regimes, lack of quality standards, and market uncertainty.[16] Addressing these challenges will enable African countries to capture maximum value from the increased uptake of DRE equipment, thereby creating highly skilled manufacturing jobs.

2.3. Addressing additional challenges related to agricultural barriers is critical to increase adoption of DRE products

The major barriers to the mass adoption of DRE technologies need to be addressed to realize its potential. Today, most DRE technologies are economically more competitive than alternatives over their lifetime, but end users and companies identify upfront cost as the major barrier for farmers.[17] India's PM KUSUM *(Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan)* scheme is one example of a successful government policy that addressed this barrier by subsidizing up to 60% of the initial cost of SWPs.[18] To increase the uptake of other technologies, similar innovative financing products with longer maturity periods and affordable interest rates need to be designed and implemented.

Additionally, the uptake of DRE equipment has been limited by the sub-commercial scale of smallholder agriculture in most of the developing world.[19] Farmers in the Focus Group Discussions (FGD) indicated that the challenge of securing an off-taker for their additional produce limits their appetite to adopt DRE equipment. Additionally, farmers are unable to realize productivity gains due to the unavailability of modern agricultural inputs.

This clearly demonstrates that efforts to increase the adoption of DRE equipment cannot happen in a vacuum and need to be part of a holistic strategy to transform the agricultural sector sustainably. This will require stakeholders in the food, energy, and water ecosystems to collaborate through joint planning and execution of interventions.

2.4. Product development stage of a DRE technology affects quantity and type of employment

The adoption of DRE technologies is a relatively recent phenomenon. Most of these appliances are still in the early stages of product development.[20] However, these technologies are demonstrating different trajectories. We have categorized this report's focus technologies into three groups: nascent, emerging, and ready to scale. The table below presents the definition of each product stage category and the technologies within each category.

The product development stage strongly affects the quantity and type of employment created in the value chain. The SWP sector in India and Kenya, respectively, employs 4,500 and 500 people.

Table 3: Product development stage for DRE technolgies

Definition	Nascent	Emerging	Ready to scale
Description	• Few units deployed (< 100 units) • Deployment led by non-profits • Pilot phase	• Medium level of technology deployment (>100 units) • Few private sector players	• Large scale deployment (in thousands) • Private sector led and fully commercialized
Technologies	**India** • Solar milking machinery **Nigeria** • Cassava grater • Cassava miller **Uganda** • Solar milk chillers / refrigerators	**India** • Solar rice mill • Solar milk chiller • Solar fodder grower unit **Kenya** • Cold storage	**India** • Solar water pump **Kenya** • Solar water pump

For nascent technologies such as cassava grater, due to limited adoption, only a few people are directly employed by companies. However, these technologies have a high potential for job creation as adoption increases and the technologies become mainstream.

There are also other distinct patterns in employment for each stage of the product life cycle. For example, for emerging and nascent technologies, the employees tend to be concentrated in few companies as compared to ready to scale products. On the other hand, companies who provide DRE technologies in the emerging and nascent category tend to have a higher share of staff who work in the office and especially in research and development functions.

Figure 3: A mapping of the SWP value chain jobs and the hard skills needed for these jobs[21]

Stage	Research and Development	Manufacturing and Assembly	Admin, Sales and Marketing	Site Assessment and Preparation	Installation	Maintenance and Repair
Hard Skills	• Prototype building e.g., including pump sizing • Entrepreneurship • Advocacy • Financing & carbon market knowledge	• Component analysis of solar controlled boxes, customized connecting cables, solar panels • Initial screening and quality checks of faulty devices to identify product failure reason	• Communication skills • Customer service • Understanding of solar and irrigation systems and equipment • Financing	• Water reservoir assessment • Soil Assessment • Agronomy • Site management • Solution recommendation including type of solar panel positions, irrigation system • Borehole drilling	• Weatherproofing solar installation in accordance with local safety regulations and the specifications of the manufacturer • Electrical installation including DC management and inverters • Mechanical installation • Identification and resolution of potential hazards	• Electrical and mechanical troubleshooting • Cleaning of solar PV • Meter reading • Initial screening and quality checks of faulty devices to identify product failure reasons • Technical repairs including post-repair checks
Professions	R&D Expert Entrepreneur	Quality Assurance Technician	Administrator/ Manager Carbon Finance Specialist Salesperson/ Marketer	Solar Installer/ Field Technician Agricultural Irrigation Technician	Solar Installer/ Field Technician Quality Assurance Technician Technician Assistant	Solar Installer/ Field Technician Agricultural Irrigation Technician

2.5. Greenfield creates more job opportunities than brownfield deployment

In the context of this report, brownfield deployment is defined as converting or retrofitting diesel-powered units into solar-powered units. In contrast, greenfield deployment refers to the commissioning or deployment of new solar-powered agricultural equipment.

Brownfield deployment is the low-hanging fruit for solar technology adoption in areas with existing diesel-powered machinery. For example, owners of diesel cassava graters in Nigeria have shown interest in retrofitting their equipment as this carries a lower cost compared to purchasing new equipment. In this instance, fewer jobs will be created compared to greenfield investment. In Nigeria's cassava case, the cassava grating companies will not hire new employees as operators of diesel graters will transition to operating electric graters.

Greenfield deployment will impact agricultural value chain jobs. This is because, in most instances, users are transitioning from manual processes to mechanized processes, leading to increased production and productivity, which in turn results in increased employment. In some cases, greenfield deployment can result in job losses, although this is rare in the long term. On the other hand, there will not be significant additional agricultural value chain jobs in brownfield deployment because converting diesel-powered machinery to electric will not significantly increase productivity. Some FGD participants have indicated that the cost savings from retrofitting diesel-powered equipment will indirectly result in employment creation; however, this type of employment was not within the scope of this report.

2.6. Women have the most to gain from DRE technologies, but gender-conscious interventions are necessary to increase their participation in the labor force

DRE technologies will have immense benefits for women by improving their lives and livelihoods. Women are predominantly responsible for repetitive and labor-intensive tasks in most agricultural value chains. In Kenya's French bean sector, women are responsible for sorting, grading, and quality control, while in Nigeria's cassava sector, women are responsible for washing and peeling. Replacing these tasks with solar-powered mechanization will free up much-needed time for women. For example, solar-powered roti-rolling makers are gaining increasing traction in India due to their ability to reduce drudgery and save time. Women who replace manual roti rolling with mechanized roti rolling can save up to 1,800 labor hours per year. If all of this saved time is used towards work, it will generate close to $6,000 USD additional income for the worker. However, this saved time is also repurposed towards childcare or other leisurely activities.

Women play a crucial role in the DRE sector's labor force. IRENA estimates that total jobs in renewable energy are currently near 14 million, with the average share of female employment at 32%—, which is 10% higher than that of the broader energy sector.[22] For the solar sector, the female shares climb to 40%. Within decentralized renewables, Power for All estimates that women comprise between 28% and 41% of jobs in sub-Saharan Africa, depending on the country.[23] As the adoption of DRE technologies in the agriculture sector grows, it will create additional employment opportunities, especially for women.

However, for women to capture the benefits from DRE technologies, some existing barriers to their participation need to be addressed. Within Indian and Africa's social and economic contexts, gender disparities persist, hindering women's access to employment in the DRE sector. Women-specific and targeted initiatives have proven successful in elevating women in the DRE sector. For instance, in India, the *Suryamitra Skill Development Program* and initiatives by the Skills Council for Green Jobs are notable in their efforts to train women and promoting gender-inclusive policies[24] In addition, the design of the technology needs to be gender inclusive in terms of the height and weight of the machine.

Photo credit: Hamish John Appleby/IWMI

THE IMPACT OF DRE TECHNOLOGIES IN INDIA'S RICE VALUE CHAIN

Chapter summary

- Rice is an economically significant commodity in India's agriculture sector. India is currently the second-largest producer of rice, with production exceeding 175 million tons per year.[25]
- USD After studying India's rice value chain end-to-end, SWPs and solar/electric milling have been identified as technologies with ahigh potential for job creation.
    - The market for SWPs is growing rapidly in India. In 2022, 151,000 SWPs were sold, and demand is expected to reach 568,000 units by the end of 2030—of which 30% (172,000 units) is expected to come from rice farmers. The market size for SWPs is projected to grow by 18% year-on-year.
    - On the other hand, the market for solar rice mills is nascent, with only 100 units currently installed.[26] However, demand is expected to grow by 28% year-on-year, and it is projected that 600 units will be installed by the end of 2030.
- The application of DRE technologies has immense potential for job creation especially for rural youth in India.
    - In the case of SWPs, up to 77,000 jobs can be created by 2030. Approximately 70% of these jobs (~55,000 jobs) will be in the downstream agricultural value chain.
    - This growth will be driven by an increased number of non-irrigating rice farmers adopting SWPs. An additional 17,000 jobs are expected to be created by SWP providers.
    - For solar rice mills, most of the jobs are expected to be created by mill operators themselves. According to the FGD interviews, up to four workers are required to operate a multi-stage mill. Therefore, based on the market size projection, up to 2,300 workers could be employed by the end of 2030.

3.1. Rice value chain in India

India currently produces 177 million tons of rice, accounting for almost a quarter of global rice production.[27] With a local rice market estimated at $42 billion USD, India is currently both the second-largest producer and consumer of rice after China. At $9.7 billion USD, the country is also the world's largest exporter of rice. In addition, 43 million farmers in India are dependent on the production of rice. Most of these farmers are SHFs with an average landholding size of 1 ha.[28]

Figure 4: A representation of India's rice value chain and major agricultural equipment used in the value chain[29]

	Input supply	Production	Trading	Processing	Wholesale & distribution	Retail	Consumption
Main Activities	• Seed research • Production of seed and fertilizer • Last mile distribution	• Land preparation • Transplantation of seeds • Irrigation • Weeding • Harvesting	• Aggregating • Transporting produce • Storing	• Parboiling • Milling • Bagging	• Aggregating • Transporting • Storing • Distribution	• Purchasing rice from wholesalers • Storing • Selling	• Purchasing from retailers • Final consumption
Agriculture equipment used	• Industrial level fertilizer and seed production	• Tractor • Irrigation systems • Paddy puddler • Rice transplanter • Combine harvester	• Trucks • Warehouses	• Steel dehusker • Rubber husker • Solar powered rice huller/ miller	• Trucks • Warehouses	• N/A	• N/A

Source: Rice value chain assessment in Eastern India, Analysis of Rice Value Chains. © 2022 Power for All. All rights reserved

The Indian rice sector is a multi-layered and complex value chain involving multiple stakeholders, including farmers, private companies, and the government. The government is a major buyer of India's rice, enabling it to play an important role in setting the price of rice.[30] In 2023, the Indian government banned the export of non-basmati white rice, resulting in a surge in international rice prices.[31] Private companies such as paddy traders, millers, wholesalers, processors, and others are also involved in the value chain. The following figure illustrates the rice value chain in India.

India has a moderate but growing level of mechanization in its rice sector. The highest level of mechanization is observed in the harvesting and threshing stages. Out of all rice farmers, 60% use harvesting and threshing equipment. On the other hand, rice transplanting—the process of transporting rice seedlings from the nursery to the field—is done manually in most parts of the country, with only 20% of farmers using modern rice transplanters.[32]

India has a lower level of mechanization than the world's largest rice producer, China. Close to 94% of rice in China is harvested using machinery, compared to just 60% in India.[33] The unavailability of power is the main reason for the relatively lower level of mechanization in India.[34] India has made tremendous progress in increasing power availability per hectare, increasing from 0.3 kW in 1970 to 2.54 kW in 2023, yet erratic power availability and prevalence of areas with no power are hindering the adoption of mechanization.[35]

3.2. DRE technologies in India's rice value chain

The use of DRE technologies can have a transformative impact on India's agriculture sector. Although 97% of Indian households are electrified, most farmers don't not have power for their agriculture equipment.[36,37] As a result, farmers resort to using diesel or manual labor for some of their agricultural tasks. In addition, while electrification rates are high, millions of households, especially those at the bottom of the pyramid, still lack reliable and dependable power.[38] Therefore, DRE technologies will have an important role to play so that Indian farmers can use power for income-generating activities.

Most of the existing agricultural machinery in India uses fossil fuels or diesel power.[39] Diesel powers tractors for field preparation and pumps for irrigation. Further operations such as sowing, transplanting, harvesting, and threshing are mostly done manually.[40] While the increasing trend of using machinery has enabled Indian rice farmers to improve their yield, the reliance on fossil fuels is squeezing their margins when diesel prices increase.[41] Additionally, the their health is negatively affected by the daily use of diesel-powered equipment. Exhaust from diesel pumps can cause lung cancer.[42]

DRE provides an alternative to fossil fuel-powered machinery, manual labor, and animal power. DRE technologies such as solar mills have the advantage of improving the throughput and quality of products over manual or animal-powered processes such as manual milling.[43] Equipment such as SWPs can achieve the same productivity gains as fossil fuel-powered alternatives such as diesel pumps at a cheaper lifetime cost.[44]

The present study identified SWPs and solar mills as the DRE technologies with the highest potential to scale within India's rice value chain. Many processes in India's rice value chain can be replaced with renewable energy-powered machinery. However, SWPs and solar milling were selected because they are already at scale or ready to scale. There are also prototypes of these technologies that are comparable to fossil fuel-based alternatives in terms of price or throughput. The following table provides a brief description of both technologies.

Use of SWPs in India is growing, with close to half a million currently in operation.[45] The PM-KUSUM program played a big role in catalyzing the SWP market. It offered subsidies to both off-grid and on-grid farmers for the purchase of solar pumps. Since its inception in 2019, the scheme has witnessed a remarkable surge in demand, with the adoption rate of pumps more than doubling. According to this report's analysis, based on the market trends, the market for SWPs is expected to have an 18% year-on-year growth and reach 568,000 new pumps installed by the end of 2030. This market projection exercise assumes the PM-KUSUM scheme will run until 2030. Figure 5 overleaf illustrates the progression of the Indian SWP market.

Table 4: Main solar-powered technologies used in India's rice value chain

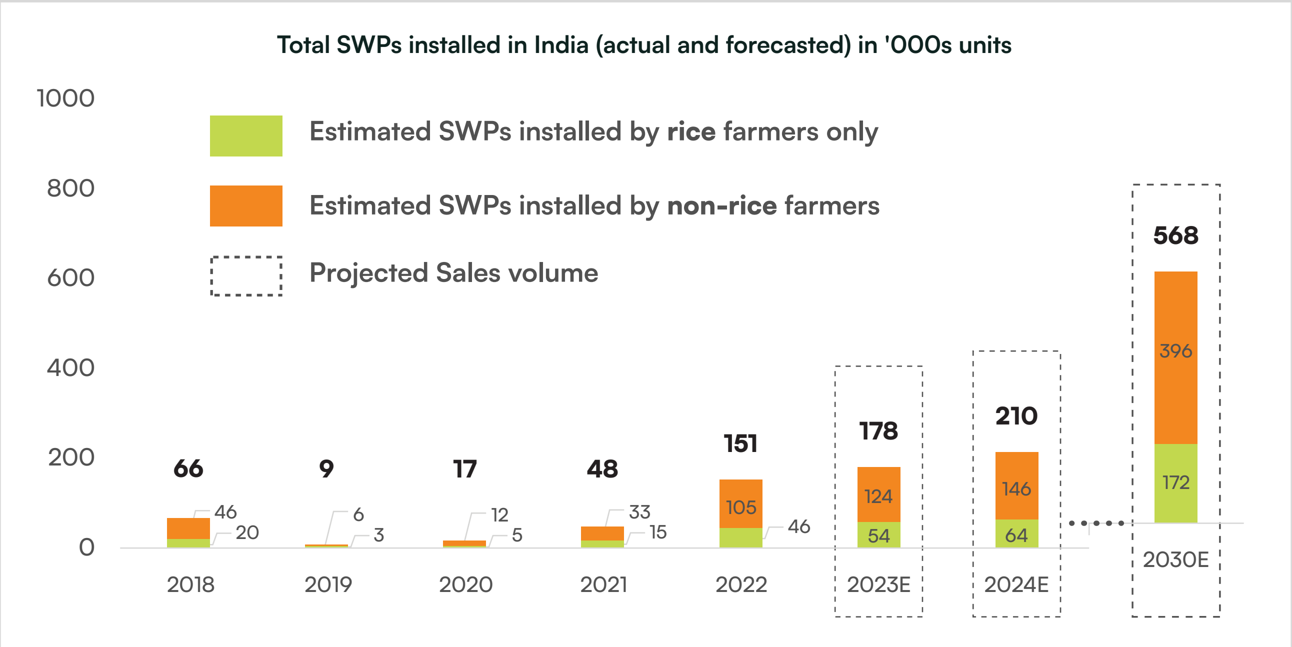
TECHNOLOGY SPECIFICATION	SOLAR WATER PUMP	SOLAR-POWERED RICE MILL
Product Category	**High-capacity pump:** Can irrigate more than 1 ha. **Micropump:** Used to irrigate less than 1 ha of land	**Single-stage mill:** Used in small villages. Can mill 20 - 100 kg per hour **Medium stage mill:** serves a larger market. Has the capacity of milling 100 - 200 kg per hour **Multistage mill:** Has the capacity to mill 200 - 500 kg per hour
Cost	$575 - 3,165 USD depending on the size of the pump	$10,000 USD for a typical medium-stage mill
Payback period	13 - 32 months depending on the size of the pump	52 months for a typical medium-stage mill

(Source: Interview with technology provider companies, FGD, CEEW[46])

Solar-powered milling is currently used for rice pre-cleaning, hulling, and polishing.[47] The demand for solar-powered milling is still nascent but it is expected to grow in the near future. According to a solar rice-mill provider, 33% of rice milling is currently done by small-scale millers. There are over 82,000 registered single rice millers in the country.[48]

In addition, the demand for small-scale mills positively correlates to rice production. If India improves its rice productivity and there is a paddy

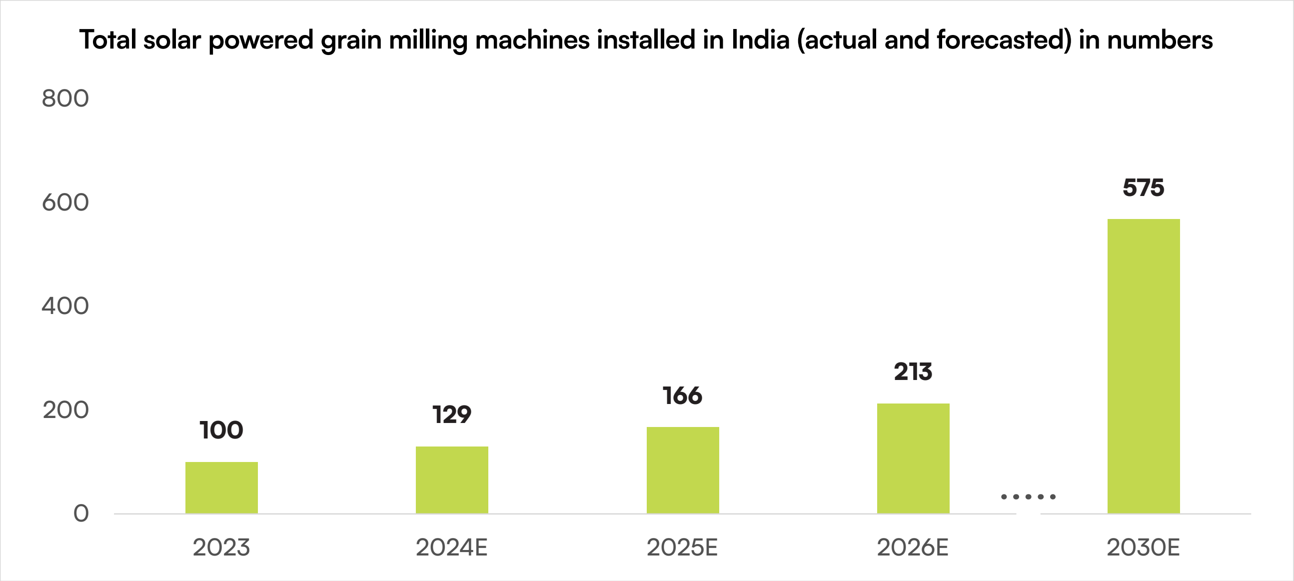
Figure 5: Demand for solar water pumps in India



(Source: Author's analysis, data collected from Indian Ministry of New and Renewable Energy (MNRE) and other sources)

surplus, the demand for mills is also expected to increase. Currently, 100 solar-powered rice mills are installed in India[49], but demand is expected to grow by 28% on a year-over-year to reach 600 units per year. In addition, according to a forthcoming study by CLASP, the serviceable market size for rice milling in India is expected to reach 340,000 units by the end of 2030.[50]

Figure 6: Demand for solar mills in India[iii]



Source: Author's analy sis, CEEW, data collected from FGDs

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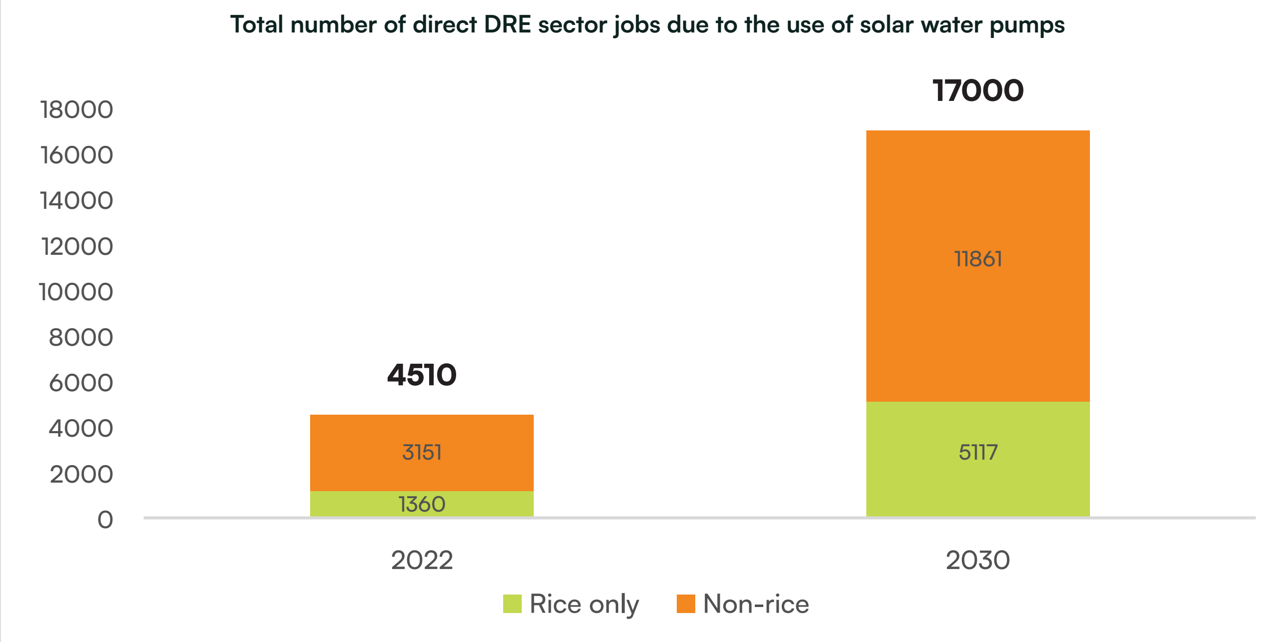
iii This forecast represents a conservative estimate of demand for solar mills. The current number of solar-powered mills installed may be higher, but they might be unaccounted for in reports estimating current demand.

"The demand for small-scale milling is essentially doubling every year. It will require at least seven companies like ours to meet demand."

— CEO of Solar Milling Company

Figure 7: Number of workers hired by DRE companies to service the SWP market in India



Source: Author's analysis

3.3. The employment effect of DRE technologies in India's rice value chain

Solar water pump (SWP)

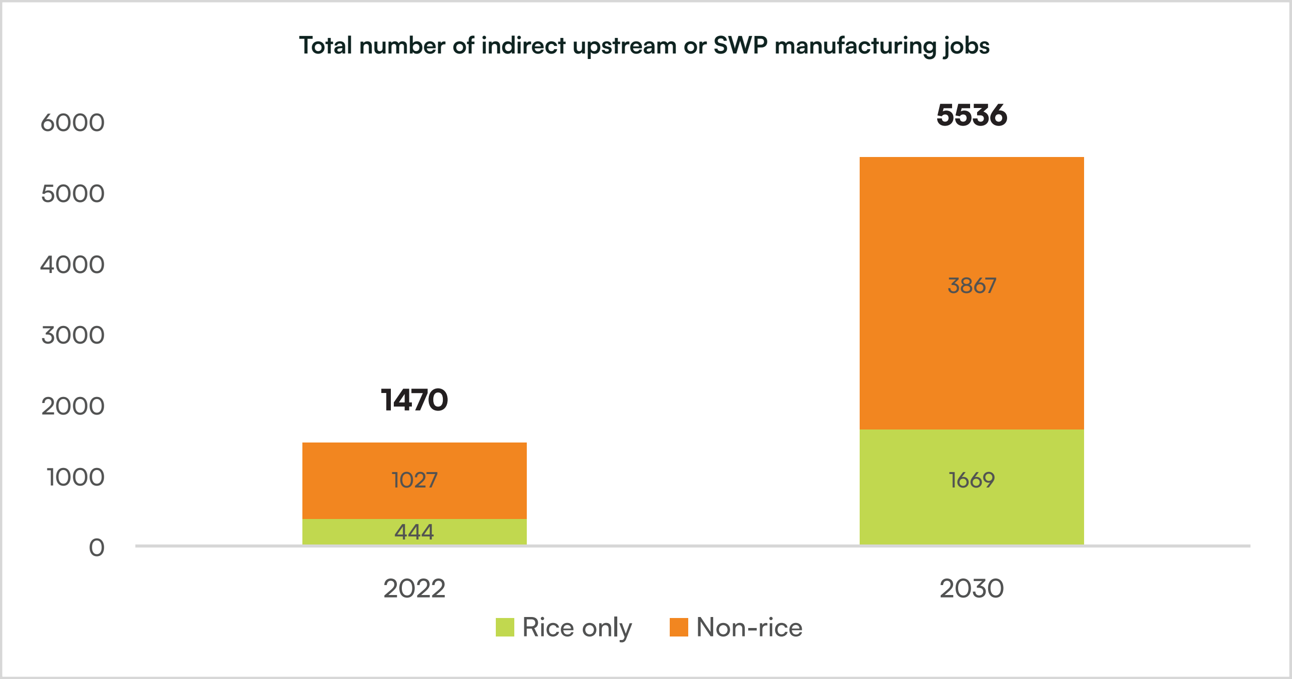
The growing demand for SWPs has increased the demand for workers. Currently, the demand for SWPs has created close to 6,000, direct and indirect jobs. Around 75% of those jobs are direct jobs created by DRE companies while the rest are indirect jobs attributed to manufacturing the components of SWPs, such as solar panels. SWP providers currently employ around 4,500, workers with 30% of the workforce employed to service rice farmers. According to this report's analysis, with the growth in the demand for these pumps, this figure is expected to rise to 77,000 jobs by 2030.

By 2030, almost 4,500 of the workers will be associated with the rice value chain. DRE companies hire quality assurance technicians, field technicians, solar installers, salespersons, after-sales staff, etc., to deploy, operate, and maintain SWPs.[51] Indian DRE companies indicated that they hire a mix of full-time and part-time workers. Most of the part-time workers are on-site technicians hired to troubleshoot when there is a technical problem with pumps.

The growth of SWPs also creates jobs in the upstream stage of the SWP especially in the manufacturing stage. India has a thriving SWP manufacturing sector. In 2024, India achieved self-sufficiency in solar modules manufacturing while the country exported $1.03 billion USD worth of solar panels.[52] The increased demand for pumps is will likely be met by local assemblers or manufacturers. Currently, it is estimated that more than 1,470 workers are engaged in SWP manufacturing with this figure expected to 5,540 surpass, by the end of 2030. These workers hold highly technical positions such as welders, CNC operators, laser cutting operators, etc.

There is indirect downstream employment that arises as a result of the growth in pump demand. In this report, downstream indirect employment is classified

Figure 8: Number of workers hired in SWP manufacturing



Source: Author's analysis

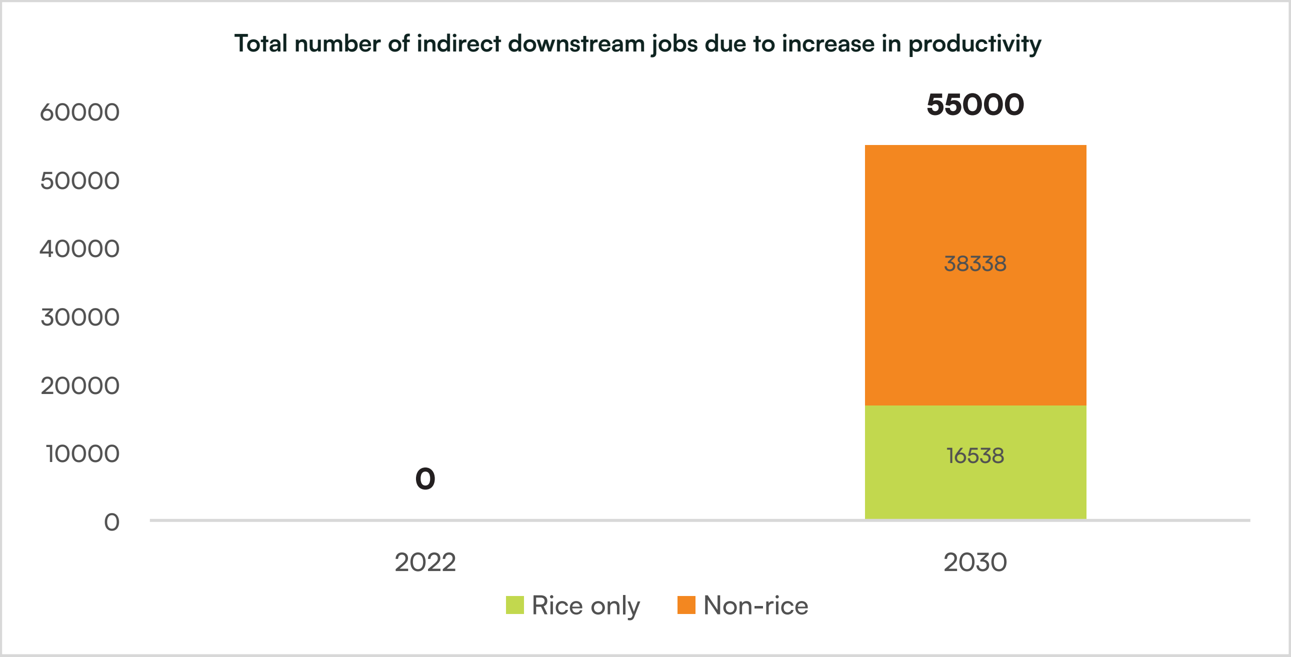
under two sub-categories: DRE mechanization jobs and agricultural value chain jobs. The first measures jobs gained due to the introduction of DRE technology and/or jobs lost due to the replacement of labor-intensive equipment. On the other hand, agricultural value chain jobs measure the increase in jobs in the rice value chain due to an increase in production. SWPs enable farmers to harvest more than once a year and this will inevitably result in creating more jobs in processing, transporting, and marketing of rice.

There is no significant gain or loss of DRE mechanization jobs due to the use of SWPs among Indian rice farmers. Farmers either operate their SWPs themselves or rely on family labor for operation, thus external laborers are not hired. However, farmers interviewed during FGDs indicated that SWPs have an indirect impact on job creation. They mentioned that SWPs contribute to increased net farm income by saving on fuel costs or by generating additional revenue through crop intensific tion. Consequently, some farmers have been able to hire daily laborers specifically or the harvesting phase. Since this aspect is beyond the scope of this report, it has not been measured.

This report estimates that the adoption of the SWP and the associated increase in production is expected to result in almost 55,000 new jobs by the end of 2030. Around 16,500 of those jobs are expected to be created in the rice value chain. According to focus group discussions and expert interviews some of the jobs will include workers who will be hired as drivers, workers at rice processing facilities, jobs in the retail sector, etc.

Another interesting aspect of the agricultural value chain or productivity gain-related jobs is the timing of job creation. It is expected that there will not be any new productivity gain in job creation. Expert interviews and FGDs have revealed that the majority of the early adopters of SWPs are farmers who were previously using diesel or electric pumps. Hence, there will not be a significant inc ease in production due to the use of SWPs. However, in the coming few years, the share of non-irrigating farmers who own SWPs is expected to increase. This will enable those farmers to harvest multiple times during the year instead of only once. The following chart shows the job creation impact of SWP due to the increase in the production of rice or other crops.

Figure 9: Number of jobs created due to increase in production of rice or other crops



Employees of SWP company report improvement in their skills

In a job satisfaction study conducted by Oorja Solutions, a major Indian provider of irrigation, milling, and cooling services, the majority of employees indicated that they are learning relevant skills such as irrigation management, business communication, and equipment maintenance. The job holders also reported feeling a sense of accomplishment from their work. They noted that they have earned great trust and respect from the community. Over half of the employees are first-time workers, demonstrating that DRE companies provide decent entry-level jobs for rural youth.

Source: Oorja Impact Performance Report

Solar rice mill

The solar rice mill is an emerging technology, currently with only 100 units installed, but it holds significant potential for expansion. FGD participants have highlighted the increasing demand for small-scale milling. The unreliability of electric mills due to erratic power supply and rising fuel costs for diesel mills contribute to making solar rice mills an attractive technology. If the growth potential of solar rice mills is realized, it could lead to substantial employment opportunities. The table below summarizes the job creation potential of solar rice mills.

Table 5: Job creation opportunities in solar rice-mill technology

JOB CATEGORY	CURRENT JOB CREATION (2023)	POTENTIAL JOB CREATION (2030)
Direct jobs	30-35 workers	172 — 200 workers
Indirect jobs - upstream	4-8 workers	23 — 46 workers
Indirect jobs- at the farm level	4 workers per multistage mill ~ 400 workers (total of 100 mills)	2300 workers
Indirect jobs — due to increase in productivity	None or insignificant Since most farmers already use diesel mill, there is limited to no increase in productivity	None or insignificant

A solar rice-mill provider for this interview indicated they currently have 30—35 workers. As per the company, half of the staff are full-time employees, including management staff such as the CEO and research and development. The remaining half are part-time employees who work on installation and after-sales service. This company has so far installed 100 solar rice-mill units. The demand for solar rice mills is expected to reach 575 units by the end of 2030. To service this market size by 2030, it is estimated that up to 200 workers will be hired by DRE companies.

Since most of the components for solar rice mills are locally sourced in India, the increase in demand for solar rice mills is expected to lead to the creation of local manufacturing jobs. Based on an interview with a solar rice-mill company, four to eight full-time manufacturing jobs have been generated for the installed solar mills thus far. With the expected growth of the solar rice-mill market, this number is projected to increase to between 23 and 46 workers. The number of jobs created will depend on the manufacturing model employed. According to a FGD participant, if solar rice-mill units are produced in a decentralized manner by small-scale companies, a higher number of jobs will be created. Conversely, a centralized, large-scale manufacturing approach will result in fewer jobs but potential cost reductions for the customers due to economies of scale. Jobs that could be created include welders, CNC operators, and laser-cutting machinery operators.

Solar rice-mill operators and owners will drive a significant portion of job creation in the solar rice-mill sector. Each solar rice-mill operation typically creates four jobs: two laborers or technicians, one entrepreneur, and one driver. Based on this calculation, if the market potential for solar rice mills is fully realized by 2030, up to 2,300 people could be employed in solar rice-mill operations.

Solar roti rolling gaining prominence due to its benefit in saving time

Solar-powered roti (Indian flatbread) rolling makers are gaining increasing traction due to their benefits in reducing drudgery and saving time. In most parts of India, roti rolling and pressing are conducted by hand, which is exhausting and uncomfortable for the women typically responsible for this task.

According to the SELCO Foundation, which leads the dissemination of the solar roti-rolling machine, it takes eight hours to make five hundred rotis by hand. With the solar roti-rolling machine, this same task can be completed in two hours. Additionally, these machines significantly reduce the physical effort required to roll the rotis, thereby improving the comfort level for women.

Using the methodology described in section 2.3, we estimated that **1,800 labor hours per year** are saved if manual roti rolling is replaced with mechanized roti rolling. This amounts to **225 working days**, assuming one working day is eight hours.

Many users, especially women, are utilizing this saved time for different purposes. It used to take four women to make 2,000 rotis, now it only takes one person. With the savings in labor costs, businesses have expanded their operations and hired additional workers. Other workers who were made redundant by the roti maker have transitioned into other businesses, such as chutney powder-making.

Photo Credit: CLASP


Credit: Sun Culture/Ashden

THE IMPACT OF DRE TECHNOLOGIES IN KENYA'S FRENCH BEAN VALUE CHAIN

Chapter summary

- French beans are an economically significant commodity for the Kenyan agricultural sector.
    - French beans are by far the largest vegetable export crop from Kenya and account for 6% of the value and 20% of the volume of total fresh vegetable exports.[53]
    - French beans are produced year-round, and their production is labor-intensive, with most value-adding activities completed within the country.
    - French beans are a significant horticultural commodity for the Kenyan agricultural sector, and this value chain is estimated to account for at least 25% of all jobs within the export crops and horticulture sector.[54]
- We studied the end-to-end value chain to identify the most feasible DRE technologies. SWP and walk-in cold storage are identified as high-potential DRE technologies for the French bean sector.
    - Demand for SWPs is expected to reach 500,000 units.
    - The cold chain market for fresh fruits and vegetables in Kenya is estimated at $511 million USD and is expected to reach approximately $1 billion USD by 2030.[55]
- The SWP sector can create more than 38,000 jobs by 2030 if the country realizes its market potential for SWP.
    - Additionally, 4,600 jobs can be created in the French bean value chain due to the increased productivity related to the adoption of cold chain.
    - The roles required to satisfy the demand for SWPs and the cold chain require various levels of skills. Some require highly technical skills, while other jobs—such as pickers, graders, and sorters—can be accomplished with little training.

Photo credit: futurepump

4.1. The French bean value chain in Kenya

French beans (green beans) are one of Kenya's largest vegetable export crops, accounting for 6% of the value and 20% of the volume of total fresh vegetable exports.[56] Kenya's French bean export is valued at $60 million USD. SHFs largely contribute to the French bean sector with about 50,000 SHFs generating 60% of the total production. The sector employs around 60,000 people and producers can earn an average of $1,000 USD per hectare, which is significantly higher than alternative farm enterprises. The crop's attractiveness to farmers stems from its short cycle, maturing within 45 days of planting, and the ability to harvest three times a week for three to five weeks.[57]

French beans can be produced all year round. Production is labor-intensive and most of the value-adding activities are completed within the country.[58] The French bean value chain in Kenya is complex, involving multiple stakeholders, including input suppliers, farmers, traders, processors, exporters, retailers, and consumers.[59] Most French bean farmers in Kenya are organized into groups that are either regulated to restrict sales to the local market or have contracts with companies that restrict the sale of their produce outside the contract.[60] Kenya is the largest supplier of French beans to the United Kingdom (UK,) followed by Morocco and Egypt. In Europe, the UK is the largest importer of Kenya's French beans, with other significant importers being France, Germany, Netherlands, Belgium, and South Africa.[61]

The French bean value chain in Kenya is held back by the massive post-harvest losses. A partnership between Wageningen University & Research (WUR), The Sustainable Food Lab (SFL), VP-GROUP, and Sainsbury's conducted a pilot study to measure and assess losses in Kenya's French bean supply chain. The study revealed that an average of 59% of French beans are lost from harvest to grading and sorting in Nairobi. The study showed that 60% of the losses happen during production and harvesting, while the rest occur between packing and grading in Nairobi.[62]

DRE technologies, such as cold chain solutions and solar irrigation, could help reduce post-harvest losses and increase production across the value chain. By implementing these technologies, the efficiency and profitability of French bean production could be greatly enhanced, benefiting SHFs and the entire agricultural sector in Kenya.

Photo credit: CLASP

4.2. DRE technologies in Kenya's French bean value chain

Agricultural mechanization is low in Kenya, and this contributes to low agricultural productivity.[63] The production process for French beans is highly manual, particularly on small farms. According to FGD participants, each hectare typically requires 20 laborers, including family labor. Although medium and large farms have mechanized many of their operations, harvesting still requires significant manual labor, with about 60 workers needed per hectare of crop.[64]

We studied the end-to-end French bean value chain to identify the most feasible DRE technologies. While solar irrigation would be beneficial in managing unpredictable weather patterns and reducing the

Figure 10: A representation of Kenya's rice value chain and major agricultural equipment used in the value chain[65]

	Input supply	Production	Packing & storing	Processing	Distribution & marketing
Main Activities	• Seeds • Fertilizers • Agro chemicals	• Land preparation • Planting • Irrigating • Weeding • Top dressing • Pruning • Harvesting	• Cleaning • Sorting • Grading • Trimming • Weighing • Packaging • Cooling	• Canning • Cooling	• Purchasing French beans from wholesalers • Storing • Selling
Agriculture equipment used	• Knapsack and boom sprayer • Irrigation systems	• Tractor • Mouldboard • Plough and ox drawn plough • Motor blower • Combine harvester	• Walk in cold rooms	• Walk in cold rooms	• Refrigerators

Source: The Status of Agricultural Mechanization in Kenya , French Bean Value Chain Analysis.

operating costs associated with other forms of irrigation, cold chain solutions would address postharvest- loss and increase productivity along the value chain. Additionally, e-mobility through electric two- and three-wheelers would help reduce transportation costs for farmers, further enhancing efficiency and profitability.

There are various growth drivers sustaining the SWP and cold chain sectors, including:

1. **Policy interventions:** Policies aimed at expanding the uptake of efficient DRE technologies. These policies support the deployment of SWPs and cold chain technologies through capacity building and demonstration projects.
2. **Financing interventions:** Efforts by the banking sector, Non-Governmental Organizations (NGOs), and private sector entities to boost the affordability of SWP technologies and cold chain

solutions. These interventions include favorable loan terms, grants, and other financial products designed to make these technologies more accessible to farmers.

3. **Innovative business models:** New business models are enhancing consumer demand for SWPs and cold chain solutions. Examples include pay-as-you-go (PAYG) systems, leasing options, cooling as a service, and cooperative ownership model, which reduce upfront costs and spread payments over time, making these technologies more affordable for SHFs.

4. **Consumer awareness campaigns:** Campaigns aimed at educating farmers about the benefits of using SWPs and cold chain technologies. These campaigns emphasize the advantages such as cost savings, increased agricultural productivity, improved product quality, and reduced post-harvest losses, thereby driving demand and adoption.

These drivers collectively contribute to the growth and sustainability of the SWPs and cold chain sectors, helping to improve agricultural productivity, reduce post-harvest losses, climate change resilience, and enhance food security in Kenya.

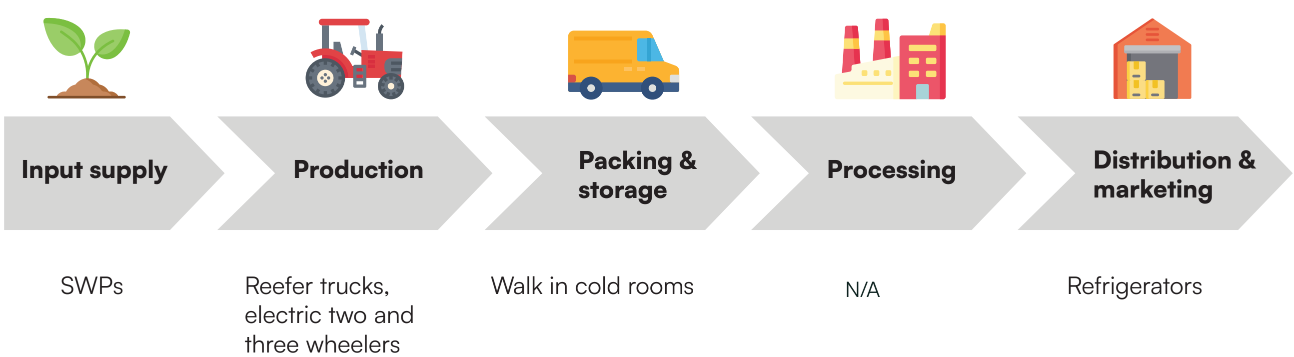
Table 6: Main solar-powered technologies used in Kenya's French bean value chain[66, 67]

TECHNOLOGY SPECIFICATION	SOLAR WATER PUMP	WALK IN COLD ROOMS
Capacity	**High-efficiency pump:** Can irrigate 1 ha.	**Two-to-three-ton walk-in cold room (10-11 cubic meters) purchased by cooperative or NGO**
Cost (for a typical technology)	$600 USD— entry level	$11000 USD and $30,000 USD
Payback period	18 months	Long payback period

Due to the nascency of e-mobility use in Kenya's horticultural sector, SWPs and cold chain solutions have emerged as high-potential DRE technologies for the French bean value chain.

The adoption of these DRE technologies is expected to impact various job categories, including sales representatives, technicians, farm laborers, pack house and storage workers, and retail staff. By integrating SWPs and cold chain solutions, farmers aim to enhance efficiency and reduce post-harvest losses, thereby improving the overall productivity and profitability of the French bean value chain.

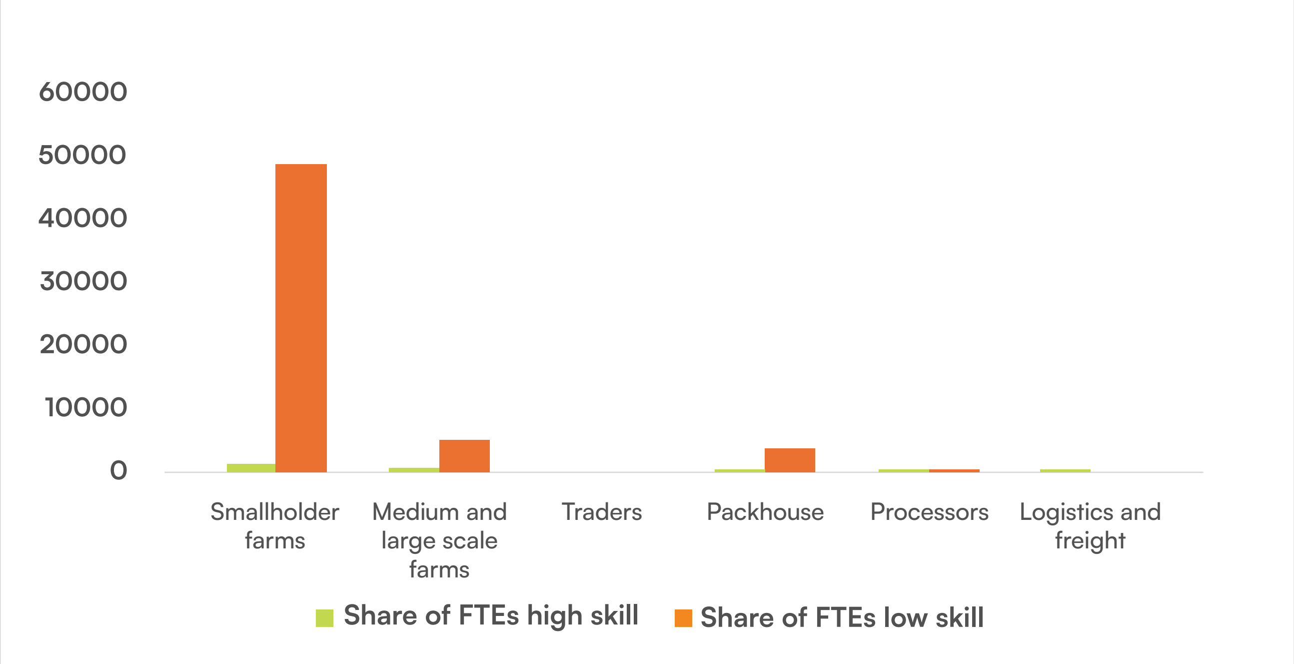
Figure 11: A representation of Kenya's French bean value chain and DRE technologies that can be used in the value chain



4.3. The employment effect of DRE technologies in Kenya's French bean value chain

Total unemployment in the country stands at 9.7% with youth unemployment for ages 15-24 at 13.7%.[68] The agricultural sector in Kenya has the highest employment multipliers, with vegetables (horticulture), livestock, and rice value chains showing the greatest potential to create jobs.[69] French beans are a significant horticultural commodity for the Kenyan agricultural sector, and this value chain is estimated to account for at least 25% of all jobs within the export crops and horticulture sector.[70] Small-scale farms are the most important source of wage jobs in the French bean value chain and account for over 80% of the 60,000 jobs generated in the value chain.[71] Additionally, it is estimated that 21% of those employed are youth, while women account for an estimated 50% of all wage jobs. [72]

Figure 12: Jobs in the French bean value chain[73]



Source: The status of agricultural mechanisation in Kenya, French bean value chain analysis

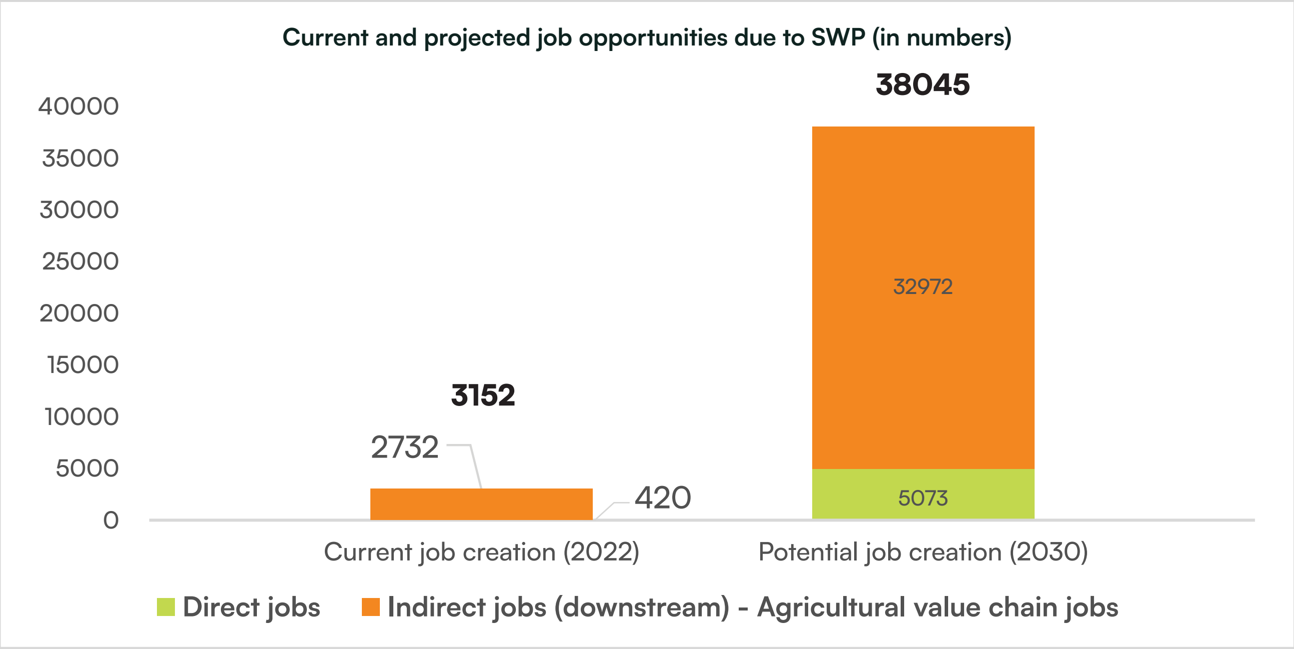
Adoption of DRE technologies, such as SWPs and cold chain solutions, could help increase productivity, reduce operational costs, alleviate drudgery (especially for women tasked with the arduous work of collecting water), and reduce postharvest- losses. Growth of the DRE technologies market would lead to creating highly skilled jobs, and adopting these technologies across the value chain would enhance productivity, increasing employment opportunities within the French bean value chain.

Solar water pumps

Kenya is the most mature market for SWPs in Sub-Saharan Africa, contributing 35% of global SWPs sales between July 2019 and December 2020.[74] The market for SWPs is estimated at approximately $30 million USD and is growing sustainably.[75] Despite this impressive growth, the current market penetration represents only a fraction of the addressable market. In the country, 4.5 million smallholder farmers (SHFs) stand to benefit from irrigation, particularly as they contend with the impacts of climate change.[76]

The solar irrigation sector in Kenya offers significant job opportunities, with approximately 5,000 direct jobs and almost 33,000 indirect downstream jobs available by 2030. These opportunities can be seized by under-employed rural youth, provided they receive appropriate training. These jobs will be distributed

Figure 13: Number of workers hired by DRE companies to service the SWP market in Kenya



across multiple cities, such as Laikipia, Kisumu, Machakos, and Taita Taveta where demand is the greatest.[77]

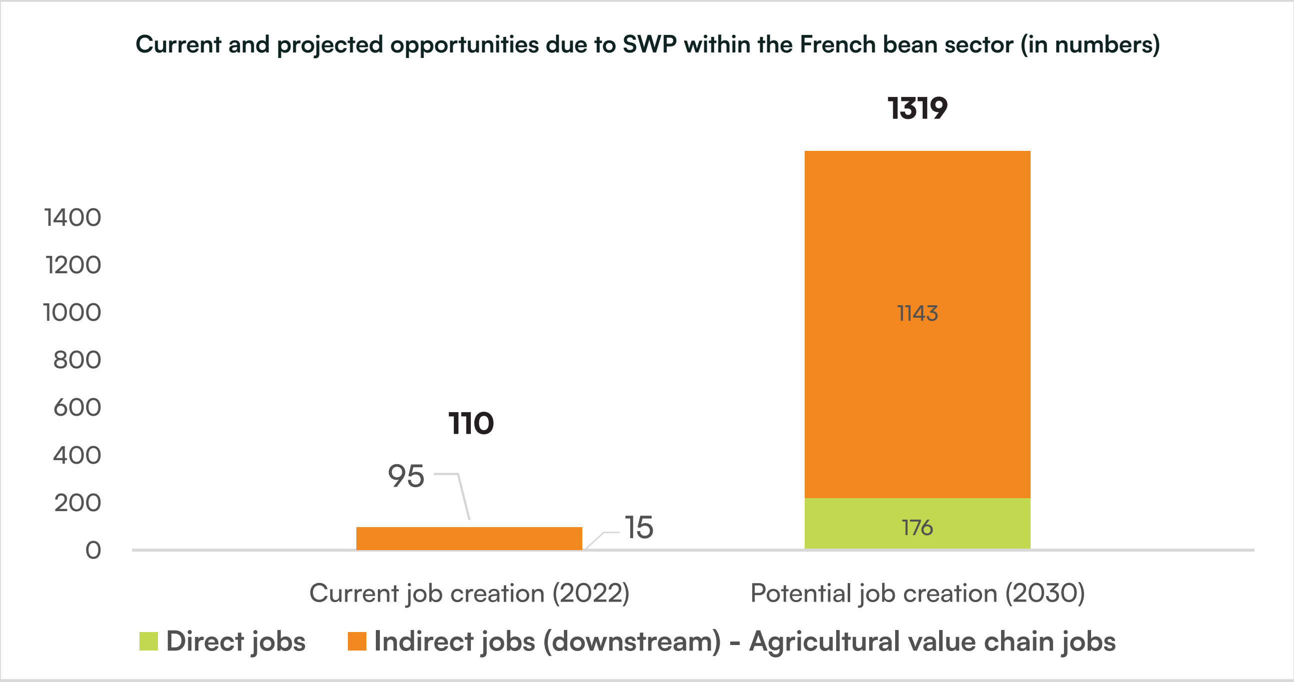
French beans are grown mainly by SHFs under irrigation in the Central, Rift Valley, and Eastern Provinces. According to FGD participants, the main methods of irrigation used are manual, utilizing buckets, watering cans, and furrow irrigation. The participants also indicated that some farmers use diesel-powered pumps that are reported to have high operating costs. The life cycle costs of SWPs are 22—56% lower than those of diesel pumps, leading to a payback period of just two years. Replacing conventional pumps with SWPs significantly reduces daily fuel, operation, and maintenance costs. Diesel-powered pumps usually have a lower initial cost but incur high operation and maintenance expenses, whereas SWPs may have a higher initial cost but very low operation and maintenance costs. As petroleum product prices rise and the cost of SWPs continues to fall, the life-cycle cost advantage of SWPs over diesel pumps is expected to increase. Additionally, SWPs generally have a longer operational life due to their lower maintenance requirements. [78]

Adoption of SWPs in the French bean value chain will lead to the creation of over 170 direct jobs and over 1,100 indirect jobs by 2030. The types of direct jobs available from the sale of SWPs include quality assurance technicians, field technicians/ solar installers, agricultural irrigation technicians, and technician assistants, with the greatest demand being for salespeople.[79] For these roles, various hard and soft skills are needed, but these skills are not currently being taught at local higher learning institutions. Globally, higher education is not keeping pace with the rapid adoption of renewable energy. Higher education institutions still tend to prioritize coal and petroleum studies.[80] This also holds true for higher learning institutions in Kenya.

French bean farmers who attended the FGD indicated that they solely rely on rainy seasons, only utilizing eight months of the year for growing French beans. The introduction of irrigation would allow the farmers that have not yet adopted irrigation farming practices to plant all year round, leading to an increase in farm-level jobs such as:

- **Pesticide sprayers:** Workers trained to offer spraying services to farmers. Enhanced production will increase demand for these services.

Figure 14: Number of workers hired by DRE companies in the SWP market to service Kenya's French bean sector



- **Pickers:** Trained individuals needed at the harvesting level to ensure the quality of produce for export is not impacted.
- **Graders:** Workers responsible for checking the quality of the produce before it is exported.

Kenyan FGD participants indicated that adoption of SWPs could lead to the replacement of manual irrigation jobs, while Kenyan French bean farmers reported that these laborers have found new jobs due to the increased capacity to cultivate more land for farming. With the adoption of solar irrigation, several farmers would introduce more harvesting rounds or expand to other crops.

Cold chain

The cold chain refers to a series of activities and processes involved in the transportation, storage, and handling of perishable goods under controlled temperature conditions. In the agricultural context, a complete cold chain involves multiple stakeholders in the supply chain, including farmers, aggregators, transportation companies, warehouses, and processing centers. From post-harvest pre-cooling and pack house technologies to cold storage, several technologies are used across the cold chain, e.g., walk-in cold rooms, ripening chambers, refrigerated or "reefer" vehicles, and retail refrigeration.[81]

The current cold chain market for fresh fruit and vegetables in Kenya is estimated at $511 million USD and is projected to reach approximately $1 billion USD by 2030. Cold chain infrastructure (CCI) is mainly found in urban centers close to exit ports like airports and shipping ports. The main technologies found in the fruits and vegetables value chain are cold storage rooms found in large packhouses. In the first mile, pre-cooling—the rapid removal of field heat shortly after crop harvest—is often omitted or not appropriately performed, leading to early dehydration and russeting, which is the biggest cause of rejection in the French bean value chain. Basic solutions like charcoal coolers are currently in use, but development partners have started piloting Cold Chain Innovations (CCI) that will benefit this segment.[82]

Limited CCI and poor road conditions, particularly feeder roads to farms, result in high post-harvest losses of up to 42% along the French bean value chain.[83] Technological interventions, such as first-mile cold storage with pre-cooling capacity and temperature-controlled trucks, would reduce the rejection rate of beans arriving in Nairobi for export.

The French bean value chain derives most of its added value from packing fresh beans and processing canned beans. These post-harvest handling operations are implemented in packhouses and canning factories, respectively. In the packhouses, the value-added activities that take place include the cleaning, sorting, grading, trimming, weighing, packaging, and cooling of produce. Packhouses could have between 50 (in the case of a medium-sized operator) and 300 (in the case of a large-scale operator) workers.

A study conducted by the Kenya Institute of Public Policy Research and Analysis highlighted two scenarios where farm-level post-harvest losses are reduced by 50% and 75%, respectively, and the resulting impact on jobs across the French bean value chain. These two scenarios would generate a 6% and 10% increment in jobs, respectively.[84]

- In the first scenario, 308 additional skilled jobs and 1,391 low-skilled jobs are generated.
- In the second scenario, 378 skilled jobs and 4258 unskilled jobs are generated.

High-skilled jobs are defined as those performed by workers with a complete tertiary education while low-skilled jobs are those performed by employees with only a primary education or lower. Investing in cold chain technology not only enhances food security and agricultural productivity but also creates significant employment opportunities across various skill levels in the supply chain.

The role of women in the French bean value chain

The French bean value chain in Kenya employs approximately 60,000 people, with an estimated 60% being women, working across commercial farms, processing, and logistics operations. Nearly half, or 44%, of Kenya's smallholder households are managed by women. Women play an integral part at every point in the food chain and are often responsible for household farming activities, also on most French bean farms. Women predominantly handle sorting, grading, and quality control, while men often take on more physically demanding tasks such as land preparation, irrigation, spraying, and loading and unloading trucks.[85]

Credit: Jeffery M Walcott/IWMI


Credit: Prashant Vishwanathan / Ashden

THE IMPACT OF DRE TECHNOLOGIES IN INDIA'S DAIRY VALUE CHAIN

Chapter summary

- India is the world's largest producer of milk and dairy products.[86]
    - The sector employs around 80 million people with women accounting for 70% of the employment.[87]
    - Dairy contributes 5% of the country's GDP at $182 billion USD.[88]
- After carefully considering the Indian dairy value chain, three high-impact DRE technologies have been identified for India's dairy sector: solar milk chillers, solar-powered fodder-grower units (hydroponics), and solar milking machinery.
    - The market for the three technologies is either nascent or at a pilot stage.
    - However, compared to other DRE dairy technologies in India, they have better levels of adoption and have been identified as having high potential for mass adoption.
- As the market for the three technologies is still in the early stages, there is currently limited job creation.
    - Companies and farmers who participate in the sector indicated that they expect the market for the selected technologies to pick up in the coming years. This is mainly due to farmers seeking alternatives solutions to the erratic power supply and increasing cost of diesel.
    - Bulk deployment of these technologies can lead to future job creation opportunities.
    - The major benefit of using technologies like solar fodder units (hydroponics) and solar milking machinery is the reduction in drudgery and time saved. For instance, solar-powered milking can enable the milking of as many as twenty to thirty cows in an hour, whereas hand milking can only manage six cows per hour.[89]

5.1. The dairy industry in India

India is the world's largest producer of milk and milk products. In 2020, the country's total milk production amounted to 209 million tons, more than twice that of the second-largest producer, the United States.[90] Majority of the milk produced in India is consumed domestically, either as milk or milk products, including butter, paneer, yogurt, etc.[91]

Dairy is an important contributor to India's economy. The sector employs around 80 million people, making it one of the largest employers by commodity. The dairy sector contributes $182 billion USD to India's economy, accounting for 5% of the country's GDP. This is expected to grow to $380 billion USD by the end of 2028.[92] Although the export of dairy products is minimal, there is notable growth, especially in the export of processed dairy products such as milk powder.[93]

The Indian dairy value chain is divided into organized and unorganized segments. The unorganized segment includes local milkmen, vendors, and self-consumption, while the organized segment comprises cooperatives and private diaries. Around 60% of the milk sold is handled by the unorganized sector, while the organized sector is responsible for the remaining share. The Government of India (at the federal, state, and local levels), cooperatives, and private dairy companies are the major buyers of the milk sold in the organized segment. Recently, the organized segment started gaining market share as customer preferences shift from milk in the unorganized segment to the organized market.[94] The following figure illustrates the value chain steps within India's organized value chain.

The Indian dairy sector consumes a significant amount of energy in its cooling, heating, and processing activities. The sector's energy consumption is estimated at 3.4 billion KWH per year, which is equivalent to the annual electricity consumption of Botswana.[95, 96] This energy mix includes the national grid, diesel power, and renewable energy. Companies interviewed during the FGD indicated that erratic power supply from the grid is a major bottleneck in their operation.

5.2. DRE technologies in India's dairy value chain

Renewable energy has immense potential to transform the Indian dairy sector. There are various use cases of renewable energy technology in the sector. This includes using solar energy for cooling and heating purposes and bioenergy (e.g., biogas)

Figure 15: A representation of India's dairy value chain and major agricultural equipment used in the value chain

	Input supply	Rearing of Livestock	Collection & Chilling Centre	Processing	Retail	Consumption
Main Activities	• Production of animal feed • Research on cattle breeds	• Farm and livestock management	• Aggregation of milk • Grading of milk • Pricing of milk	• Steps varies based on different types of dairy products (e.g. butter, cheese, ghee, etc.)	• Buying • Storing • Selling	• Purchase from retailers • Final consumption
Agriculture equipment used	• Solar powered fodder grower unit	• Livestock shelter • Mik tanks • Milking machine • Feed store • Veterinary care	• Cold transport • Cold storage • Solar milk chiller	• Trucks • Cold storage • Thermal-powered heating systems • Pasteurization technology • Sterilization technology	• N/A	• N/A

for dairy processing.[97] Using renewable energy in the dairy sector has multiple benefits. First, it protects dairy farmers from erratic power supply. As per the FGD and interviews with stakeholders, farmers complain about the country's erratic power supply. The second reason is reducing the sector's carbon footprint. Technologies such as solar milk chillers will reduce the need for fossil-fueled alternatives.

Similarly, farmers who adopt DRE technologies in their dairy farm can realize the above-mentioned benefits. Farmers in rural and remote areas are especially affected by India's erratic power grid. Due to this, many dairies use expensive diesel generators to refrigerate their milk or risk high percentage of spoilage. Hence, dairy farmers are looking into alternative solar-powered technologies.

Three high-impact DRE technologies have been identified for the dairy sector in India, namely solar milk chillers, solar-powered fodder-grower units, and solar milking machinery. These technologies were selected because they are either in the pilot or growth stage, with a sizable number of farmers using them. Other alternative DRE technologies not selected for analysis include solar water heating. Solar heating was not prioritized in this report because its current application is largely dominated by large-scale players with limited adoption by small-scale dairy farmers.

The following table provides a brief description of the prioritized DRE technologies in the Indian dairy sector.

5.3. The employment effect of DRE technologies in India's dairy value chain

Solar milk chillers

Solar milk chillers are used to cool milk from its harvest temperature of 35 °C to 4 °C to control bacterial growth. This allows the milk to be preserved for an additional seven days, preventing deterioration. Currently, at least 3% or 15.4 million liters of milk are wasted per day due to unreliable and erratic power supply.[98] This represents an annual monetary loss of $2.2 billion USD to the Indian economy.

Due to the above facts, the demand for milk chilling systems is immense. Two different reports estimate the total addressable market for solar milk chillers at 90,000 units and $164 million USD.[99,100] However, the current milk chilling infrastructure in India can only accommodate 12% of the total milk production.[101] Additionally, farmers use diesel generators as a backup system, which adds to the operational cost of dairy production. Solar-powered milk chillers enable farmers to preserve their milk for additional days while also reducing the operational cost of chilling, as they are cheaper over a lifetime. Interviews with stakeholders indicated that solar milk chillers resulted in $100—200 USD savings on diesel cost per month. This is almost 25% of the milk collection's income.

Table 7: Main solar-powered technologies used in India's dairy value chain

TECHNOLOGY SPECIFICATION	SOLAR MILK CHILLERS	SOLAR-POWERED FODDER-GROWER UNIT	SOLAR MILKING MACHINERY
Capacity	500 liters per day storage capacity. They can serve 2—3 villages and 70—100 dairy farmers	Can produce 25—30 kg of fodder per day. The fodder growth cycle is 7—8 days	It can milk 20—30 cows within an hour
Cost (for a typical technology)	$9,000 USD 40% of the cost is the solar component and the rest is the chiller system	$530 USD	$840 USD
Payback period	45 months	22 months	No information available

Source: Interview with technology provider companies, FGD, CEEW[102], New Indian express[103])

There is considerable promise for solar milk chillers, yet the industry is in its early stages. As of mid-2023, only 50 solar milk chiller units have been installed.[104] Limited consumer awareness, poor brand recognition of solar milk chilling and off-grid refrigeration, and high upfront costs contribute towards the low level of penetration of solar milk chillers.[105]

There are currently very few jobs created as the market for solar milk chillers is in early stages. The following table summarizes the employment landscape of solar milk chillers.

All manufacturing for solar milk chillers is done in India. According to an executive at a non-profit organization that installs solar milk chillers, most equipment, including inverters, batteries, and solar panels, is sourced locally. The only imported items are lithium, which is a critical component of lithium-ion batteries, and electronic parts. This means that, as the market for solar milk chillers grows, most of the jobs to service this demand are created locally. In addition, the installation, servicing, and maintenance tasks are completed by local-level technicians to ensure that services are provided in a timely manner. This creates additional jobs for local technicians and after-sales maintenance.

In addition to the jobs mentioned above, the adoption of milk chillers can aid indirect job creation. Testimonials from renewable energy companies indicate that entrepreneurs who have adopted milk chillers are reinvesting their new profits into expanding their existing businesses or opening new companies.

"One of our clients increased its profit after installing a milk chiller. He is now planning to open a paneer or khoya making business." InfiCold representative

Solar-powered fodder grower unit

The solar-powered hydroponic fodder unit allows dairy farmers to harvest about 25 kg of fresh green fodder daily with a minimal amount of water. India's milk yield is lower than the global average. For instance, while the milk yield is close to 11,000 kg per animal in the US, it is only 1,600 kg per animal in India.[106] One of the factors contributing to the low milk yield is a shortage of animal feed and fodder. As much as 32% of Indian dairy farmers don't have access to quality green fodder. Solar-powered fodder units can play a huge role in meeting this demand, resulting in an increase of 10—15% or 1—3 liters of milk per cow per day.[107] According to a user survey by the Council on Energy, Environment, and Water (CEEW) dairy farmers who use solar fodder units reported a 25% increase in income compared to the

Table 8: Job creation due to solar milk chillers

JOB CATEGORY	JOB CREATION	TYPES OF JOBS
Direct jobs	**15—20 people are needed to manufacture one milk chiller.** This estimate is based on a vertically integrated company managing all parts of the value chain themselves, including manufacturing and distribution.	Almost a third are installation technicians The remaining are manufacturing workers including wielders, technicians
Indirect downstream jobs — at the site	One technician and one entrepreneur are required per system. The owner can also serve as the operator. Therefore, only one job is created. If market potential for solar milk chillers is realized more than 90,000 jobs will be created.	**Technician:** for cleaning and upkeep machinery, pour the milk into the tank, conduct quality assessment of milk **Entrepreneur:** tracking dairy product stored

Source: Interview with solar milk chiller provider company, non-profit organization providing milk chillers, and dairy farmer

baseline. This is attributed to the improved quality and quantity of yield obtained from green fodder.[108]

Similar to most solar-powered energy technologies, the solar-powered fodder-unit market is in its early stage with only 210 units currently installed.[109] On the other hand, the addressable market size is estimated at $4.2 billion USD or 3.4 million units.[110] As a nascent market, the solar fodder-grower market is still far from realizing its full potential, but there are strong pull and push factors driving growth. The major pull factor is the increase in milk yield due to high-quality fodder. As stated above, dairy farmers who use fodder have 1-3 liters more milk per cow compared to farmers who rely on pasture-raised livestock. While the major push factor is the reduction in India's pasture due to rapid urbanization.[111]

The current levels of job creation in solar fodder units are very limited as very few units have been installed. Additionally, the operation of a solar fodder unit requires minimal manpower. According to a company that provides solar fodder units, one person is sufficient to run a small-scale fodder unit. Most of the time, this person is the dairy farmer themselves, so no new jobs are created. However, employment creation is expected to rise as demand for fodder units increases. The biggest job creation opportunity can be realized in the deployment of large-scale fodder units and/or the bulk deployment of small-scale fodder units.[112] Large-scale fodder units can produce up to 250 tons of fodder per month, and four full-time employees are needed to operate them. Medium-scale farmers which own up to ten cows will require smaller fodder units.

The major benefit of using solar fodder units comes from reducing drudgery. According to a solar fodder company, their units can, on average, eliminate four hours of work per day that was spent searching for fodder. This benefit is particularly advantageous for women, as they are largely responsible for collecting fodder and feeding the cattle. According to a survey, women who use solar fodder units reported that the technology has enabled them to increase their participation in public and community events.[113]

Solar-powered milking machinery

Solar-powered milking machinery is designed to make the milking process more efficient and offer backup power during outages, thereby reducing the effort and time required for milking. Most Indian dairy farmers currently practice hand milking or manual milking, which results in high levels of drudgery, extended milking times per cow, and sometimes contamination of the milk.[114]

The market for solar milking machinery is currently in its nascent stages, with minimal private sector participation. The sector appears to be dominated by non-profit organizations. For instance, SELCO has distributed 331 solar-powered milking machines to date machines.[115] However, as India is home to around 17 million dairy farmers who mostly currently use hand milking[116], the market for solar milking machinery is expected to grow exponentially in the coming years.

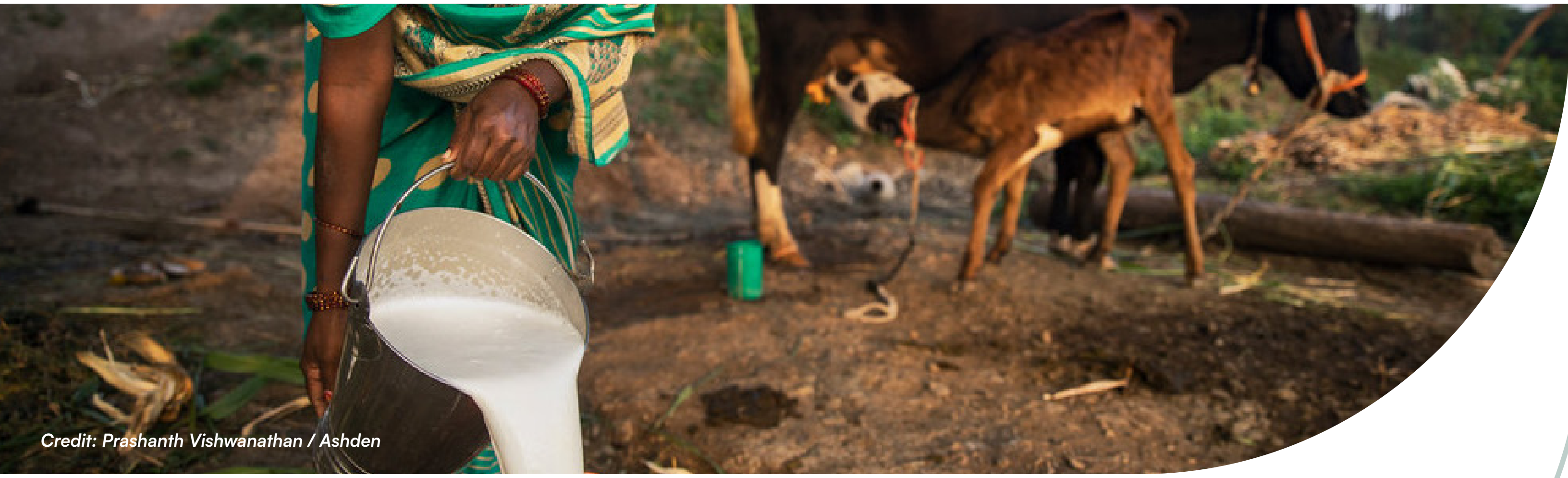
As the market for solar milking machinery is currently at a pilot stage, there is limited job creation associated with this technology. The primary labor-related benefit of solar milking machinery is the reduction in time spent milking livestock. With hand milking, it would require up to ten minutes to milk a cow and sometimes an additional laborer.[117] However, using solar-powered milking machinery, as many as 20—30 cows can be milked within an hour, eliminating the need for additional labor. In addition, solar-powered milking machinery was found to reduce physical exertion, exhaustion, pain, and difficulty involved in the milking process. This is particularly beneficial for women, who are primarily involved in the milking process.[118]

The role of women in India's dairy business

Women are integral to the success of India's dairy sector. They constitute 70% of the dairy labor force. Women are mostly responsible for physically demanding activities such as animal care, milking, processing, and farm management.[119]

DRE technologies can alleviate some of the physically demanding tasks that are currently completed by women. Solar fodder units and solar miking machinery are especially useful to reduce the drudgery and reduce time spent on dairy activities. In addition, other spillover effects have been reported by women who use either of these technologies. For example, a high proportion of women who use solar fodder units reported they have relevant skills and knowledge to become self-reliant.[120]

Additionally, dairy farmers reported a significant decline in lower back pain after adopting solar milk machinery.[121] This demonstrates the added benefit of using solar technologies, in addition to job creation and increased productivity.



Credit: Prashanth Vishwanathan / Ashden

THE IMPACT OF DRE TECHNOLOGIES IN NIGERIA'S CASSAVA VALUE CHAIN

Chapter summary

- Cassava is an important crop for Nigeria. The country produces 63 million tons of cassava annually which accounts for 20% global cassava production.[122] 6 million smallholder farmers are engaged in cultivation in Nigeria, both.
- Cassava graters and millers have been prioritized for further analysis due to the high demand for grating/milling services.
  - Two types of technologies exist for both grating and milling, depending on how they are powered: I) plug-in or electric equipment (usually connected to mini-grid), and II) standalone solar equipment.
  - However, both technologies are still nascent. Most of the grating or milling in off-grid locations is conducted using diesel-powered machineries.
  - Plug-in equipment's show greater promise for mass adoption than standalone options as they are economically competitive compared to fossil fuel-based alternatives.
- There are few jobs created due to the application of DRE technologies in the Nigerian cassava value chain. The market for those technologies is still nascent.
  - Plug-in cassava graters or millers require one person to operate them. But usually, previous operators of diesel mills are hired for those roles.
  - Most of the parts for graters or millers are manufactured locally. As owners of diesel-powered equipment decide to replace their machinery, this will create more manufacturing jobs.
  - Women can especially benefit if a technically- and economically-viable cassava mechanical peeler is brought to market, as they are overrepresented in cassava peeling.

6.1. Cassava value chain in Nigeria

Nigeria is the world's largest producer of cassava. The country produces 63 million tons of cassava annually, which accounts for 20% of global cassava production.[123] Yet Nigeria accounts for only $1 million USD of the global cassava trade, which is estimated at $3.6 billion USD. Most of Nigeria's cassava production is consumed locally in the form of garri, fufu, cassava starch, and high-quality cassava flour. However, there is currently limited processing into high-value cassava-derived products such as ethanol, chips, syrups, starch, and other industrial applications (e.g., sorbitol).[124] According to analysis by PwC, Nigeria can generate an additional income of $427.3 million USD and $3 billion USD from domestic and international markets, respectively, by shifting production from primary processing of cassava to high-value addition activities within the cassava value chain.[125]

In Nigeria's, 90% of the cassava is produced by almost 6 million SHFs. Generally, Nigeria's cassava sector is characterized by its focus on prioritizing production for the local market. In addition, there is very little involvement from corporations in the value chain. Most of the retailing, wholesaling, and processing is dominated by local or family-owned companies.[126] The following image depicts the existing value chain for cassava in Nigeria.

However, Nigeria's cassava value chain is plagued by low yields, post-harvest losses, and limited processing. Although Nigeria has been improving its yield per hectare, the country still lags far behind other cassava-producing countries such as Thailand. In Thailand, cassava production is mainly led by SHFs, yet yields are almost three times higher than in Nigeria.[127] Additionally, there is massive post-harvest losses in the cassava value chain in Nigeria, with almost 40% of fresh cassava tubers lost. The primary driver for this loss is the physiology of the crop, as fresh tubers can spoil within 24 to 72 hours if left unprocessed.[128]

There is very limited mechanization in Nigeria's cassava production. For instance, farmers rely on hand tools and animal power for land preparation.[129] Additionally, the majority of harvesting is done manually, which damages the cassava's roots, further reducing its shelf life.[130] Currently, almost all cassava in Nigeria is processed using electric or diesel-powered processing plants. However, due to a lack of power (either electricity or diesel), the processing facilities are located far from the farmers, which reduces the quality of cassava and increases processing costs.[131] This highlight how DRE technologies, due to their decentralized nature, can address some of these challenges and potentially lower lifetime costs.

Figure 16: A representation of Nigeria's cassava value chain and major agricultural equipment used in the value chain[132, 133]

	Input supply	Production	Trading	Processing	Wholesale & distribution	Retail	Consumption
Main Activities	• R&D • Production of inputs such as seeds and fertilizers • Import and distribution	• Land preparation • Plant stem of cassava • Replace stem that don't sprout	• Aggregation of cassava root by village assemblers • Sell to wholesalers	• Process differs for garri and HQCF but involves peeling, grating, and packaging	• Aggregate and distribute to retailers	• Storing • Marketing	• Final consumption
Agriculture equipment used	• No application of agricultural equipment as they are industrialized processes	• Tractor	• Trucks	• Peeling and washing grinder • Dryer • Miller	• Trucks	• None	• None

Source: PWC, IITA, Cassava Matters, FAQ - Cassava, HarvestPlus - Cassava VC, Rockefeller Foundation - Cassava Innovation

6.2. DRE technologies in Nigeria cassava value chain

DRE technologies have immense potential in replacing fossil fuel-powered and manual processing activities for the cassava value chain in Nigeria. DRE-powered technologies can be applied at various stages of the value chain. Some of the existing technologies include cassava graters, cassava mills, cassava peeling machines, cassava chipping machines, solar dryers, Electric trucks, and tractors. The following figure depicts the various processes for cassava from harvest up to the final processed product such as cassava flour or garri.

Most of the existing DRE technologies are either in the early or pilot stages, with minimal adoption by farmers. For example, standalone solar mills or cassava graters are currently in pilot stage and are not cost competitive with plug-in or fossil fuel-

Figure 17: The process from cassava tubers to garri and cassava flour

Priority processes for DRE interventions: Grating, Pulverizing, Milling

Process	Cassava tuber harvested →	Peeling →	Washing →	Grating →	Ferment and Dewatering	→ Pulverizing → Milling → Roasting
Equipment		Mostly done manually	Hand washed	Diesel or solar powered grater	Presser	→ Solar or diesel mill → Any type of roasting equipment
Final product of the process		Peeled Cassava	Washed Cassava	Mashed Cassava	Cassava cake	→ Cassava flour → Garri

powered equipment in the short term.[134] Plug-in or mini-grid powered equipment show promise for mass adoption, but they face barriers—such as lack of access to credit for equipment purchase, lack of awareness, and lack of market access—that prohibit adoption.[135]

Despite their low adoption, it is still important to study the potential impact of DRE technologies on employment. After conducting a rigorous assessment of the cassava value chain, we have prioritized cassava grating and cassava milling for further assessment because of their impact on employment.

Both technologies were selected for their high deployment readiness and economic potential. For instance, a report by Power Africa classified cassava grating as a tier 1 opportunity, indicating immediate readiness for deployment and high potential for scalability.[136] Additionally, some solar companies, such as CEESolar, one of the major Nigerian mini-grid developers, are piloting cassava mills in their mini-grid sites.

The following table provides a brief description of cassava grater and cassava mill.

Table 9: DRE powered technologies in Nigeria's cassava value chain[137, 138]

TECHNOLOGY SPECIFICATION	CASSAVA GRATERS		CASSAVA MILL	
	Electric grater (powered by mini-grids)	**Standalone solar grater**	**Electric mill (powered by mini-grid)**	**Standalone solar mill**
Capacity	3,000 kg/hour	No information available	Average throughput of 120—150 kg/hour	Average throughput of 32 kg/hour
Cost (for a typical technology)	$2,000 USD	No information available	**$2,000 USD**[iv]	**$2,500 USD**. Cost includes PV system batteries and other components. Batteries are the most expensive component
Payback period	**24 months.** This is for an electric grater with garri production. The payback period will depend on the amount of garri produced	No information available	No information available	No information available

iv The cost of a standalone solar miller was used as a proxy. Since most solar mills are multi-crop, a maize miller can be used for cassava with minimal modification.

6.3. The employment effect of DRE technologies in Nigeria's cassava value chain

Cassava grater/grinder

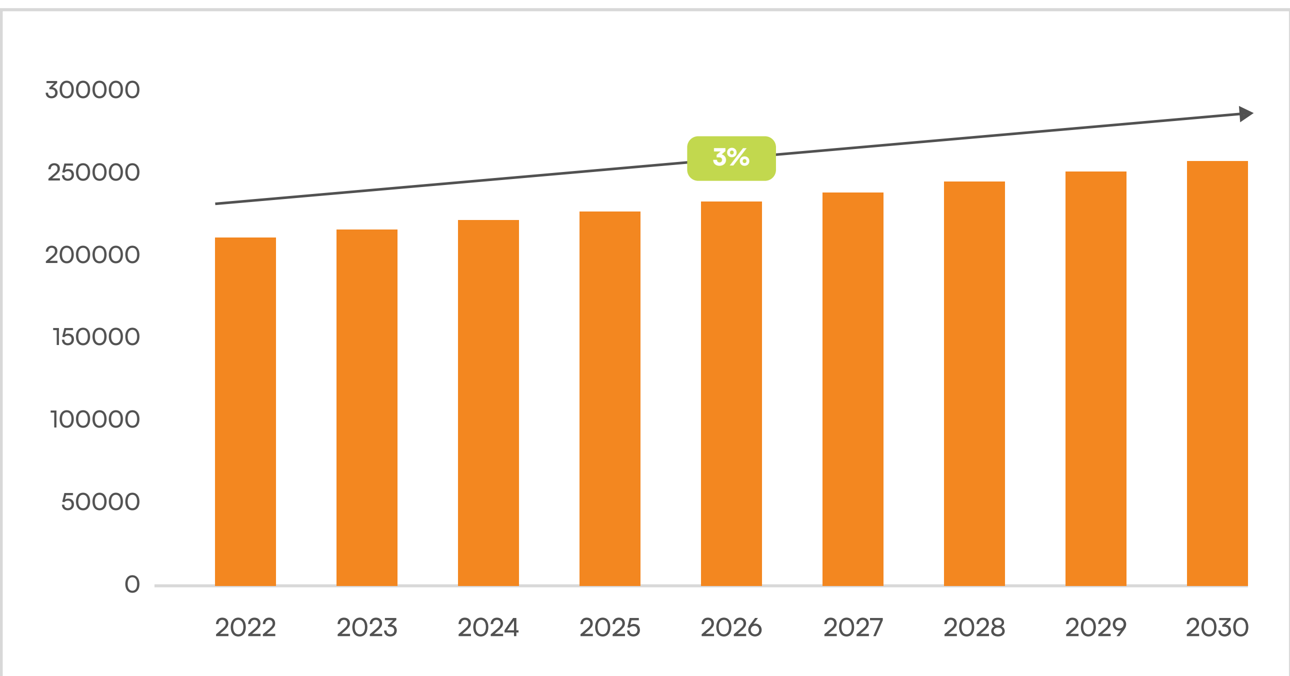
Cassava grating involves the process of converting peeled cassava roots into a soft mash. This soft mash then undergoes fermentation, dewatering/pressing, and frying, resulting in the final product known as garri. As garri is a staple of the Nigerian diet, cassava grating is an important part of cassava processing in Nigeria. Nearly all grating is mechanically powered by a diesel engine. This presents an opportunity to replace fossil fuel-powered processing with electric or standalone solar types of processing.[139]

Electric cassava graters can be more than twice as affordable as diesel cassava graters. However, despite the cost advantages, electric cassava graters are not deployed at scale in Nigeria's off-grid areas. Various factors contribute to the low level of adoption of electric cassava graters. One of the main factors is that the equipment is not readily available in the market. End users are not aware of where to buy or get electric graters. Even if they are available, owners of grating businesses need affordable financing to purchase or rent the equipment, which is not easily accessible.

Additionally, consumer preferences also make electric graters less attractive. For instance, during a focus group discussion, a representative of a mini-grid developer indicated that customers believe garri produced using a diesel-powered grater taste better than garri produced with other types of graters.

As a result, there are few jobs currently created through the application of electric cassava graters. The other technology option for cassava grating is standalone systems. However, standalone solar cassava graters are still in the pilot stage and are not cost-competitive compared to electric or diesel graters.[140]

Figure 18: Serviceable market size for cassava mills (2022—2030)



"Mini-grid companies these days understand that the only way to be profitable is by integrating PUE appliances such as plug-in grater." Representative of a Mini-Grid Company

Cassava graters, especially plug-in or electric graters, have substantial potential for adoption and thereby creating employment opportunities. Due to their low cost and the increasing demand for garri, owners of diesel cassava graters have shown interest in retrofitting their old equipment or upgrading it. This will increase the demand for technicians with skills in retrofitting diesel equipment. However, few jobs will be created in the operation of the machinery, as people working with diesel graters will transition to operating electric graters.

Cassava mill

Cassava mills, also known as hammer mills, are used to make cassava flour from cassava mash. The demand for high-quality cassava flour (HQCF) has skyrocketed since the government mandated that bakeries in Nigeria use 20% HQCF in their bread. Due to this mandate, the potential demand for HQCF is estimated at 500,000 metric tons per year.[141] Currently, HQCF processing is dominated by large milling companies, and local producers have struggled to keep costs low enough to compete with these big players.[142] Hence the market for electric or standalone cassava mills is nascent.

However, despite the current low levels of adoption, there is unmet demand for cassava mills in Nigeria. According to an estimate by CLASP, the serviceable market size for cassava mills in off-grid areas is expected to reach 257,000 units by the end of 2030.[143] The main reason for this is the increasing demand for cassava flour (either high-quality or medium-quality). Additionally, with the growth in income of cassava farmers and the increased affordability of hammer mills, the serviceable market is expected to grow at a steady rate.

Similar to cassava graters, the current level of job creation due to the low adoption of cassava mills is very low. There are some pilot projects of cassava mills that have created a few jobs. For example, CEESolar installed three mini-grid-connected hammer mills in the southern part of Nigeria. Those hammer mills each employed one person to operate the mill. This indicates that most of the employment associated with cassava mills in the short term will involve the transition of workers from diesel to plug-in or standalone solar mills rather than the creation of new jobs. In addition, the milling job is seasonal. During off-peak periods, which normally occur between January and May, milling only happens twice a week. During the peak season, which is between August and December, milling can happen up to five times a week.

Companies interviewed during the FGD are optimistic about the prospects of plug-in or mini-grid-connected cassava appliances. The bulk deployment of both cassava graters and mills is expected to create new employment opportunities. The first opportunity lies in the assembly and/or manufacturing of these appliances. Except for the solar panels and electrical parts, other components of cassava graters and mills are manufactured locally by small and medium enterprises (SMEs).[144] This will create highly technical assembly and manufacturing jobs for rural youth. Additional employment opportunities arising from the growth in demand for cassava graters and mills include sales jobs, maintenance/after sales positions, and other roles within the cassava value chain.

The case for mechanical cassava peelers and how it can benefit women

Cassava peeling is an important step in cassava processing. Currently, hand peeling with knives is the most predominant method, as it minimizes losses. So far, viable mechanical equipment has not been developed to accommodate the differences in the shape and size of cassava roots.[145] However, hand peeling is extremely tedious and accounts for 35% of labor hours in cassava processing operations.[146]

Most of the cassava peeling is done by women. Cassava is essentially considered a "women's crop" as women contribute 60% of agricultural labor in cassava production and processing.[147] However, women are overrepresented in cassava peeling, with many spending up to ten hours a day on the task and earning less than $2.50 USD a day.[148]

The availability of mechanical peelers can greatly benefit women. It can reduce drudgery during the peeling process, save time, and generate income for women entrepreneurs who wish to open cassava processing businesses. However, there is a need for innovation in developing appropriately sized and economically viable plug-in or standalone cassava peelers. There is ongoing research conducted by different entities including University of Greenwich's Natural Resources Institute, International Institute of Tropical Agriculture, and universities in Nigeria (such as Abia State University). But further research is needed to accelerate the development of viable mechanical peelers.[149, 150] Women who were involved in peeling needed to be provided with appropriate training to reduce massive job displacement after introduction of cassava peelers.

Credit: Tolu Owueye


Photo credit: CLASP

THE IMPACT OF DRE TECHNOLOGIES IN UGANDA'S DAIRY VALUE CHAIN

Chapter summary

- Dairy has been prioritized as one of the top ten agricultural commodities by the government of Uganda.[151]
    - The sector contributes close to $700 million USD to Uganda's GDP and almost $300 million USD to Uganda's exports, making it one of the largest producers in Africa.[152]
    - Uganda produced 2.4 billion liters of milk in 2018.[153]
    - Around 1.2 million small-scale dairy farmers participate in the sector.[154]
- Solar milk chillers have been selected for further assessment among the various DRE technology options in the Ugandan dairy sector.
    - There are multiple DRE technologies with use cases in Uganda's dairy value chain. Some of these include milk chillers, milking machines, SWPs for cattle watering, and chaff cutters.
    - The current market status for all of the technologies is nascent. Milk chillers are selected as there is some equipment being installed. In addition, farmers select milk chillers as the most in-demand technology hence showing the positive future potential of milk chillers.
- Deployment of solar milk chillers can create jobs in two ways: I) workers to retrofit diesel-powered milk chillers into solar-powered equipment; and II) bulk deployment of new solar milk chillers.
    - Current job creation is minimal as few milk chillers have been installed.
    - One milk chiller needs ten informal workers to deploy the asset and two technicians to operate the milk chiller. The technicians will have multiple roles, including the upkeep of machinery, quality assessment, tracking milk stored, loading and unloading milk, etc.
    - Solar milk chillers will also create indirect jobs. These include drivers to transport the milk and workers for marketing and value addition of milk.

7.1. The dairy industry in Uganda

Dairy is a very important agricultural commodity for Uganda. The sector contributes close to $700 million USD to Uganda's GDP and almost $300 million USD to Uganda's exports.[155] This makes it the second most important agricultural commodity in Uganda after coffee. Uganda produced 2.4 billion liters of milk in 2018, making it one of the largest milk producers in Africa. To tap into this opportunity, the Ugandan government has identified milk as one of the ten commodities of focus for the agriculture sector.[156]

Uganda's dairy sector is dominated by small-scale producers. Those 1.2 million small-scale dairy farmers in Uganda are producing for their own consumption but also sell a significant amount of milk.[157] It is estimated that 70% of total milk production is sold in the market.[158] The milk is then collected by small traders and transported to milk collection centers. Milk collection centers preserve the milk in bulk milk coolers and is then sold to either consumers or processors. Most milk in Uganda is consumed raw, accounting for 90% of final dairy produce.[159]

There is increasing use of energy in Uganda's dairy value chain. For instance, Uganda has close to 100 medium-scale collection centers with capacities ranging from 2,000 to 8,000 liters per day. Most of these collection centers are located in off-grid areas and are powered by diesel generators.[160] On the other hand, many dairy-producing communities in Uganda don't have access to modern agricultural equipment. Consequently, 20—40% of all milk production in Uganda is wasted due to a lack of timely cooling.[161]

7.2. DRE technologies in Uganda's dairy value chain

Only 35% of Uganda's rural population has access to electricity.[162] The focus of the off-grid sector has been on providing electricity for consumption, such as lighting and household appliances. Therefore, it is expected that the share of farmers with access to electricity on their farms will be lower than 35%.[163] Consequently, DRE equipment is expected to be

Figure 19: A representation of Uganda's dairy value chain and major agricultural equipment

	Input supply	Rearing of Livestock	Collection & Chilling Centre	Processing	Retail	Consumption
Main Activities	• Production of animal feed • Research on cattle breeds	• Farm and livestock management	• Aggregation of milk • Grading of milk • Pricing of milk	• Steps varies based on different types of dairy products (e.g. butter, cheese, ghee, etc.)	• Buying • Storing • Selling	• Purchase from retailers • Final consumption
Agriculture equipment used	• Not relevant to DRE	• Livestock shelter • Milk tanks • Milking machine • Feed store	• Cold transport • Cold storage • Solar milk chiller	• Trucks • Cold storage • Thermal-powered heating systems • Pasteurization technology • Sterilization technology	• N/A	• N/A

*Source: UNDP. *

crucial for the transformation of the agricultural sector.

DRE technologies with viable use cases in Uganda's dairy industry include milk chillers, milking machines, SWPs for cattle watering, and chaff cutters. Among these technologies, milk chillers have been prioritized for further assessment due to their current level of adoption and potential future adoption. Although the current market status for all technologies is nascent or even non-existent, some milk chillers are being installed by private companies or non-profits. In various surveys, farmers select milk chillers as the most in-demand DRE technology among the various options.[164, 165] The following table illustrates a brief description of milk chillers available in the Ugandan market.

The market for milk chillers is in its early stages in Uganda. There are around 100 off-grid milk collection centers in the country; however, they are all powered by diesel.[166] These diesel-powered milk chillers provide an immediate opportunity for solarization.

On the other hand, nonprofits- organizations and NGOs are piloting solar-powered milk chillers. For instance, Heifer International has introduced two solar-powered milk chillers and has another six systems in the pipeline. Each solar milk chiller serves 200 farmers and can chill 8,000 liters of milk per day. Dairy cooperatives have reported various benefits from the solar milk chillers, including a 50% savings in energy costs. Due to this, the demand for solar milk chillers is expected to increase. According to a report on the market potential of milk chillers, up to $1 million USD can be invested in the next five years to convert diesel-powered milk chillers into solar milk chillers and to invest in new solar milk chillers.[167]

7.3. The employment effect of solar milk chillers in Uganda's dairy value chain

There are currently very few jobs created due to the application of solar milk chillers as the product segment is in early stage of adoption. The following table indicates the direct jobs created by solar milk chillers as reported by a non-profit organization.

The growth in the demand for solar milk chillers is expected to have a knock-on effect on jobs. There are two major job creation opportunities in the long term. The first opportunity will arise from replacing diesel-powered milk chillers with solar-powered chillers.

Table 10: Types of milk chillers in Uganda

TECHNOLOGY SPECIFICATION	SOLAR MILK CHILLERS	
	SMALL-SIZED CHILLERS	MEDIUM-SIZED CHILLERS
Capacity	50- to 200-liter units They enable short-term storage of milk at a farmer level. They can be used to store evening milk in each household before it is delivered to collection centers	1,000 to 10,000-liter capacity Used for long-term storage capacity. Especially useful to store milk for larger farms and cooperatives
Cost (for a typical technology)	**$1,700—2,000 USD** This is the cost for 50 liters refrigerator	**$25,000—31,500 USD** Price of milk cooler for a volume that ranges from 1000 — 2500 liters. If battery storage is added to the system, the cost can increase by up to 100%
Payback period	**2 years** Payback period is correlated to prior spoilage rate. Hence, in off-grid areas with no prior access of cooling technology, the payback period is shorter	**2—5 years** The lower range represents the payback period for an area with low spoilage rate (~10%) while the high range represents payback period for areas with high spoilage rate

Source: Interview with solar milk chiller installer[168, 169)]

There are 100 off-grid diesel-powered chillers in the country that are an immediate opportunity for conversion. The second opportunity arises from bulk deployment of new solar-powered milk chillers.

In addition to the direct jobs created at the milk chilling facility, there will be additional indirect jobs before and after the milk reaches the collection center. The first opportunity is in the assembly of the milk chiller. Currently, job creation in this area is limited compared to India, as most of the components of the milk chiller, including the solar panels, have to be imported. There are additional jobs in transporting milk as well. With the introduction of milk chillers, milk production is expected toincrease, creating a need for more drivers to transport milk from the farmer to the cooperative.

There are additional indirect jobs that can be created, especially on the downstream side of the value chain. Participants of the FGD indicated that there will be additional job creation in the value addition and marketing of milk. Women, in particular, can benefit from this as they can engage in the production of ghee, milk powder, and other dairy products, which will increase their income and provide capital to hire more workers. However, additional job creation will depend on the existing spoilage rate in an area. More jobs will be created in locations with high spoilage rates and no alternative milk-chilling facilities. On the other hand, in locations with existing diesel milk chillers, there will be a transition of workers rather than the creation of new jobs.

Figure 20: Direct jobs created by a solar milk chiller as reported by a non-profit organization

JOB CATEGORY	JOB CREATION	TYPES OF JOBS
Direct jobs	**Ten informal workers per site.** These workers are hired for the installation and commissioning of the system. They are hired for a three-month contract.	Construction workers
	Two technicians are hired to operate one solar milk chiller.	**Technician:** for cleaning and upkeep machinery, pour the milk into the tank, conduct quality assessment of milk, keeping data of milk stored Solar milk chillers users in India also reported the same level of job creation.

Solar milking machinery and its impact on jobs

Milking is done manually in Uganda. Dairy farmers usually utilize family labor to do the milking. FGD participants also indicated that some farmers hire local milkers to do the milking. Dairy cows are milked twice a day, in the morning and afternoon.

Using a manual milking process, it takes about ten minutes to milk one cow, often requiring excess labor.[170] While this is good for employment, the task is labor-intensive, and manual milking reduces the amount of milk produced compared to mechanical milking. To address this problem, some non-profits are piloting solar milking machinery. Using a solar-powered milking machinery, milk can be drawn from as many as twenty to thirty cows within an hour (two to three minutes per cow).

During the FGD and interviews with dairy sector stakeholders, there was excitement regarding the introduction of milking machinery that can increase production. On the other hand, there were concerns about the technology's potential contribution to job loss. According to one FGD participant, up to five jobs per cooperative[v] could be lost if mechanical milkers are widely adopted. However, many stakeholders indicated that these would be temporary job losses and that these workers would be reallocated to more productive segments of the dairy value chain.

v A dairy cooperative in Uganda comprises up to 100 dairy farmers


Photo Credit: CLASP

CONCLUSIONS AND WAY FORWARD

8.1. Conclusion

This report has demonstrated that the DRE sector can be an engine for job creation, especially among the rural youth. The SWP sector alone can create up to 77,000 jobs in India and 38,000 jobs in Kenya.

Other DRE technologies, such as solar mills, solar milk chillers, and cassava graters, also have the potential to create jobs in the future. This report also highlighted how the path for job creation varies for each country and each DRE technology. The following table provides a comparison of the main insights per country.

Table 11: Opportunities and challenges for DRE sector job creation in the focus countries

COUNTRY	INDIA	KENYA	NIGERIA	UGANDA
Value chain selected	Rice Dairy	French bean (green bean)	Cassava	Dairy
DRE technology prioritized	**Rice** SWPs Solar rice mills **Dairy** Solar milk chillers Solar fodder grower units Solar milking machinery	SWPs Cold storage	Cassava graters Cassava millers	Solar milk chillers
Jobs created	Up to 77,000 jobs can be created in 2030 due to adoption of the SWP Up to 2300 workers can be employed by the solar mill sector by end of 2030	Up to 38,000 jobs can be created in Kenya due to the use of SWP	Few jobs created due to adoption of cassava graters or miller as the market is in infant stage	Limited job creation as very few solar milk chillers have been installed
Opportunities for further job creation	Larger market size for agricultural equipment, including DRE technology More advanced DRE market with multiple players Developed solar manufacturing sector, resulting in highly technical positions created domestically Active government participation through schemes such as PM-KUSUM	Growing SWP market. Average growth of 49% over the past four years[171] Immense market potential for cold chain infrastructure. It is expected to reach $1 billion USD by 2030 (including grid and off-grid)	Retrofitting of diesel graters with plug-in graters is expected to become the major job creator for highly skilled technicians Nigeria's growing clean energy manufacturing sector expected to create employment opportunities as the demand for DRE products increases	Replacing 100 diesel-powered off-grid chillers in the country with solar-powered chillers is low hanging fruit for job creation
Challenges that can hinder job creation	Competition from legacy or new diesel-powered alternatives Unmet demand for solar milk chillers due to various factors such as high upfront cost	Lack of practical training programs targeted at DRE technologies Limited in-house manufacturing capability means very few indirect jobs will be created	Upfront cost of plug-in or standalone solar cassava graters and millers is still expensive compared to diesel-powered alternative Lack of quality training programs targeted at DRE technologies	Lack of practical training programs targeted at DRE technologies Limited domestic milk chiller assembly capability lowers the country potential to create highly technical jobs

8.2. Way forward

DRE technologies have immense potential to create both on-farm and off-farm jobs. This report has estimated the current job creation and provides an estimate for future job creation if the market for DRE technologies in agriculture scales up. The future job estimation assumes that more DRE technologies will transition from their current nascent status to the scaling-up phase. Although DRE technologies have the dual benefit of improving sustainability while enhancing productivity and production, they face competition from incumbents such as diesel-powered alternatives. Hence, stakeholders in the energy and agriculture sectors need to make a concerted effort to make DRE technologies attractive to farmers. This will inevitably result in more job creation in the future. In the section below, we have highlighted three main actions governments can take to achieve the full potential of DRE technologies.

Strengthen market-based interventions to boost demand for DRE equipment in the agriculture sector

DRE equipment, especially SWPs, has enabled farmers in India, Kenya, and other countries to more than double their production while also reducing greenhouse gas emissions from agriculture. This has been achieved through private sector business model innovations (e.g., irrigation as a service) and support from the public sector. While the type of market activation interventions must be specific to each country's circumstances, some proven best practices should be considered for adoption.

In India, the launch of the PM-KUSUM scheme was critical in catalyzing the SWP market. The main reason for its success was addressing the primary bottleneck to adoption: the high upfront cost. Other countries may not have the fiscal space to subsidize the purchase of SWPs, but the public sector has other levers at its disposal to address this problem. One such example is setting up a fund that supports microfinance institutions to provide financing instruments for DRE equipment.

Apart from affordability, the sector faces other barriers, such as limited awareness and limited availability of products, which hinder adoption. Since most DRE products are in the early stages of development, the public sector needs to actively support this sector. Doing this will eventually translate to more jobs for the rural youth.

Strengthen solar equipment manufacturing

Governments and stakeholders need to strengthen the manufacturing sector for solar equipment to create thousands of skilled jobs in the DRE industry. For example, India could see up to 5,500 manufacturing jobs in the solar water pump sector are expected by 2030.

Uganda, Kenya, and Nigeria also have huge potential for the manufacturing of renewable energy products. For example, Kenya is on its way to achieving 100% renewable energy in its electricity sector. This will create massive local demand for renewable energy products. In addition, both Kenya and Nigeria have legislative frameworks for renewable energy and manufacturing. However, to attract investment in manufacturing, challenges such as political instability, infrastructure (especially energy for industrial uses), and a lack of local expertise need to be addressed.[172]

Strengthen DRE technologies' relevant reskilling and upskilling programs

The reskilling and upskilling of the DRE workforce requires the collaboration of various stakeholders, including educational institutions, government institutions, DRE companies, and development programs. The lack of a skilled workforce can derail job creation in the sector.

TVETs are well placed to provide skill development programs, especially for rural youth. However, there are various challenges with TVET courses, such as outdated curricula, inadequately qualified trainers, and high tuition costs.[173]

In addition to TVETs, other forms of reskilling and upskilling programs, such as short-term internships, apprenticeships, and experience sharing, need to be integrated. In addition, increased support is necessary to make the labor transition—where manual farm jobs are replaced with the uptake of DRE technologies—smoother. Short-term job training programs can be considered to support this transition.

Improve coordination between agriculture and energy stakeholders

Key stakeholders—national governments, development partners, SHFs, and the private sector—must align and work cooperatively to support an energy transition in the agricultural sector. Such alignment is expected to result in policies favorable to the DRE sector, ultimately leading to its growth and job creation.

Coordination between agriculture and energy stakeholders can begin with joint planning. Countries such as Uganda and Ethiopia have integrated renewable energy into their agricultural development plans. Uganda has gone a step further by assigning responsible parties and establishing key performance indicators for implementing renewable energy targets. This approach is expected to drive growth in the DRE market by sending a positive signal to businesses interested in investing in the sector.

Credit: Duncan Moore


Photo credit: CLASP

METHODOLOGY APPENDIX

Value chain analysis and prioritization

The first step in this study was to prioritize one agricultural value chain per country. There are a plethora of DRE technology options available for the various agricultural value chains. However, by selecting a few high-impact technologies, we can develop a deeper and more nuanced understanding of their impact. Hence, prioritizing value chains per country will help us achieve this.

We followed a three-step process to identify the commodities for further analysis.

Step 1: Identify the top ten most produced crops/ livestock products for each country.

Step 2: Filter high value crops/livestock products based on their market size (export and local market) and other social factors such as women's share of employment, the role of crop in dietary consumption of the country, and the number of SHFs engaged in the value chain.

Figure 21: Illustration of the formulas used for each job category

Categories of jobs	Unit	Formula
A Direct Jobs	**Jobs per 100 equipment (e.g. Jobs per 100 equipment sold)**	Employment factor (Number of Jobs per unit of PURE equipment) X Annual number of PURE products sold
B Indirect - Upstream Jobs	**Indirect Jobs per equipment (e.g Jobs per 1000 equipment sold)**	Indirect jobs employment factor (Number of indirect Jobs per unit of PURE equipment) X Annual number of PURE products sold
C Indirect - Downstream Jobs; **C1** Onsite Farm Jobs	**Jobs per equipment (Farm jobs per 1000 SWPs)**	Number of **new** employees required to operate the PURE technology X Total number of PURE machineries in the market
C Indirect - Downstream Jobs; **C1** Agricultural Value Chain jobs	**Jobs per additional unit of production (e.g., Jobs per additional 1 ton of rice)**	**2 options to calculate Agricultural Value Chain Jobs** **Option 1:** Productive use jobs multiplier (Direct to productive use job converter) X Annual number of PURE products sold **Option 2:** Additional number of workers per a unit increase in agricultural production X Total increase in production caused by the PURE product (**New** increase in production)

Step 3: Select the top commodity based on the current prevapence DRE equipment.

Based on this methodology, the following country and commodity combination were selected:

- **India**
    - The rice value chain
    - The dairy value chain
- **Kenya**
    - French bean value chain
- **Nigeria**
    - The cassava value chain
- **Uganda**
    - The dairy value chain

Those value chains were also intentionally selected so that we could study different types of DRE equipment. For instance, the maize value chain in Kenya was deprioritized because the type of DRE technologies used is similar to those in the rice value chain in India.

Methodology to estimate new jobs created

The formula used to calculate the job impact for each job category is listed below.

Methodology to estimate time saved

In addition to new net job creation, the introduction of DRE technologies helps farmers reduce the time it takes to complete a task. For instance, motorized irrigation has been shown to greatly reduce the time spent on fetching water, benefiting girls in particular.[174] This time can then be used for other income generating activities, leisure, and/or for care activities.

The following methodology can be used to estimate the time saved due to DRE technology.

Time saved = (Old process - New process) X Days of the year, where

Time saved = The time saved due to mechanization expressed in labor hours per year

Old process = The time it takes to complete one task per day. It is expressed in hours per one unit of task

New process = The time it takes to complete one task using mechanization. It is expressed in hours per one unit of task. The task needs to be standard in both the old and new processes

Days of the year = How many days during the year is the task conducted

Limitation of the study

The present study has the following limitations that can impact the interpretation of results.

Induced employment estimates: Induced employment refers to jobs created due to the spending of earnings by those directly and indirectly employed by the projects. Induced jobs are beyond the scope of this report. There is limited qualitative data in the literature to estimate induced jobs.

Future market size estimation: The projection of future market demand assumes that present conditions will prevail until 2030. However, significant events in the market, such as major investments in one technology or changes in government priorities, can have a substantial impact on market size and, consequently, job creation.

The availability of high-quality data: This report relies on labor multipliers and employment factors for job estimation. For some DRE technologies key and up to date market data is not available.

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