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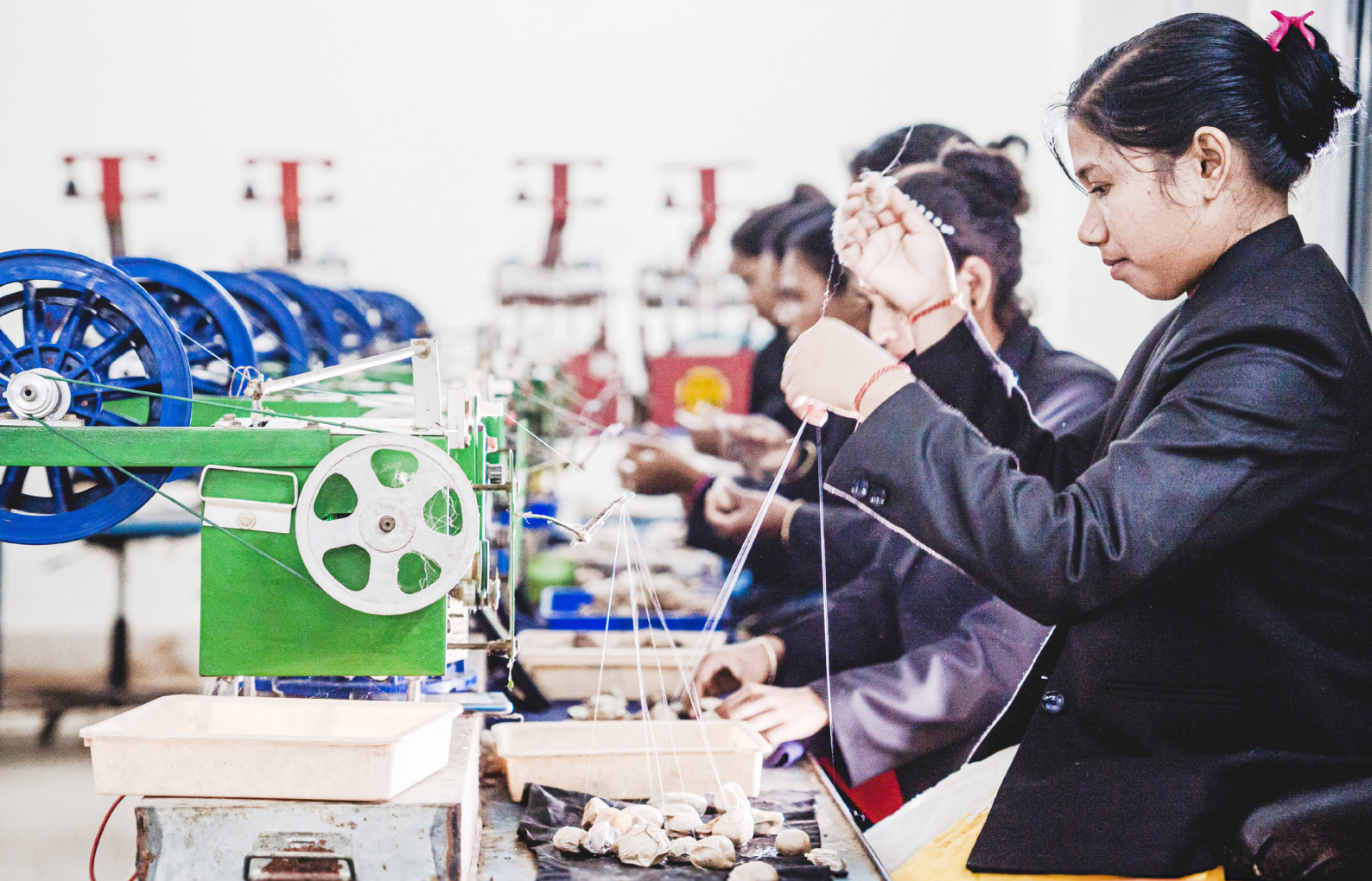
Powering Livelihoods
A CEEW-VILLGRO INITIATIVE

How Decentralised Renewable Energy-powered Technologies Impact Sustainable Livelihoods

Findings from the Ground (2025)

Priyatam Yasaswi, Divya Gaur, and Abhishek Jain

Report | April 2025



Suggested citation: Yasaswi, Priyatam, Divya Gaur, and Abhishek Jain. 2025. *How Decentralised Renewable Energy-powered Technologies Impact Sustainable Livelihoods? Findings from the Ground (2025)*. New Delhi: Council on Energy, Environment and Water.

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Cover image: CEEW/Emotive Lens.

Peer reviewers: Alreena Pinto, Consultant, World Bank Group; Vivek Shastry, Senior Research Associate, Center on Global Energy Policy at Columbia University, School of International and Public Affairs; Priyadarshini Karve, CEO of The Clean Energy Access Network (CLEAN), and Vishwas Chitale, Senior Programme Lead, CEEW.

Publication team: Purnima P. Vijaya (CEEW); Alina Sen (CEEW); The Clean Copy; MADRE Designs, and FRIENDS Digital Colour Solutions.

Acknowledgment: The authors are thankful to reviewers and colleagues at CEEW and Villgro for their inputs and feedback during the study. We are also indebted to the support from our cohort enterprises, Sustain Plus Energy Foundation (SPEF) and other implementation partners without which this study would not have been possible. We extend our gratitude to Kantar Public (now Verian), our data collection partner who supported us in data collection for the study.

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About CEEW

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About Powering Livelihoods

A joint initiative between CEEW and Villgro, Powering Livelihoods (PL) is boosting India's rural economy by scaling up the penetration of clean energy-powered (decentralised renewable energy) livelihood technologies, especially amongst women. It is doing so by:

- providing deep technical and capital assistance to social impact enterprises deploying RE-powered livelihood equipment
- enabling sectoral partnerships with various enabling stakeholders including financiers, investors, and state government departments, and go-to-market partners.
- generating bespoke market research insights and evidence at scale about the impact and viability of DRE-livelihoods
- supporting national and sub-national policy frameworks to mainstream DRE-livelihoods to positively impact rural incomes, especially of women.

Solar refrigerators, energy-efficient food processors, solar reeling machines, cold storages, solar dryers, etc., are some of the technologies supported under the programme. By leveraging these enterprises' growth, the programme generates rigorous evidence about these solutions' impact, viability, and scalability to garner the support of investors, financiers, and policymakers to realise a potential USD 50 billion market opportunity. As of March 2025, through the PL supported enterprises, more than 32,000 livelihoods have been positively impacted, with around 50 per cent being women, driven by over 16,000 technology deployments.

Contents

Enabling reliable cooling solutions can empower fisherwomen by minimising spoilage and maximising profits.

Image: CEEW/Emotive Lens

Executive summary

Mainstreaming DRE-powered livelihood solutions, especially in rural and remote areas, can help enhance incomes, improve productivity, and enhance demand for consumer goods, leading to rural prosperity

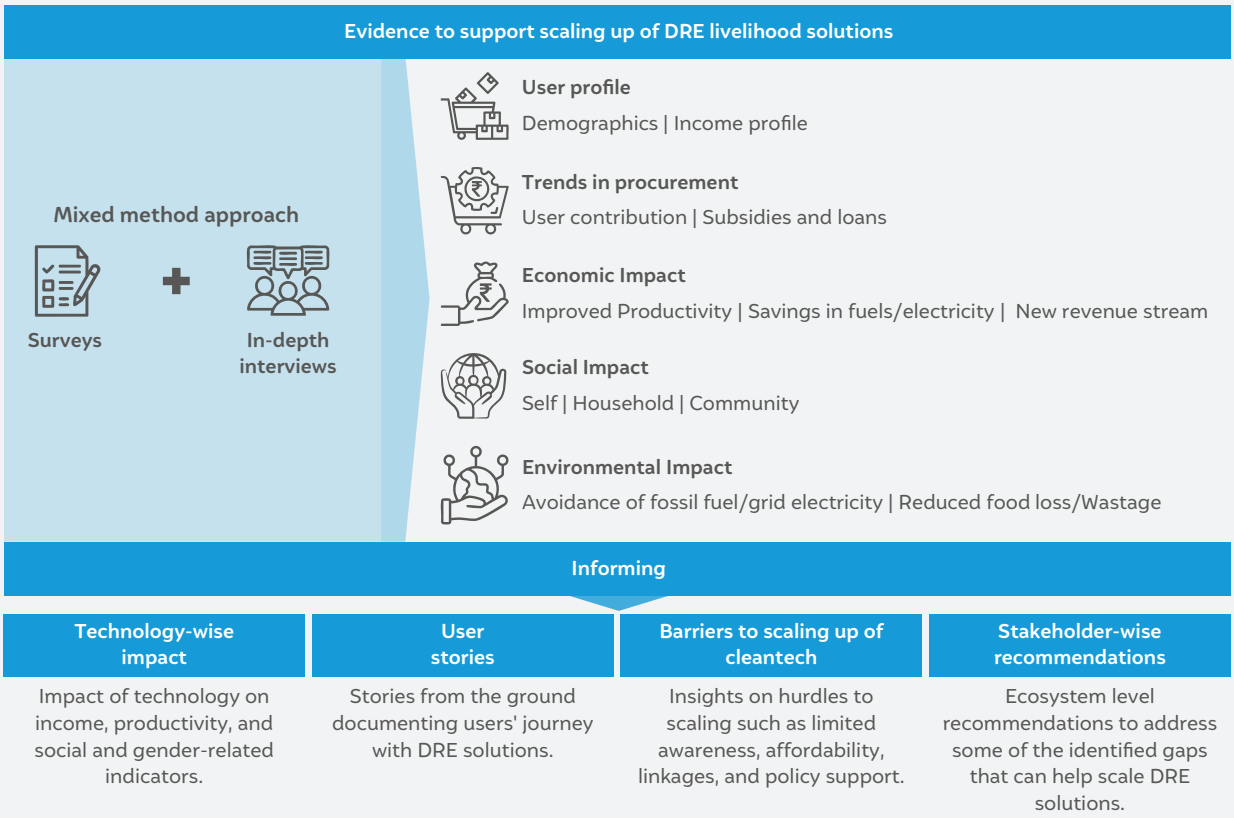
Agriculture continues to employ nearly half (45.8 per cent) of India's workforce, mainly in rural areas. However, the rural economy's contribution to India's GDP remains limited due to the impacts of climate change, water shortages, reverse migration and low productivity. (Ministry of Finance 2024). Evidence shows that lack of access to affordable and reliable energy hinders agricultural productivity and the growth of agribusinesses, thereby curbing the overall rural economy (Ringler et al. 2022). Therefore, enabling access to reliable energy, ideally through clean energy, is important in realising the potential of the rural economy. A decentralised renewable energy (DRE) system that generates and distributes energy independently of a centralised grid to power lighting, space heating, and consumer and productive appliances presents a cost-effective solution for ensuring reliable energy access at the last mile (Jain, Ghosh, and Chhabra 2021). These decentralised solutions help meet rural communities' electricity loads and requirements, which are often unmet by centralised grids (IRENA and SELCO Foundation 2022). Consequently, documenting and understanding the social, economic, and environmental impact of DRE systems is crucial, as these technologies could potentially impact livelihoods of 37 million people in India (Jain, Khalid, and Jindal 2023). In 2020, CEEW and Villgro launched the Powering Livelihoods programme to promote DRE-powered solutions in rural India. It aims to foster a supportive ecosystem for mainstreaming clean energy livelihood solutions. Through impact assessment research, it seeks to inform sectoral stakeholders by generating nuanced evidence on the social, economic, and environmental impacts of DRE livelihood solutions deployed across the country.

This impact assessment research is an ongoing effort that will take place over multiple rounds, with new technologies being added in each round and cross-sectional data collected. In our previous study (Gaur, Yasaswi, and Jain 2023), we examined the impact of six DRE livelihood technologies on users' livelihoods and highlighted the factors that constrained the usage of these solutions and the steps stakeholders must take to address them. In Round 2, the present study, we examine eight DRE technologies. To do so, we interviewed 889 users across 18 states and union territories. These technologies primarily support livelihoods in the agricultural, textile, and food processing sectors. These technologies are a) solar silk reeling and spinning machines, b) small horticulture processors, c) solar refrigerators, d) vertical fodder grow units, e) micro solar pumps, f) solar dryers, g) solar dehydrators, and h) biomass-powered cold storage.

This study through a nationally representative survey aims to provide evidence on the following questions (Figure ES1):

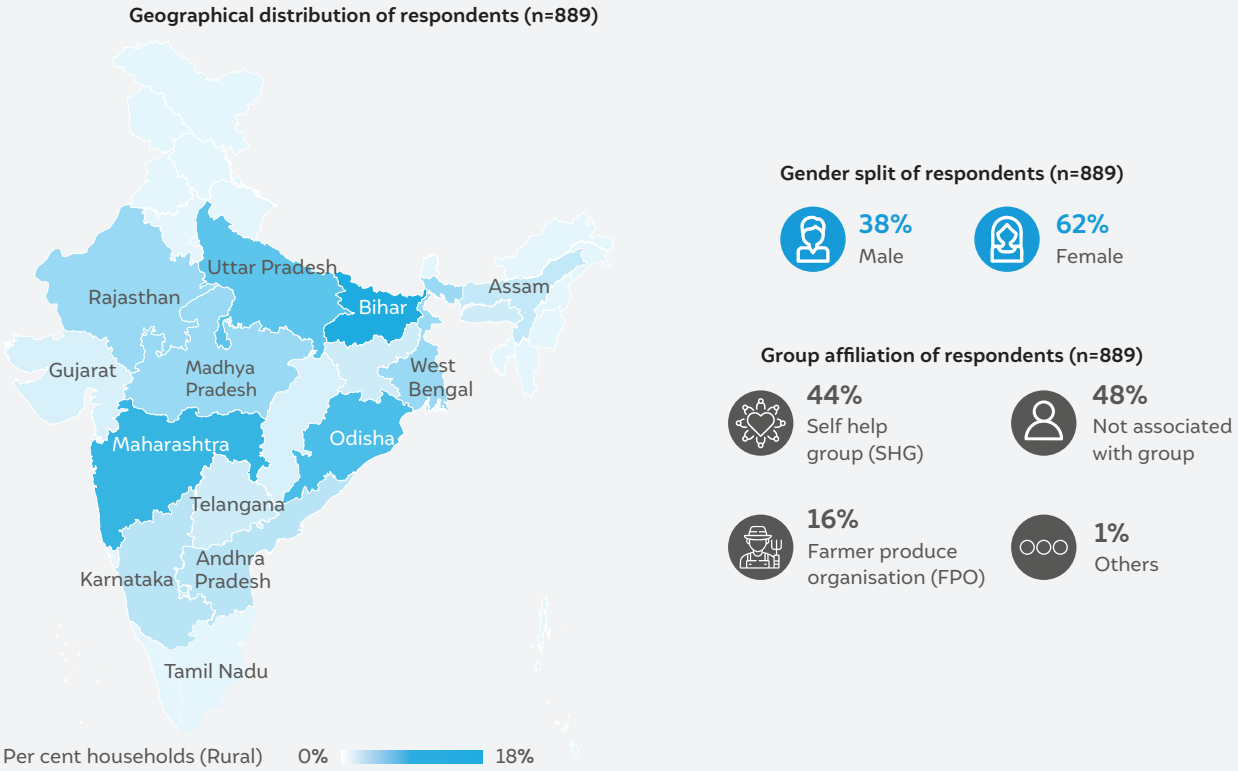
- Who are the users of DRE livelihood solutions in India and how are they purchasing these solutions?
- What is the impact of DRE livelihood solutions on users' incomes?
- How do users engage with the solutions, and what barriers limit their usage?
- How significantly do DRE solutions impact aspects of users' lives other than their incomes?
- How is clean tech in rural livelihoods reducing carbon emissions?

Figure ES1 Aspects covered under this impact assessment research



Source: Authors' compilation

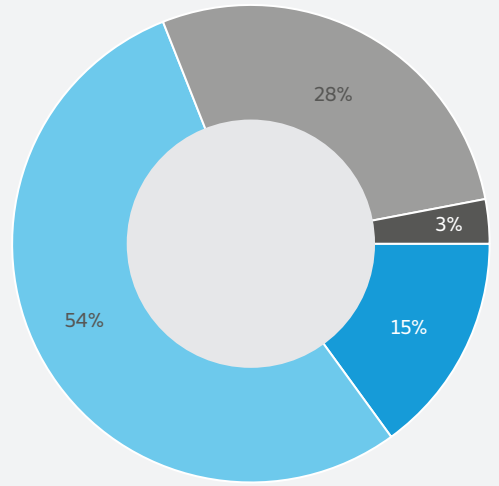
Figure ES2 A typical respondent is a 30-45 year old female, part of a collective and residing in the central or eastern regions of India.



Source: Authors' analysis

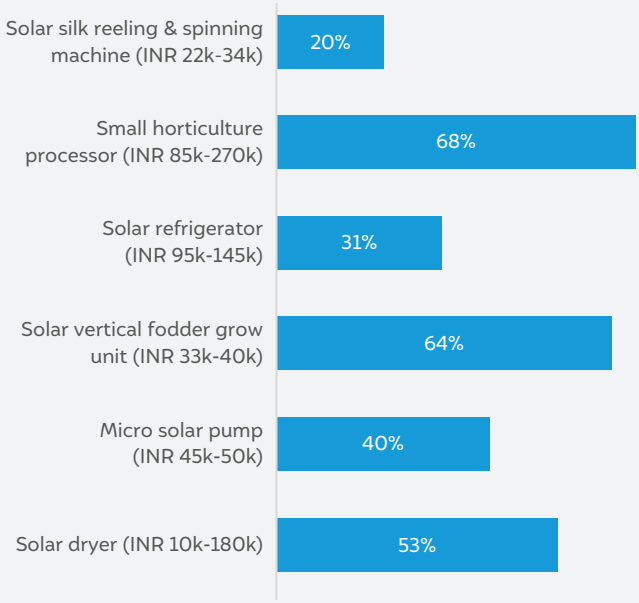
Figure ES3 Most users contribute upfront but dependent on subsidy to procure the technology

User upfront contribution (n=889)



- Bought with more than 60% upfront contribution
- Bought with less than 60% upfront contribution
- No user upfront contribution
- Lease/rent/using it as service/employee

Average user upfront contribution across technologies



Source: Authors' analysis

Figure ES4 DRE adoption increased incomes for almost 90%, while also enabling positive social impact, especially among women

Economic impact of DRE livelihood solutions

87%
n=660
users reported income increase

- **48.4%** Higher number of earning days
- **70.7%** Improved productivity
- **46.3%** Lower input costs
- **29%** Improved quality of product and better selling price

Impact on women users

84%
Increased participation in public/community events

69%
Increased mobility (public/pvt transport)

91%
Increase in knowledge/skills

86%
Increase in agency to make decisions

Source: Authors' analysis

Figure ES5 Availability of market linkages, working capital and satisfactory output are crucial for long term usage of DRE solutions.

62% users were using the solution at the time of survey after at least 6 months of owning it

Top reasons DRE solutions go unused

- Unavailability of raw materials
- Unsatisfactory output (quality/quantity)
- Lack of working capital

Source: Authors' analysis

SOLAR SILK REELING AND SPINNING MACHINES

Energy-efficient, solar-powered silk reeling and spinning machines enable users (usually women) to reel high-quality silk. The machine reduces the drudgery of traditional manual thigh reeling, increases productivity, and promises increased incomes.

Image: CEEW/Emotive Lens

Kuni Dehury, a master silk reeler and trainer, successfully oversees operations at the Tassar Silk Park which houses more than 250 solar silk reeling machines in Bhagamunda, Keonjhar, Odisha.

States surveyed

56% Bihar
22% West Bengal
13% Others
9% Assam

Respondents

277 Total
97% Females

68% OBC
26% SC/ST
6% General

Primary income

69% Non-farm
31% Farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experiencing income increase

74%

100%

₹ 44,000
increase in annual income for a typical user from a baseline income of ₹ 1,26,000

120%
Increase in the average selling price of yarn

Source: CEEW analysis 2024

USERS' EXPERIENCE

2x
increased in productivity, compared to earlier reeling practices (Manual & Grid based machine)

97%
of users reported an **increase in the quality of reeled silk**

10 months
of usage reported in **a year on average**

ENVIRONMENTAL IMPACT

1.1 MT
CO_2e abatement*

**For every 100 units of Unnati (Silk Reeling) machine used for 5 hours for 250 days a year.*

SMALL HORTICULTURE PROCESSORS

A multi-purpose food processor that extracts juices, pulp and essential oil from various vegetables, fruits, herbs and flowers. It can be also used to make jams, candies and squashes, etc. It enables value addition for otherwise perishable horticulture produce, increasing the users' income.

Image: Manish Singh/CEEW

Shiv Kumar, an entrepreneur from the Gonda district of Uttar Pradesh, uses the small horticulture processor to manufacture over fifteen varieties of products from fruits, vegetables and herbs, which he then markets through local retailers.

States surveyed

38% Rajasthan
25% Uttar Pradesh
25% Others
12% Uttarakhand

Respondents

32 Total
16% Females

66% General
31% SC/ST
3% OBC

Primary income

50% Non-farm
50% Farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experiencing income increase

80%

50%

₹ 59,000
increase in annual income for a typical user from a baseline income of ₹ 2,12,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

88%
users reported **decrease in the wastage of produce**

100%
users reported **no physical strain** in operating the machine

88%
respondents use the small horticulture processor to make fruit, vegetable and herbal juice products

ENVIRONMENTAL IMPACT

11.6 MT
of CO_2e abatement*

** For every 100 units of solar powered small horticulture processor used for 3 hours daily for 180 days a year.*

SOLAR REFRIGERATORS

The energy-efficient and solar-powered DC refrigerator provides reliable cooling for a wide range of commodities (dairy products, fish, cold drinks, vaccines). It decreases spoilage of perishables and provides savings on users' electricity bills.

Image: CEEW/Emotive Lens

In the fisheries value chain, solar refrigerators serve as an effective solution, replacing the expensive ice boxes used for storing fish produce.

States surveyed

60% Uttar Pradesh | **29%** Rajasthan | **11%** Karnataka

Respondents

169 Total | **31%** Females

40%	SC/ST
36%	OBC
23%	General
1%	No data

Primary income

60% Non-farm | **40%** Farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experiencing income increase

77%

88%

₹ 22,000
increase in annual income for a typical user from a baseline income of ₹ 1,11,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

85%
users purchased the solar refrigerator for business use

28%
users reported **savings on electricity bill**

₹ 450
reported **average monthly savings on electricity bill**

58%
users own the 200 litre solar refrigerator

Source: CEEW analysis 2024

ENVIRONMENTAL IMPACT

29.4 MT
of CO_2e abatement*

**For every 100 units of solar refrigerators used for 21 hours daily for 250 days a year.*

SOLAR VERTICAL FODDER GROW UNIT

A solar-powered, microclimate-controlled, hydroponics unit enables users to harvest about 25 kgs of fresh green fodder daily with less than a bucket of water. This solution promises an increase in the milk and meat yield of animals, thereby helping animal rearers realise better incomes while reducing the time and drudgery involved in fodder procurement and preparation.

Image: Selvaprakash Lakshmanan/Swiss Re Foundation/Fairpicture

Solar vertical fodder grow unit can reduce the time involved for women in rural areas for fodder collection and management.

States surveyed

38% Karnataka
28% Andhra Pradesh
26% Telangana
8% Others

Respondents

39 Total
62% Females

62% OBC
28% General
10% SC/ST

Primary income

79% Farm
21% Non-farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experienced income increase

67%

60%

₹ 59,000
increase in annual income for a typical user from a baseline income of ₹ 2,19,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

59%
users reported reduced physical effort with fodder collection and preparation

47%
users reported reduced concentrate feed purchase

2 hours
average reported time saved in fodder collection and feed preparation

₹ 2/litre
average reported increase in the price of milk

Source: CEEW analysis 2024

ENVIRONMENTAL IMPACT

15.4 MT
of CO_2e abatement*

**For using 100 units of solar vertical fodder grow units for 225 days a year.*

MICRO SOLAR PUMPS

A hyper-efficient, portable, open-well submersible pump system, designed for small farmers with a land holding of up to two acres. The pump increases income by expanding the irrigated area, increasing cropping cycles and displacing diesel use. It also reduces the overall effort that typically goes into starting and operating diesel pumps for irrigation.

Image: Khethworks

A micro solar pump enables small and marginal farmers to provide timely irrigation for their crops without relying on costly diesel or kerosene-operated pumps in rural areas.

States surveyed

55% Odisha | **35%** Madhya Pradesh | **10%** Jharkhand

Respondents

159 Total | **60%** Females

79%	SC/ST
16%	OBC
4%	General
1%	No data

Primary income

92% Farm | **8%** Non-farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experienced income increase

96%

100%

₹ 28,000
increase in annual income for a typical user from a baseline income of ₹ 63,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

81%
users reported an **increase in irrigated area** post the adoption of micro solar pump

84%
users reported **reduced cost of irrigation** post the adoption of micro solar pump

₹ 14,600
average reported annual savings in irrigation costs

82%
users mention the water discharge quality as 'very good'

ENVIRONMENTAL IMPACT

11.4 MT
of CO_2e abatement*

**For every 100 units of micro solar pump used for irrigating 2 acres on average across 6 months of a year.*

SOLAR DRYER

A portable solar dryer helps farmers increase the shelf life of perishable agricultural produce, thereby enabling savings from food loss and better value for farmers. Solar dryers are commonly used for drying fruits, vegetables, spices and grains in bulk.

Image: CEEW/Emotive Lens

Solar dryers are a viable solution for mitigating produce loss and price volatility in commodities such as tomatoes.

States surveyed

30% Andhra Pradesh
29% Others
24% Odisha
17% Maharashtra

Respondents

87 Total
38% Females

40%	OBC
38%	SC/ST
16%	General
6%	No data

Primary income

85% Farm
15% Non-farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experienced income increase

91%

77%

₹ 46,000
increase in annual income for a typical user from a baseline income of ₹ 89,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

91%
users mentioned that they had no prior experience with dryers as they relied on open sun drying

88%
users experienced an **increase in the quality of dried produce**

₹ 700
average reported **price realised for dried spices and flowers** (per kg)

52%
users process fruits in the solar dryer, 35% process vegetables

ENVIRONMENTAL IMPACT

20.3 MT
of CO_2e abatement*

**Through drying 60 batches per year in ten units of 100 kg solar dryers*

SOLAR DEHYDRATOR

A portable solar dehydrator helps farmers increase the shelf life of perishable agricultural produce, thereby enabling savings from food loss and better value for farmers. Designed for small-scale use, solar dehydrators effectively remove moisture from food items to ensure preservation.

Image: S4S

Solar dehydrator-based village processing centres offer women viable livelihood opportunities, reducing the physical effort and drudgery associated with traditional farm-based work.

States surveyed
100% Maharashtra

Respondents
75 Total **96%** Females

67%	General
27%	SC/ST
3%	OBC
3%	No data

Primary income
40% Farm **60%** Non-farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experienced income increase

82%

33%

₹ 74,000
increase in annual income for a typical user from a baseline income of ₹ 1,53,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

6 hours
average reported time spent per day on dehydrator

92%
users reported a **decrease in physical effort** from earlier livelihood activities

53%
users mention confidence from assured buyback of dried produce

ENVIRONMENTAL IMPACT

20.3 MT
of CO_2e abatement*

**Through drying 60 batches per year in ten units of 100 kg solar dryers*

BIOMASS-POWERED COLD STORAGE

The biomass-powered cold storage offers reliable cooling to farmers for storing their agricultural products at minimal running cost. It utilises the waste biomass available at the farm gate.

Image: CEEW/Emotive Lens

Biomass-powered cold storage offers a cost-effective means for farmers and farmer collectives to store produce like lemons and tomatoes, helping mitigate price volatility.

States surveyed
100%
Maharashtra

Respondents
51 Total **8%** Females

53%	SC/ST
35%	General
12%	OBC

Primary income
100%
Farm

Source: CEEW analysis 2024

INCOME IMPACT

Users experienced income increase

100%

100%

₹ 60,000
increase in annual income for a typical user storing produce in the cold storage from a baseline income of ₹ 81,000

Source: CEEW analysis 2024

USERS' EXPERIENCE

72%
of users were first-time users of cold storage

84%
users reported **improved price realisation for commodities with the use of cold storage**

73%
users store fruits in cold storage on average for 73 days, 23% store vegetables

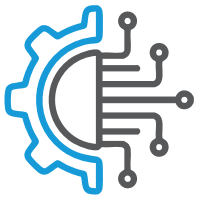
30%
users mention **'low price during harvest' as one of the reason for adopting the biomass cold storage**

ENVIRONMENTAL IMPACT

94 MT
of CO_2e abatement*

**By one biomass cold storage unit through avoiding 15% food loss per batch for 15 batches in a year*

Key recommendations for scaling up of DRE livelihood solutions



Targeting of DRE solutions through SHGs and FPOs, incentivising user upfront contribution, policy alignment, and streamlined value chain linkages is crucial to mainstream DRE livelihood solutions

This impact assessment study is the first of its kind effort to generate evidence at scale on the social, economic, and environmental impacts of DRE livelihood solutions on its users in India. The insights provide broader implications for the scaling up of these solutions in the DRE sector in the Global South. Notably, 87 per cent of users reported an income increase after adopting DRE solutions, in addition to enhancing productivity, reducing drudgery, and contributing to carbon emission reduction.

This study offers actionable recommendations to accelerate the scaling of these technologies on the ground. These recommendations are informed by both research findings (quantitative and qualitative) and experiences from the Powering Livelihoods programme, emphasising evidence-based strategies to overcome adoption barriers and maximise impact.

- **DRE livelihood technologies can be targeted towards SHGs and FPOs, to enable group ownership and creation of micro/nano-enterprises**. Our data reveals that 60 per cent of self-selected DRE technology adopters are members of Self-Help Groups (SHGs) or Farmer Producer Organisations (FPOs). Leveraging group lending preferences of financiers and government revolving funds is key to scaling these enterprises and unlocking economic activity.
- **Commercial scale up of technologies should be incentivised to reduce subsidy-heavy deployments for long-term usage**. Our regression analysis shows a strong and statistically significant relationship between user upfront contribution and usage of the solution (p-value=0.00). Therefore, user contribution is crucial to ensure long-term usage and hence, commercial models of deployments should be advanced.
- **Facilitate sustained use of DRE solutions by strengthening market linkages and ensuring access to working capital to maximise user benefits**. Consistent utilisation of DRE solutions is essential for securing reliable incomes for users. Our findings indicate that approximately 18 per cent of users have never used the solution, while about 5 per cent have discontinued its use. Although the reasons for non-usage may vary across different technologies, we found that a lack of working capital is the primary barrier for 86 per cent of respondents who have never used the solution. Additionally, 30 per cent of those who stopped using the solution cited the unavailability of raw materials or inputs as a significant constraint.

Enhancing the targeting of DRE solutions through SHGs and FPOs, incentivising user upfront contribution, policy alignment, and streamlined value chain linkages is crucial to mainstream DRE livelihood solutions. This study provides evidence to stakeholders for informed decision making to materialise these actions.

1. About the study

Image: CEEW/Emotive Lens

This impact assessment aims to generate evidence at the national level on the social, economic, and environmental impacts of DRE livelihood technologies. These energy-efficient and renewable energy–powered solutions help support traditional livelihoods in the agriculture, animal husbandry, textile, and small-scale business sectors. This report provides analysis and insights based on responses from users who have used a DRE solution for at least six months. The current study includes eight DRE technologies, three more than those covered in the Round 1 study (Gaur, Yasaswi, and Jain 2023). These are a) solar silk reeling and spinning machines, b) small horticulture processors, c) solar refrigerators, d) vertical fodder grow units, e) micro solar pumps, f) solar dryers, g) solar dehydrators, and h) biomass-powered cold storages.

1.1 Study objective

Powering Livelihoods aims to help scale up DRE technologies by generating evidence on the socioeconomic impacts of these solutions. By doing so, we strive to inform stakeholders of the following:

- Trends in technology procurement and the end-user level impacts of DRE technologies
  - How are users procuring the technology? (ownership, source of capital)
  - How are these technologies impacting the livelihoods of their end-users? (income changes, productivity, social and gender impact, environmental impact)

- Existing barriers to scaling up adoption and continued usage
  - What are the usage trends after at least six months of procuring the technology?
  - What are the challenges that limit continued usage?
- User case stories from across geographies
  - How have these technologies enhanced the livelihoods of end-users across value chains and geographies? (real-life examples)

1.2 Methodology

The research comprises multiple rounds of cross-sectional studies, using a mixed-method approach consisting of both quantitative and qualitative research tools, such as surveys and in-depth interviews. This report compiles findings from Round 2 of the impact assessment data collection.

1.3 Sampling

We drew the study's target population from user data provided by enterprises supported by the Powering Livelihoods (PL) programme; this included users who have had access to DRE solutions for at least six months. At the technology level, each sample was arrived at using a random sampling approach with a 95 per cent confidence interval and a 5 per cent margin of error. For each technology, we collected geographically distributed samples using the probability proportional to size (PPS) method. We initially intended to select users randomly for data collection. However, in certain cases, we had to use a convenient sampling approach, owing to challenges in reaching users. Overall, for the study, we interviewed 889 users out of the planned sample of 1000. The following sub-section lists the limitations involved in the study.

1.4 Limitations

- **Sampling approach**

  The PL programme allows users to select and procure the DRE technologies they needed on their own, which ruled out the possibility of having a treatment and control group (Gaur, Yasaswi, and Jain 2023). This study aims to cover users from a wide range of settings and use cases to capture the impacts and challenges of DRE solutions from diverse perspectives. Since these technologies are self-selected and widespread, it becomes challenging to ensure random selection of users due to limited data availability and respondent accessibility. As a result, a convenient sampling approach was the most feasible for the study.

- **Enumerator training**

  Given the multi-layered impact of various DRE technologies on users (Shastry and Rai 2024, 6), we provided training for enumerators, primarily in the local language. The training provided a description of the solution, its functionality, the impact it enables, and typical user challenges. The training also included user case stories and testimonials to illustrate on-ground perspectives. However, some data gaps were observed, primarily due to a lack of understanding of the user–technology dynamic, which we noted in the qualitative interviews. Typically, in-person interviews allow for follow-up questions to understand interactions better, but issues were often not explored in depth as moderators lacked the subject knowledge to extract relevant information. The key learning here is that researchers should ideally participate in qualitative interviews to maximise in-person interactions with DRE technology users.

- **On-ground data collection**

  Reaching users, confirming their availability, and getting permission from Farmer Producer Organisation (FPO)/Self Help Group (SHG) leaders in some interior pockets was challenging. There were instances where enumerators had to return without collecting data due to communication gaps with on-ground stakeholders. In one case, an enterprise stated that DRE users in a particular village had been interviewed multiple times on similar topics by different entities shortly before our planned data collection. Collaborations at the ecosystem level between research organisations, implementation entities, and manufacturers could prevent such duplication of efforts and increase buy-in from users and on-ground stakeholders. This is especially important in the DRE livelihoods sector, where only a few manufacturers exist.

- **Income data validation**

  Collecting data on users' incomes and establishing the extent of income realised through DRE solutions is challenging, especially when there are multiple sources of income (Gaur, Yasaswi, and Jain, 2023). Additionally, the study only considers the reported income values for the analysis and has not undertaken any validation exercises for these values. This is mainly due to difficulties in reaching users for follow-up to verify the reported income and the operational details of the DRE solution.

1.5 Profile of decentralised renewable energy technologies

The current study discusses eight DRE livelihood technologies. These technologies support livelihoods in various sectors, such as the agricultural, animal husbandry, retail business, textiles, and food processing sectors. These eight technologies are manufactured by enterprises supported through the PL programme. These eight solutions can potentially impact at least 21 million livelihoods across the country (Jain, Khalid, and Jindal 2023).

Table 1 Details of technologies covered in the Round 2 impact assessment study

Image: Resham Sutra

Technology: Solar silk reeling and spinning machine

Livelihoods supported: Silk reelers and weavers

Indicative cost range: INR 22,000–34,000

Image: CEEW/Emotive Lens

Technology: Small horticulture processor

Livelihoods supported: Small and medium food processing entrepreneurs

Indicative cost range: INR 85,000–270,000

Image: CEEW/Emotive Lens

Technology: Solar refrigerator

Livelihoods supported: Departmental/kirana/ medical store owners

Indicative cost range: INR 95,000–145,000

Image: Selvaprakash Lakshmanan/Swiss Re Foundation/ Fairpicture

Technology: Solar vertical fodder growing unit

Livelihoods supported: Small dairy farmers

Indicative cost range: INR 33,000–40,000

Image: Khethworks

Technology: Micro solar pump

Livelihoods supported: Small and marginal farmers

Indicative cost range: INR 45,000–50,000

Image: CEEW/Emotive Lens

Technology: Solar dryer

Livelihoods supported: Farmers and farmers' collectives

Indicative cost range: INR 10,000–180,000

Image: SaS

Technology: Solar dehydrator

Livelihoods supported: Farmers and farmers' collectives

Indicative cost range: INR 25,000 –40,000

Image: CEEW/Emotive Lens

Technology: Biomass-powered cold storage

Livelihoods supported: Farmers and farmers' collectives

Indicative cost range: INR 12,00,000–15,00,000

2. Users of clean tech for livelihoods in rural India

Image: CEEW/Emotive Lens

Decentralised renewable energy (DRE)–powered livelihood solutions are small-scale livelihood applications powered through DRE such as solar, wind, micro-hydro, biomass, or their combinations. They can operate in off-grid, mini-grid, or grid-tied settings. These solutions include solar or biomass-powered cold storage/chiller units, solar refrigerators, fodder-grow units or dryers/dehydrators, looms, and grain millers. DRE-powered livelihood solutions have the potential to significantly reduce and eventually eliminate users' reliance on diesel, especially in rural areas. These clean energy technologies hold great potential for creating sustainable livelihoods by promoting income diversification, improving productivity, and facilitating micro-entrepreneurship among economically disadvantaged communities with limited access to conventional energy sources (MNRE 2022).

The Powering Livelihoods programme, a joint initiative by CEEW and Villgro, aims to boost India's rural economy by scaling up the penetration of clean-energy livelihood appliances (Gaur, Yasaswi, and Jain 2023). The programme supports manufacturers of clean energy technologies in undertaking commercial deployments, generating evidence at scale, disseminating knowledge to key stakeholders, and unlocking sectoral support and growth (CEEW and Villgro Innovations Foundation 2024). It is currently working with more than 15 enterprises to address sectoral challenges by generating awareness, unlocking credit, creating linkages, and generating evidence for users to facilitate deployments at scale.

2.1 Geographical distribution

The study covered respondents from 18 states and union territories (Figure 1). Most of the respondents were from Uttar Pradesh (12 per cent) and Bihar (18 per cent) and use solar silk reeling machines and solar refrigerators. In some regions, certain livelihoods are more prevalent, leading to concentration of users of a particular technology. For example, many communities in the central-eastern belt practice silk reeling, and almost 85 per cent of solar silk reeling machine users are from the states of Odisha, West Bengal, Chhattisgarh and Bihar. About 23 per cent of respondents had access to a DRE solution for less than a year, 57 per cent had access for more than a year but less than two years, and 20 per cent had access for more than two years.

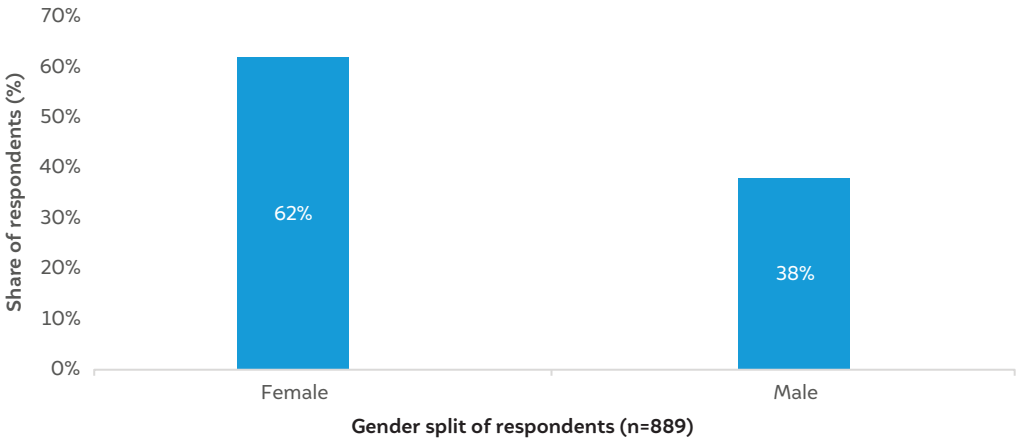
Figure 1 Nearly half of the respondents are from Bihar, Maharashtra, and Odisha

Source: Authors' analysis

2.2 Demographics

Overall, the study included 889 respondents, of whom about 62 per cent were female (Figure 2). Women made up over 50 per cent of users of solar silk reeling and spinning machines, solar vertical fodder grow units, solar dehydrators, and micro solar pumps.

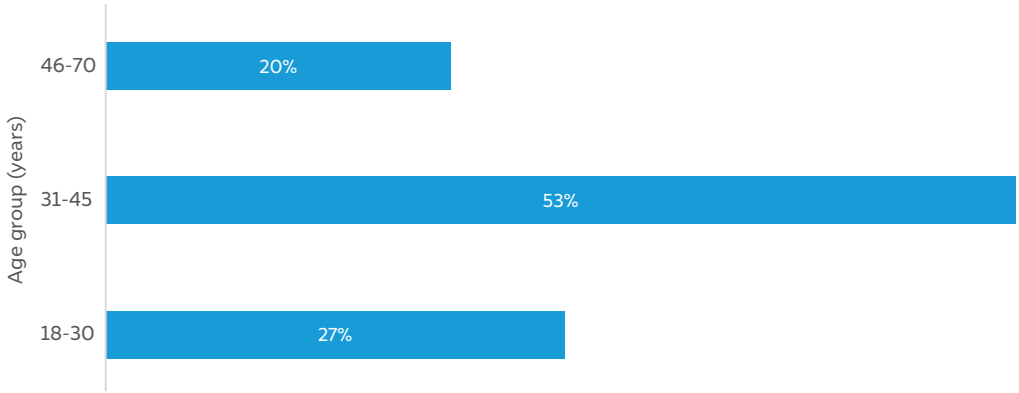
Figure 2 Six in ten users of DRE solutions are women



Source: Authors' analysis

The average age of respondents was 38, highlighting a relatively younger user base. Across technologies, nearly 80 per cent of the users were aged below 45 indicating a significant number of relatively younger individuals engaged with these solutions (Figure 3). In addition to establishing micro-enterprises using DRE solutions, the age distribution of users indicates significant promise for building a resource pool. The willingness and ability to adapt to new technologies and methodologies, along with familiarity with digital tools and platforms, mean investing in younger individuals who can contribute to the sector is a considerable advantage. This pool can be achieved by upskilling users in related ecosystem components, such as after-sales service, monitoring, and training community resource persons for key government schemes.

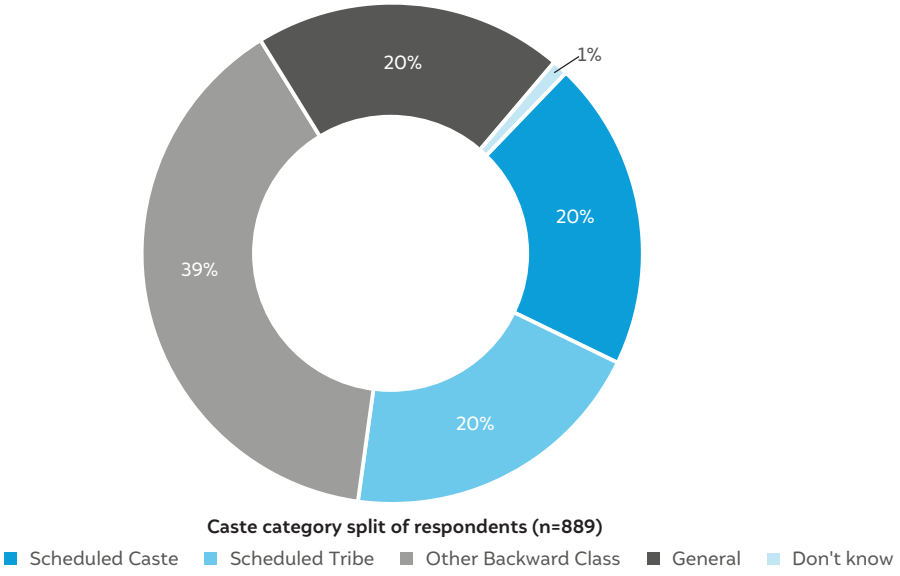
Figure 3 Eighty per cent of the users are below 45 years of age



Source: Authors' analysis

About 40 per cent of respondents belong to the Scheduled Castes (SCs) and Scheduled Tribes (STs) category. Other Backward Classes (OBCs) constitute 39 per cent of users (Figure 4).

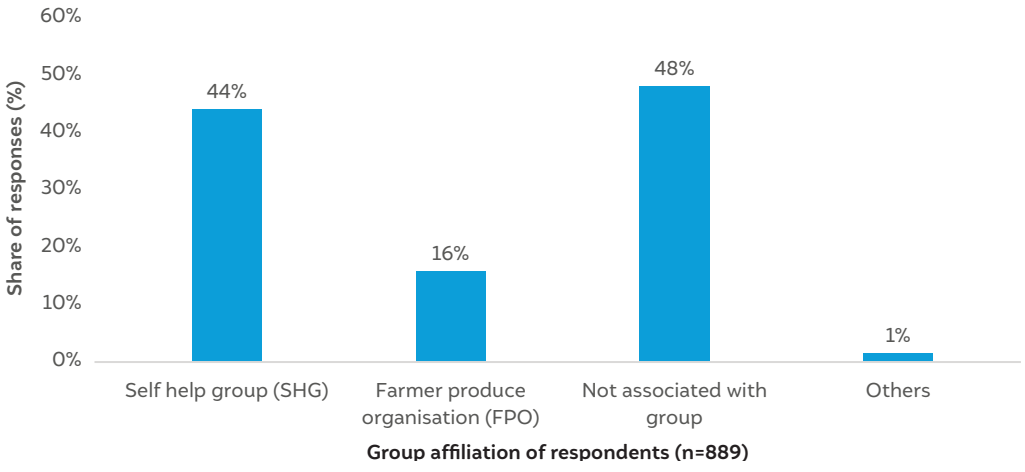
Figure 4 Marginalised communities such as SCs and STs constitute 40% of respondents



Source: Authors' analysis

About 44 per cent of users report being part of a self-help group (SHG), whereas 48 per cent indicated they were not part of any collective.

Figure 5 Six out of ten respondents belong to collectives



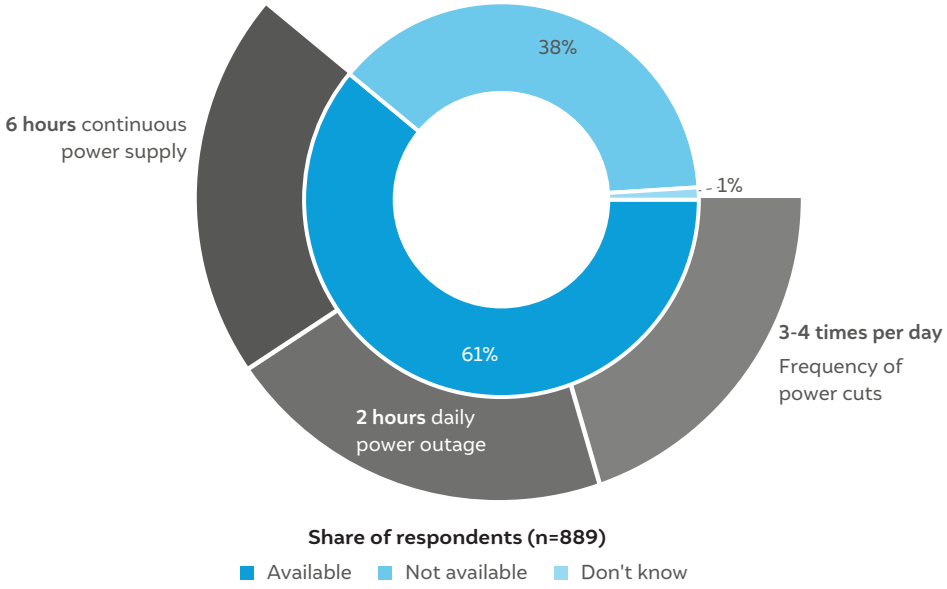
Source: Authors' analysis

This distinction is significant when categorising respondents based on their method of procuring DRE-based livelihood solutions. For instance, DRE solutions purchased by individuals are registered in the individual's name, whereas shared procurements are registered in the name of the group or collective. The group members share ownership and usage of the solution per their group's agreed-upon provisions. DRE-powered cold storage units and high-capacity solar dryers exemplify solutions typically procured by farmer groups and used on a shared basis.

2.3 Electricity scenario

In addition to collecting details about the respondents' households, we also enquired about each user's electricity scenario. Regarding the availability of electricity in the place where the DRE solution is used, 61 per cent of users reported having an active electricity connection, 38 per cent stated that they did not have one, while the remaining 1 per cent mentioned that they did not know (Figure 6). We enquired about the availability of electricity where the DRE solution is used, as these sites may be situated in places other than the user's household in the case of rural businesses (tailoring, bakery, *kirana* stores, etc). Almost half of the respondents who reported not having an active electricity connection use solutions such as micro solar pumps and solar dryers. This underscores the difficulties users face in accessing reliable electricity, which in turn impacts productivity.

Figure 6 Most respondents have access to grid electricity where DRE solutions are used



Source: Authors' analysis

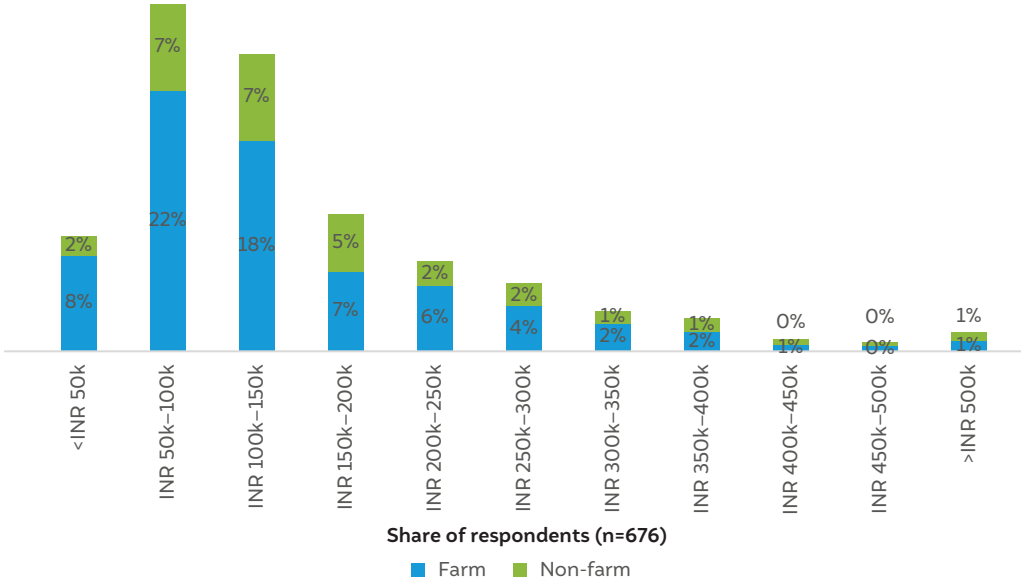
We further asked users who have an electricity connection about the quality of power available at the sites where DRE solutions are used. We defined a typical productive day as one that lasts from 8 a.m. to 6 p.m. We observed that, on average, six hours of continuous power are available, with the average power outage totalling two hours per day. This underlines the need to ensure quality power in rural areas, beyond mere access, to ensure sustainable livelihoods.

2.4 Primary income

We categorised the users into a) farm income and b) non-farm income based on their primary source of income.

- Most users (62 per cent) are engaged in farming, indicating a reliance on farm income and the relevance of DRE technologies in agriculture and allied sectors.
- Less than 40 per cent of users rely on non-farm-related economic activity for their primary income, with the majority involved in daily wage labour.

Figure 7 60% of respondents report an annual income above INR 1 lakh



Source: Authors' analysis

More than 50 per cent of the respondents reported a household income below INR 1.5 lakh per annum; the self-reported typical annual income was approximately INR 1.48 lakh (Figure 7).

Image: Priyatam Yasaswi/CEEW

CEEW researcher with the user of a solar dryer in Nalgonda district, Telangana.

3. Loans, subsidies, and ownership: Financing DRE in India

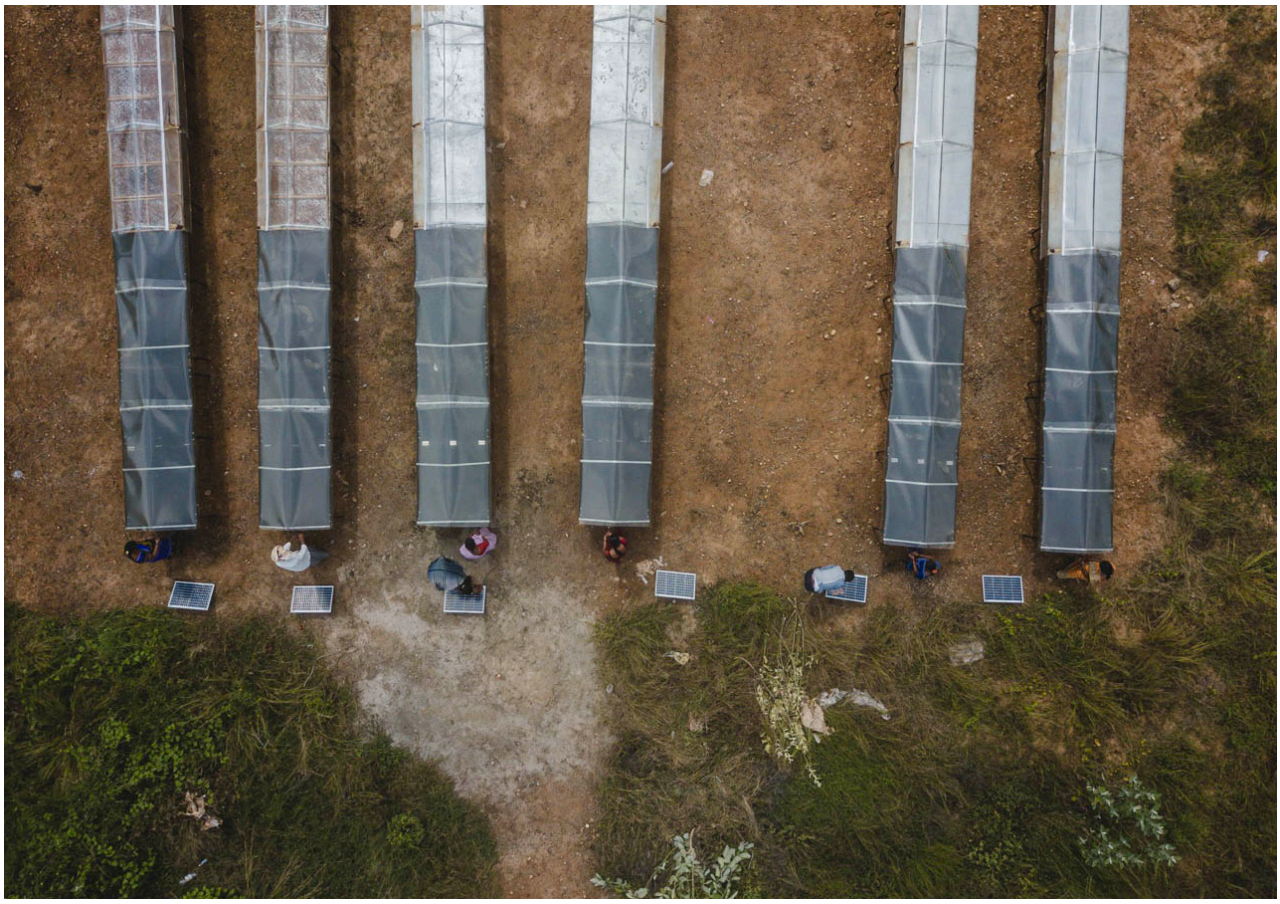


Image: CEEW/Emotive Lens

To understand the impact of DRE livelihood solutions on users, we analysed users' pathways to procuring/accessing DRE solutions. Additionally, the extent of investment indicates how the user perceives the solution's impact when procuring/accessing the solution.

3.1 Key research questions

This section aims to answer the following questions:

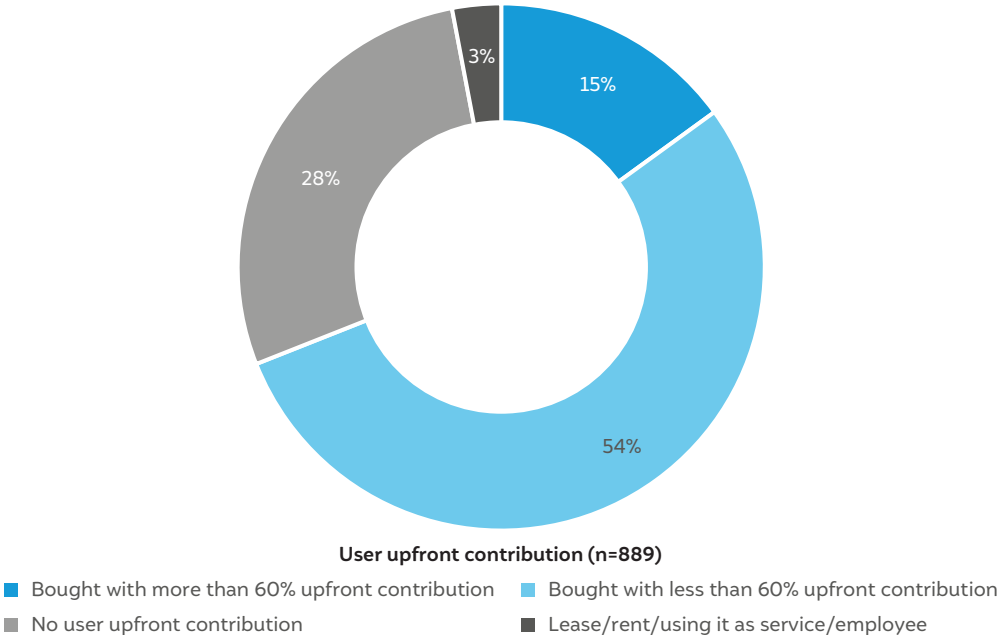
- How are users procuring/accessing DRE solutions?
- How much is the users' upfront contribution for procuring DRE solutions?
- What is the share of deployments by philanthropic organisations?

About **69 per cent** of users reported making an upfront monetary contribution to procure a DRE livelihood solution (Figure 8). Only about **15 per cent** of users paid more than 60 per cent of the cost of the solution (without considering any subsidy or loan amount).

To determine the progress that enterprises have made in shifting away from grants and subsidies to driving sales, the PL programme categorises sales with more than 60 per cent upfront user contribution as commercial. The rationale for using this threshold to define commercial sales is that 60 per cent is approximately the cost of goods sold as a percentage of the product price; selling a product below this rate would not be viable for an enterprise without subsidies.

About **28 per cent** of users received the solution for free, suggesting that philanthropic organisations or the government fully paid for it. Solar silk reeling and spinning machines, along with micro solar pumps, are two solutions where more than 50 per cent of users received the solution without making any user contribution. A significant proportion of respondents using these two solutions were from Bihar and Madhya Pradesh; in these states, as part of a local project, the relevant state department and a philanthropic organisation had entirely subsidised the cost of the solution.

Figure 8 Seven in ten users made an upfront contribution towards adopting a DRE solution



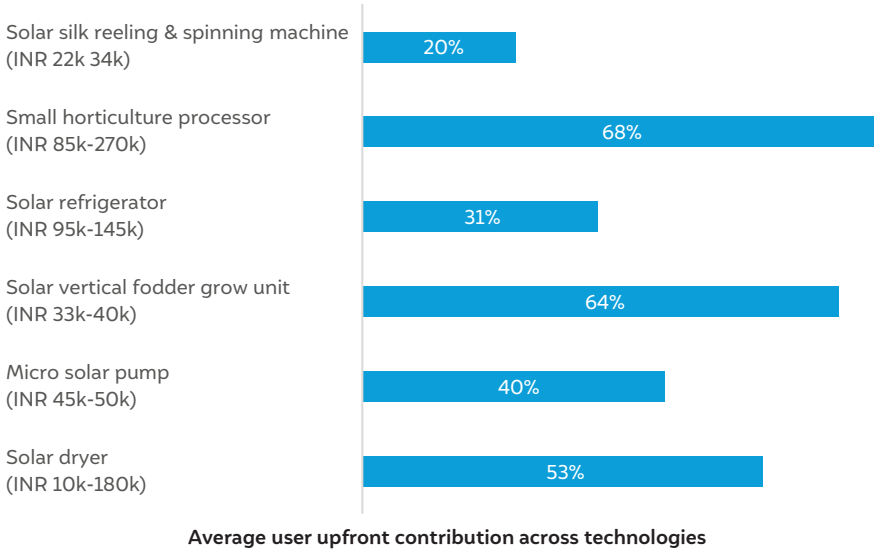
Source: Authors' analysis

3.2 User contribution

We analysed the distribution of individual user contributions against the cost of the selected technologies. Using a bar chart (Figure 9), we plotted the user contribution as a percentage of the cost of the solution. A higher average (against the cost of the solution) indicates a greater ability on the part of the user to pay upfront for the solution across variants.

The small horticulture processor had the highest average user contribution, at **68 per cent**, while solar silk reeling and spinning machines had the lowest average user contribution, at **20 per cent.** Nevertheless, it is important to note that, beyond the cost of the solution, several other factors (such as the users' annual income, the maturity of the solution ecosystem, and the required linkages) play a role in determining the extent to which the user will likely pay for the solution. It is vital to strengthen these factors, which can facilitate higher user down payments towards these solutions. A higher user contribution is likely to make users feel more committed and invested in the solution. This, in turn, inclines them to change their behaviours and practices to fully utilise and benefit from the technology, leading to greater acceptance and sustained adoption.

Figure 9 On average, users pay less than half of the cost of the solution across technologies



Source: Authors' analysis

3.3 Extent of subsidy

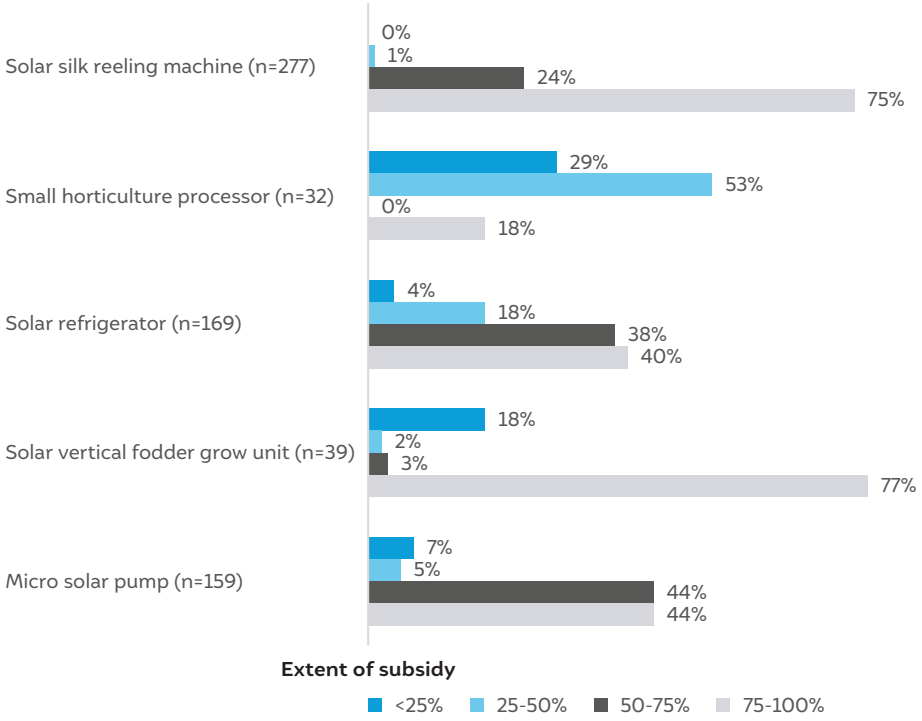
We found that approximately 60 per cent of the total individual purchases were significantly subsidised (>40 per cent of solution cost). While upfront subsidies drive adoption, users are often unaware that they have received a subsidy. Among those who bought the solution, only 34 per cent reported availing of a subsidy. However, we found that about 61 per cent of such users had availed of a subsidy (Figure 10).

3.4 Loan

To understand the relevance of credit in adopting DRE livelihood solutions, we assessed the share of users availing of loans and the underlying reasons.

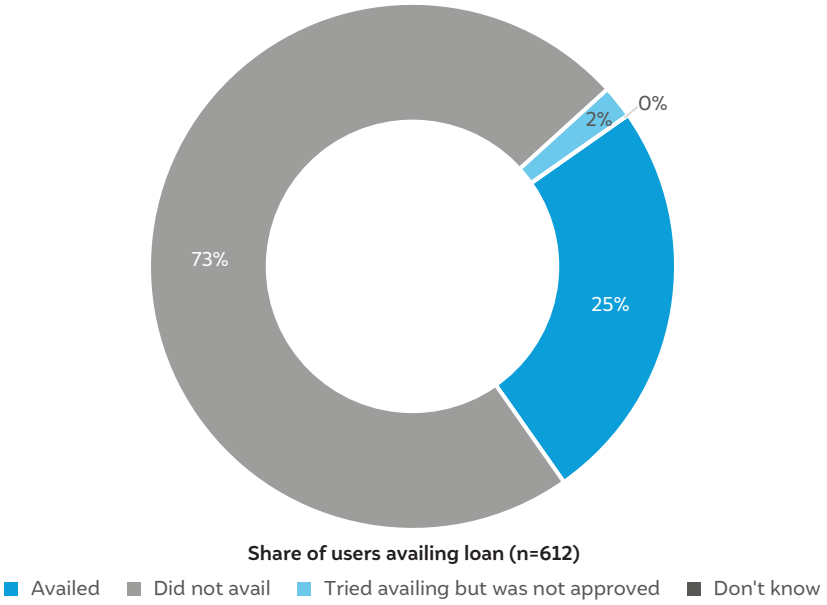
- A quarter of the users reported taking a loan to procure a DRE livelihood solution (Figure 11).
- Banks were the dominant choice among borrowers (42 per cent).
- The average loan amount was INR 42,681 (67 per cent of the average unit cost), and the average monthly repayment amount was INR 2,984.
- More than half (55 per cent) of the borrowers reported that they are able to make the repayments on time.

Figure 10 Small horticulture processors have the lowest share of deployments receiving more than 75% subsidy



Source: Authors' analysis

Figure 11 About 25% of users report availing loans for purchasing DRE solutions



Source: Authors' analysis

4. Economic impact

Image: CEEW/Emotive Lens

DRE livelihood applications can enhance users' incomes by improving productivity through mechanisation; in particular cases, the number of productive days increases as well, and there is an expansion of revenue streams. Moreover, by switching to appliances powered by clean energy, users can achieve savings through reduced input costs, such as those associated with diesel or electricity consumption. Therefore, we measured the economic impact of the technologies using the indicators listed in Table 2.

In this section, we assess the overall economic impact of adopting DRE solutions by calculating the reported change in net income. The technology-wise section offers further insights on changes in productivity, expansion of revenue streams, savings on conventional energy sources, and other specific aspects of the technology and its usage.

Table 2 List of indicators used for analysing DRE livelihood solutions' impact on income

Indicators	Measure
Productivity	Change in output per day
Productive days	Change in the number of annual productive days
Savings on conventional energy sources	Amount of annual savings
Expansion of revenue streams	Number of new products/services added as a result of adoption of the technology
Net Annual Income change	Median change in net annual income (pre vs post-adoption)

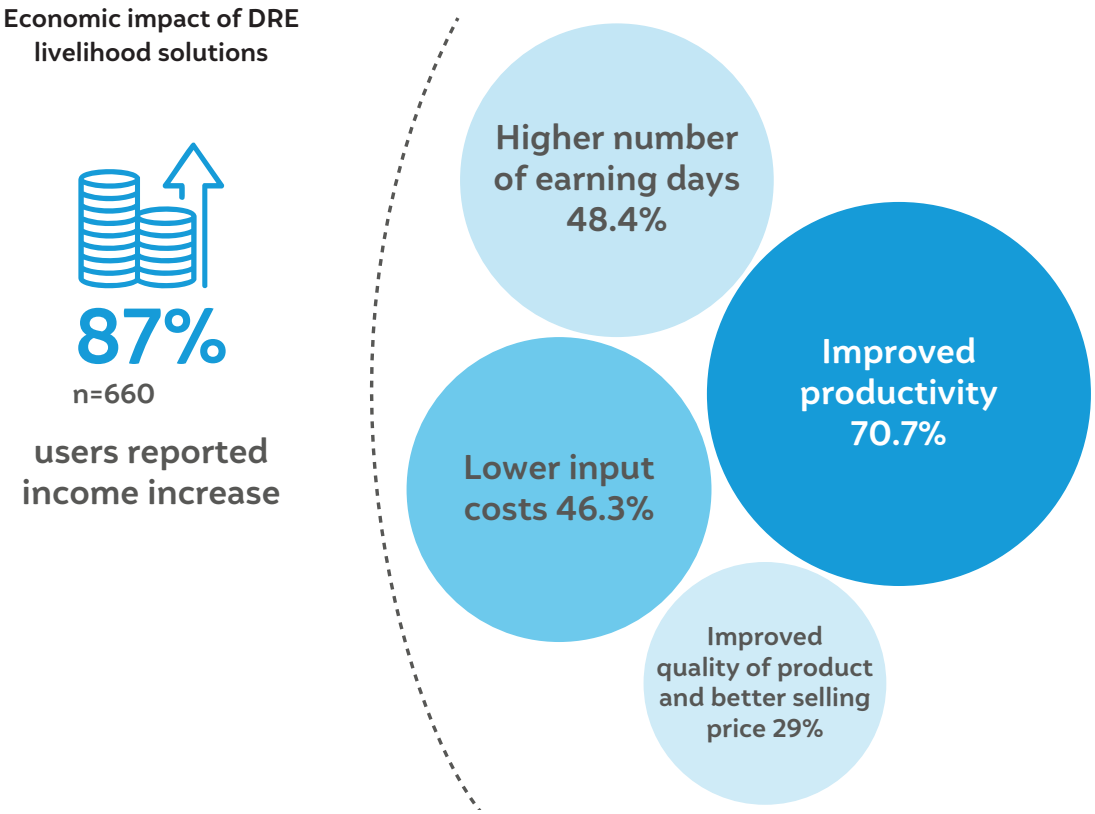
Source: Authors' compilation

4.1 Improvements in productivity

The mechanisation of livelihoods leads to improved productivity for more than half of the technology users

- With access to a reliable source of energy, users can sustain their livelihoods for more days, leading to increased incomes.
- Reduced input costs related to the use of conventional energy sources such as diesel and grid electricity, and, in some cases, the use of ice boxes and the purchase of fodder from the market, have helped increase incomes.
- For some users, especially in the case of silk reeling machines and solar dryers, improvements in the quality of the product have resulted in an increased selling price (Figure 12).

Figure 12 About 90% of users reported an income increase after adopting a DRE solution



Source: Authors' analysis

4.2 Extent of income increase

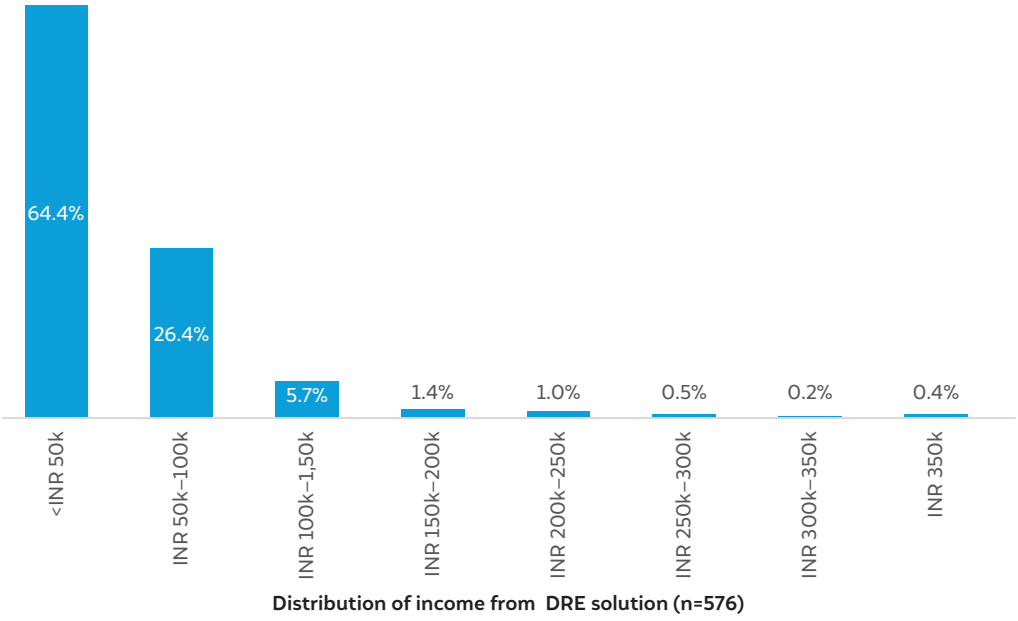
Nearly half of the respondents, who had an annual income of less than INR 50,000, moved to higher income brackets

Typically, a DRE solution leads to a net increase of INR 40,000 (33 per cent) in annual income

- With an average usage of eight months, users of DRE livelihood applications can typically earn an additional INR 40,000 annually. The median income for women is 40 per cent higher than that for men.
- The higher median income among women is primarily due to earnings from milk processing and solar dryers, especially when forward market linkages are ensured through a buyback guarantee by the manufacturer.
- Almost half of the users experienced an increase in income of up to INR 40,000 annually.

Figure 13 A median income increase of INR 40,000 was observed among users

Figure 14 About 20% of users earn more than INR 80,000 annually from DRE solutions



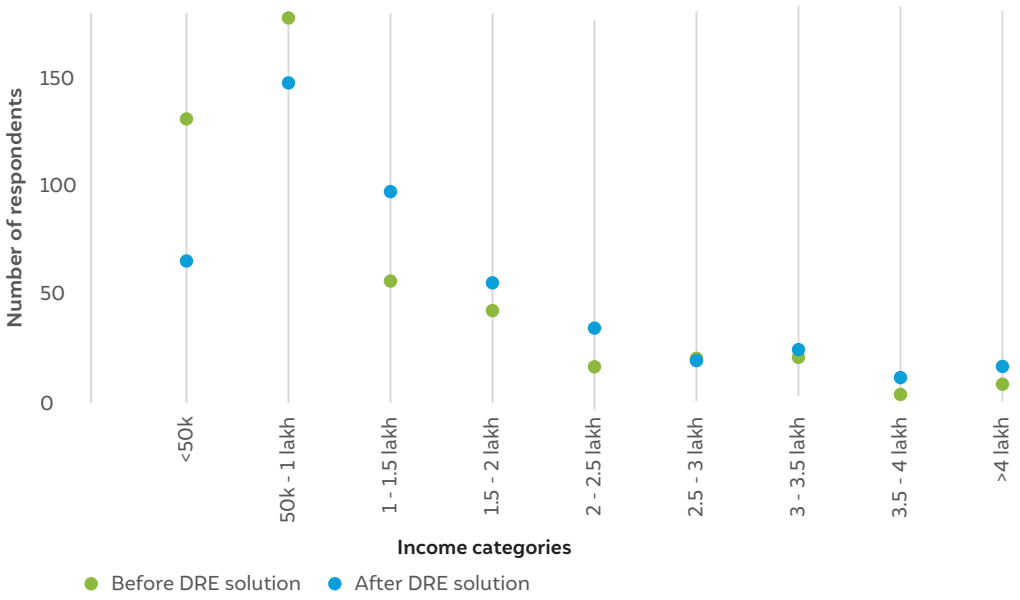
Source: Authors' analysis

4.3 Income level progression

Most users moved to a higher income bracket after using the DRE livelihood solution

- Nearly half of the respondents, who had an annual income of less than INR 50,000, moved to higher income brackets because they earned additional income after using the DRE solution (Figure 15).
- After using the technology, 16 per cent adopted it for their primary occupation, with a median annual income of INR 95,000; most of these users use solar refrigerators or micro solar pumps.

Figure 15 Almost half of the users belonging to the lowest income slab moved to higher income slabs



Source: Authors' analysis

Box 1 **User story | Solar refrigerator, Uttar Pradesh**

Image: Manish Singh/CEEW

Deepak, 25 from Chandrapur, Gurbaksh Ganj, Raebareli has been running a grocery store since 2020. He invested in a solar refrigerator for storing cold drinks and water. He made a down payment of INR 13,000 and opted for EMI payments of INR 3,110 per month for 12 months, with the total cost around INR 50,000. During peak seasons, Deepak's daily sales range from INR 1,000 to 1,200, potentially reaching up to INR 35,000 monthly. However, business tends to slow down during November - February. **The solar refrigerator operates on solar power through panels connected separately and helps Deepak save approximately INR 20-30 per day in electricity costs. Despite facing some challenges with performance, especially in the evening, Deepak appreciates the refrigerator's benefits and continues to prefer solar equipment over conventional refrigerators.** While all nearby users have successfully completed their EMI payments, some face performance issues, particularly with cooling efficiency and temperature maintenance. Nevertheless, they remain optimistic about the potential of solar solutions.

Source: Authors' compilation

Box 2 **User story | Solar dryer, Telangana**

Image: Priyatam Yashaswi/CEEW

Saidamma, 43, is the Chairman of Kattangur Farmer Producer Company Limited (FPCL) in Aitipamula, Kattangur, Nalgonda District, Telangana. The FPC, comprising around 1,100 farmers, Initially focused on providing seeds, fertilizers, and pesticides with at least a 5% subsidy, has expanded its scope over the years.

About three years ago, the FPC procured seven solar dryers, each with a 100 kg capacity, to dry lemon, tomato, moringa, curry, and henna leaves. **These solar dryers, backed by a buyback guarantee from the manufacturer, provided a solution for farmers struggling with low market prices and rejection of lower-grade produce by buyers like supermarkets. The dryers offered a viable alternative for farmers to process their produce effectively**.

The FPC is also exploring further processing of these dried commodities to create pickles, powders, and other products, marketing them under the Kattangur FPC brand. Additionally, this FPC is involved in various progressive activities for farmers, including deploying solar-powered cold storages and integrated packing facilities, renting out battery-operated farm equipment, and providing drones with trained operators for fertilizer application.

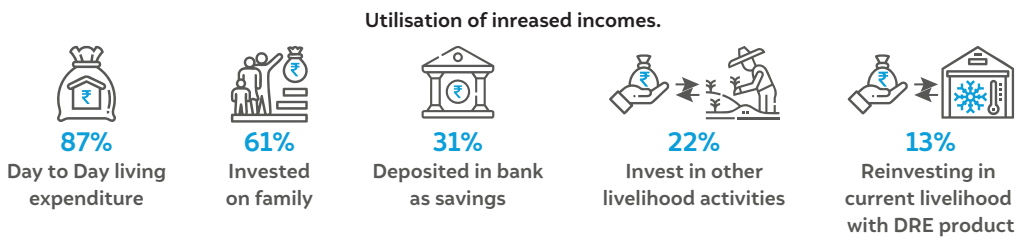
Under Saidamma's leadership, Kattangur FPC continues to support and innovate for its farmers ensuring sustainable and profitable agricultural practices.

Source: Authors' compilation

4.4 Utilisation of increased income

Households mostly spend increased incomes on daily expenditure

Figure 16 Day to day expenditures are the main use of increased incomes



Source: Authors' analysis

- Additional income essentially went to day-to-day household expenditures such as groceries or food (Figure 16).
- Further, 60 per cent mentioned spending on children's education, followed by access to better healthcare and better dietary intake. Female users make up 63 per cent of these respondents.
- The remaining users either deposited the extra income in the bank or invested in livelihood activities, procuring more raw materials or expanding their livelihoods.

Workers handling cocoons at the Tasar silk park in Keonjhar, Odisha.

Image: CEEW/Emotive Lens

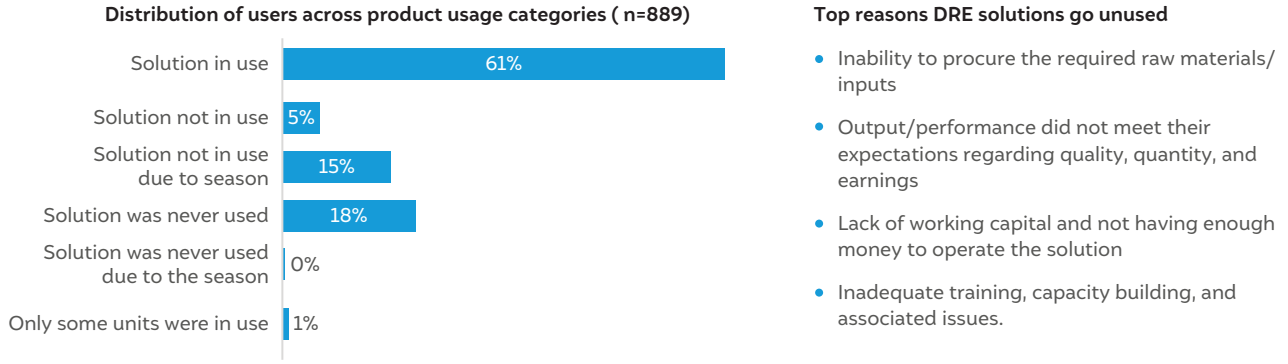
5. Utilisation of DRE Livelihood solutions in the rural context

A key objective of this study is to understand trends in the use of DRE solutions and identify challenges that stakeholders need to address to sustain DRE use. Sustained usage of these technologies is critical to boosting regular incomes and thereby creating sustainable livelihoods.

From the analysis, we observe that:

- The majority (61 per cent) of respondents used a DRE solution at the time of the survey (Figure 17).
- Among users, biomass-powered cold storage was the only solution, with 100 per cent of its users reporting its usage at the time of survey, while solar refrigerators came next at 94 per cent.
- There was a clear link between user upfront contribution and solution usage. As many as 87 per cent of those who reported 'using the solution' had made an upfront contribution to procuring a DRE solution.

Figure 17 About 60% of users reported using the solution at the time of the survey



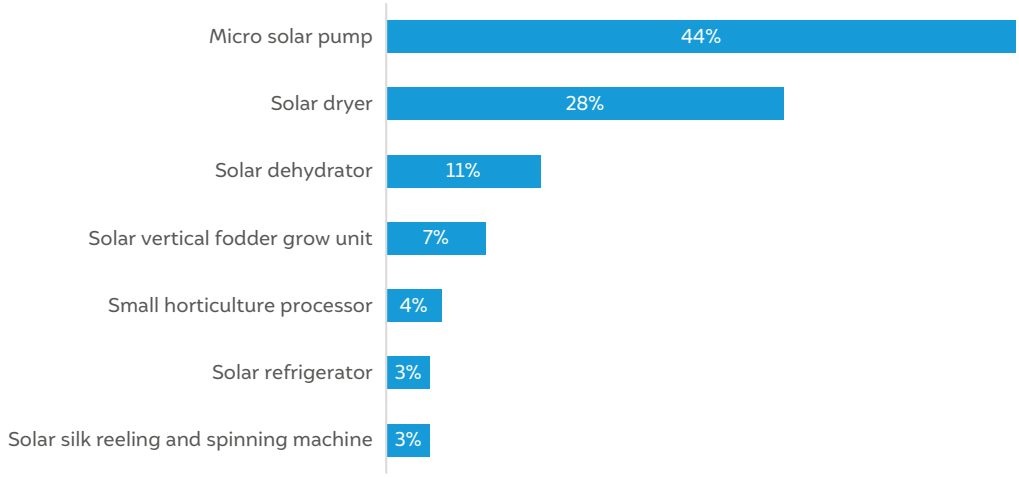
Source: Authors' analysis

5.1 Seasonality in usage

For those users who did not use the solution at the time of survey due to seasonal challenges, we further analysed the kind of solutions they used.

- Most respondents (83 per cent) who mentioned seasonality as a reason for non-usage used micro solar pumps, solar dryers, and solar dehydrators (Figure 18).
- We collected the data during May–July, which typically overlaps with the monsoon season in some of the geographies covered in this study.
- Users require solar pumps less in the early monsoon months and cannot utilise solar dryers during the rainy season.

Figure 18 Micro solar pump and solar dryer users are most impacted by seasonal challenges



Source: Authors' analysis

Image: Manish Singh/CEEW

A basket of products being marketed by a user of the small horticulture processor in Gonda, Uttar Pradesh.

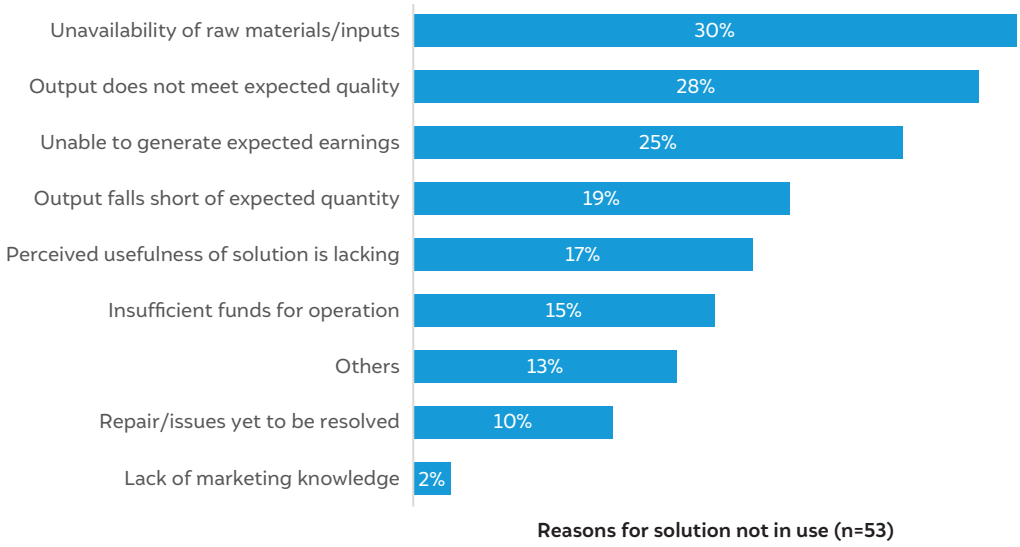
5.2 Reasons for non-usage

Important to have needs assessments to understand users' and market conditions to inform interventions.

For users (5 per cent) who stopped using the DRE solution, we tried to understand the main reasons:

- **Thirty per cent responses mention inability to procure the required raw materials/ inputs**. This issue was predominant among solar silk reeling and spinning machine users in Bihar, who could not access cocoons to reel silk (Figure 19).
- **More than seventy per cent** of responses highlight that the solution's **output/ performance did not meet their expectations regarding quality, quantity, and earnings**. This underscores the need for improved needs assessments to understand users' and market conditions to inform interventions. This issue was predominant among users of small horticulture processors and solar vertical fodder grow units.
- Beyond these challenges, individual-level issues also hamper the usage of the solution.

Figure 19 Raw material unavailability is the top-cited reason for the solution not being in use

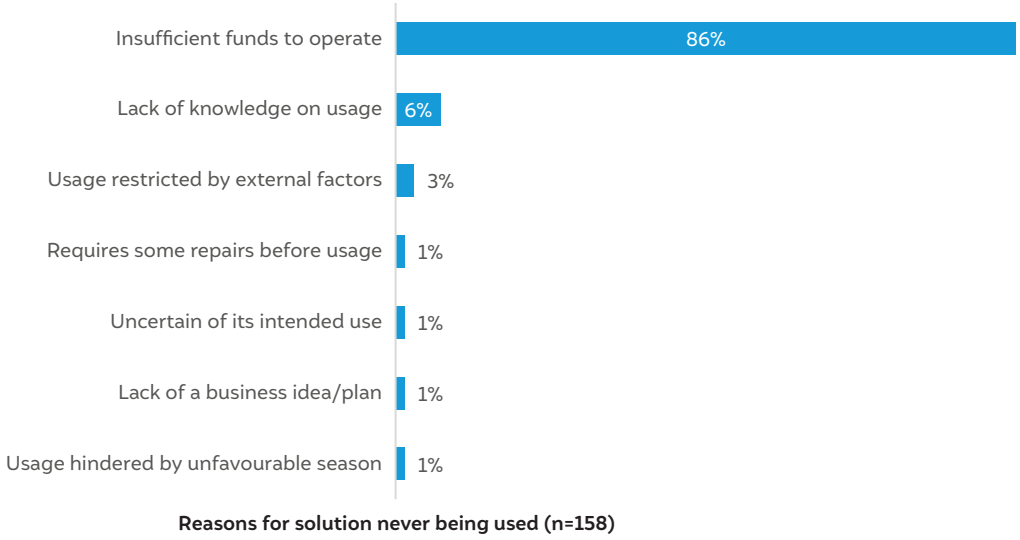


Source: Authors' analysis

A sizeable proportion of the DRE adopters (18 per cent) never used the DRE solution. We tried to understand why they never used the procured DRE solution.

- Most users cited **a lack of working capital and not having enough money to operate the solution**. Almost all such users are adopters of solar silk reeling and spinning machines, which received a 100 per cent government subsidy (Figure 20).
- Often, users find it challenging to procure raw materials of the required quality at reasonable prices.
- Others who never used the solution cited **inadequate training, capacity building,** and associated issues.

Figure 20 Lack of working capital constraints the usage of the solution



Source: Authors' analysis

Box 3 **User story | Small horticulture processor, Uttar Pradesh**

Image: Manish Singh/CEEW

Shiv Kumar, 54, from Raipur village in Gonda District, Uttar Pradesh, uses an energy-efficient horticulture processor since 2021 to make aloe vera juice, soap, and rose water. After discovering a video of the processor, he purchased the machine using a INR 65,000 loan from the Kisan Credit Card Scheme. **Shiv Kumar found the machine easy to operate and it produces high-quality end products, initially earning him INR 15,000–20,000 per month. Despite having market access challenges for further expansion, he started working with retail outlets like Reliance Mart and Chaupal Sagar in Gonda enabling his monthly income to go up to INR 35,000 – 40,000**. Shiv Kumar conducts training programs in partnership with Jan Shikshan Sansthan in Gonda, serving 20+ female participants from local villages. The training covers food processing skills and lasts 2-3 hours daily for 75 days. He has been acknowledged for his knowledge and skills, with frequent visits from government officials showcasing his facility. His wife, Kusum Mourya, collaborates with a self-help group to train 20 women in manufacturing and packaging. Through these efforts, both Shiv Kumar and Kusum contribute to rural entrepreneurship, empowering local communities.

Source: Authors' compilation

6. Social and gendered impact of adopting DRE technologies for livelihood

Image: CEEW/Emotive Lens

We studied the impact of DRE solutions on social and gender indicators, documenting evidence beyond the economic aspect. In addition to enhancing incomes, one of the most significant advantage of DRE livelihood solutions is their ability to reduce drudgery by mechanising traditional livelihoods. We find that almost seventy-seven per cent experienced reduced physical drudgery (Figure 21).

Figure 21 Access to technology makes livelihood activities efficient and easier

66.2%
First-time access to DRE-technology for livelihood

61%
Reduced physical effort/Not Physically draining to work

31%
Time saved

Source: Authors' analysis

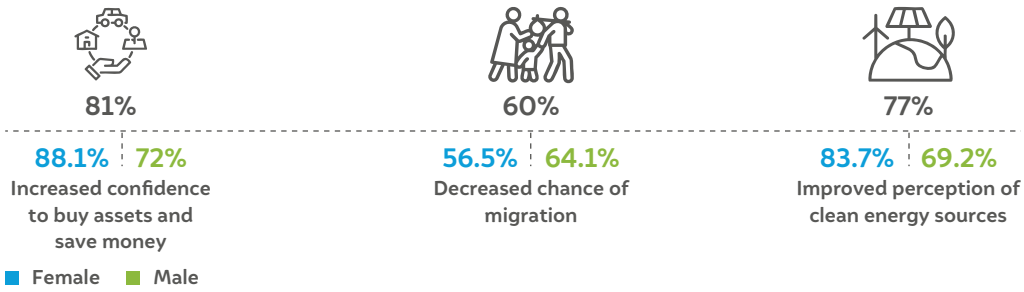
- More than 50 per cent of the users mentioned not having access to DRE technologies for their livelihoods. Majority of these are users of solar silk reeling and spinning machine and small horticulture processor who have taken up a livelihood for the first time (Figure 21).
- According to the respondents, many DRE livelihood solutions reduced physical drudgery. For example, silk reeling machines reduced the physical effort of thigh reeling; a solar-powered vertical fodder grow unit minimised the effort required to collect green fodder; and a solar micro pump was lighter to carry around.

DRE solutions are able to increase users' ability to save money, and improve their perception of clean energy sources, while also reducing their chances of migrating for better livelihoods

6.1 Social impact

We observe that DRE solutions are able to increase users' ability to save money, and improve their perception of clean energy sources, while also reducing their chances of migrating for better livelihoods.

Figure 22 Mainstreaming DRE technologies helps diversify household incomes and disincentivises migration



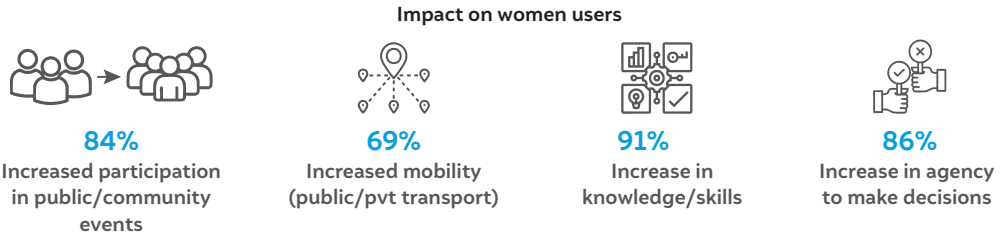
Source: Authors' analysis

- Adopting DRE technologies helps households improve their incomes, which subsequently helps them save money and buy assets; at least 30 per cent of our respondents bought an asset such as a television or automobile or saved money in banks.
- More than 50 per cent of respondents acknowledged that their motivation to migrate has decreased since adopting DRE technologies. This suggests that DRE solutions have improved resilience, helped diversify household incomes, and reduced vulnerabilities (Figure 22).

6.2 Impact on women users

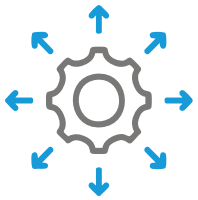
DRE livelihood solutions hold immense potential in improving the livelihoods of women users. Many rural areas still have women practising traditional livelihoods. These solutions offer a productive alternative to their livelihood practices. We tried to understand how these solutions impact women and their roles within their families and communities.

Figure 23 Increased incomes and improved livelihoods lead to greater confidence among women users



Source: Authors' analysis

- Most DRE technology users are women, especially among those who use solar-powered equipment such as silk reeling machines, micro pumps, dehydrators, and dryers.
- DRE technologies benefit women by offering them localised livelihood opportunities, improving their incomes, and helping them save time or reduce manual work. More than 80 per cent of women users experienced improved agency in terms of decision-making or participation in public or community events(Figure 23). Increased incomes play a crucial role in enabling these. Using these technologies for the first time also increased their knowledge about how to use technology, undertake basic repairs/maintenance, etc.



DRE technologies benefit women by offering them localised livelihood opportunities, improving their incomes, and helping them save time or reduce manual work

Workers using solar-powered silk reeling machines at the Tasar Silk Park in Keonjhar, Odisha.

Image: CEEW/Emotive Lens

7. Technology-specific impacts on users in related value chains

In addition to the social, economic, and environmental impact, we analysed the impact of the identified technologies on productivity and the challenges specific to each technology's value chain. Since DRE technologies support livelihoods across various sectors, it was crucial to analyse their impact and challenges independently. Therefore, we asked users about specific changes in productivity that they had experienced after adopting the DRE solution. We also enquired about the challenges users face with specific DRE solutions or the stakeholders involved in the value chain. The aim was to identify gaps that stakeholders could address through sectoral collaboration. This section outlines the findings related to each technology showcased in this study.

7.1 Solar silk reeling and spinning machine

Energy-efficient, solar-powered silk reeling and spinning machines allow users to reel high-quality silk, replacing tedious manual thigh reeling. Using 100 solar silk reeling machines for 5 hours a day across 250 days can mitigate CO_2 emissions by approximately 1.1 metric tonnes (MT) per year.

Image: CEEW/Emotive Lens

States surveyed (share of respondents)

Bihar	56%
West Bengal	22%
Assam	9%
Others	13%

Respondents

Total	277
Male	3%
Female	97%

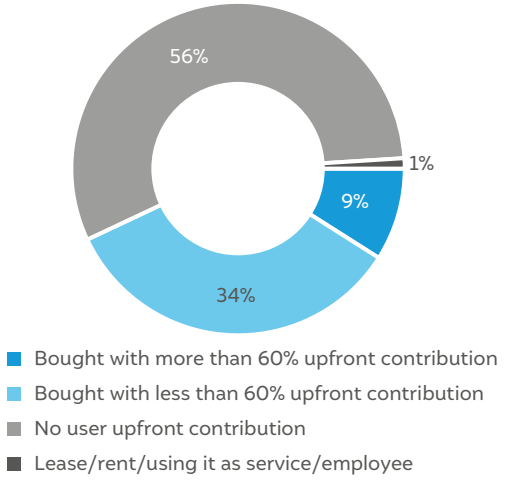
Caste category

OBC	68%
SC/ST	26%
General	6%

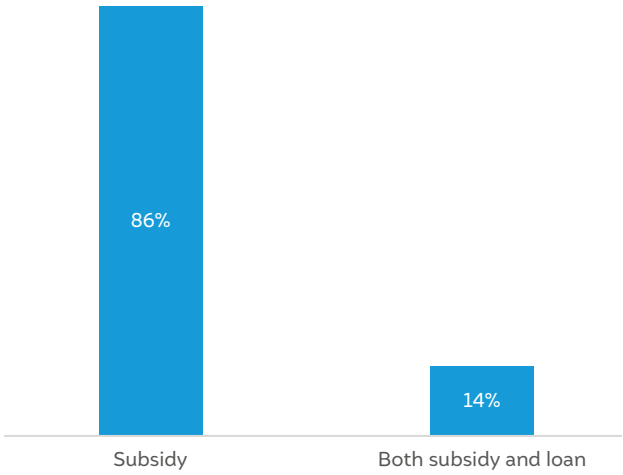
Primary income

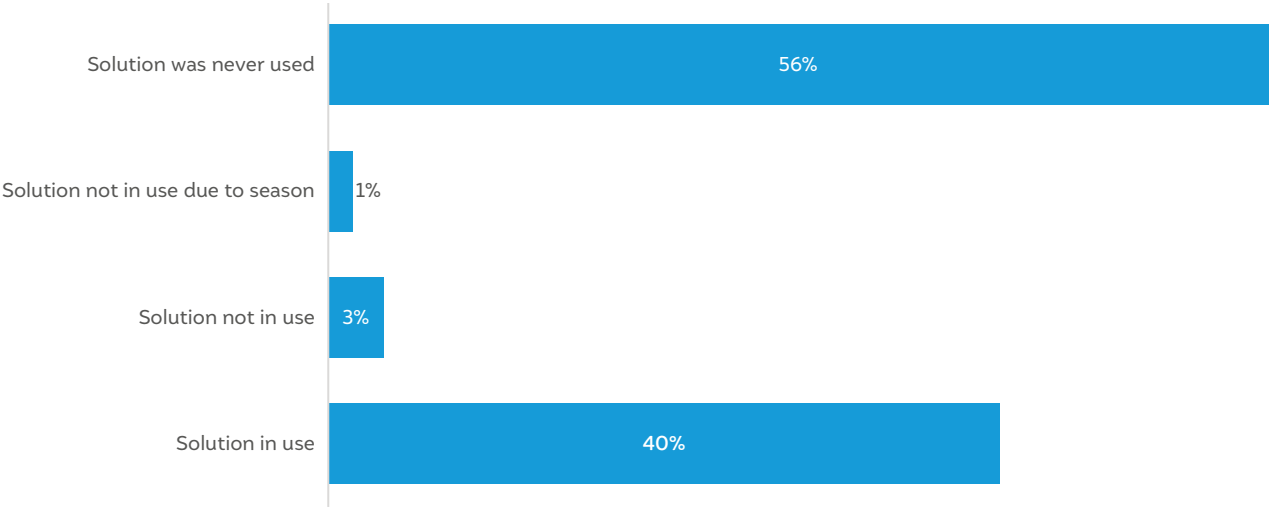
Non-farm	69%
Farm	31%

Users' upfront contributions to access solar silk reeling and spinning machine



Source of capital for individual purchase and ownership (n=66)



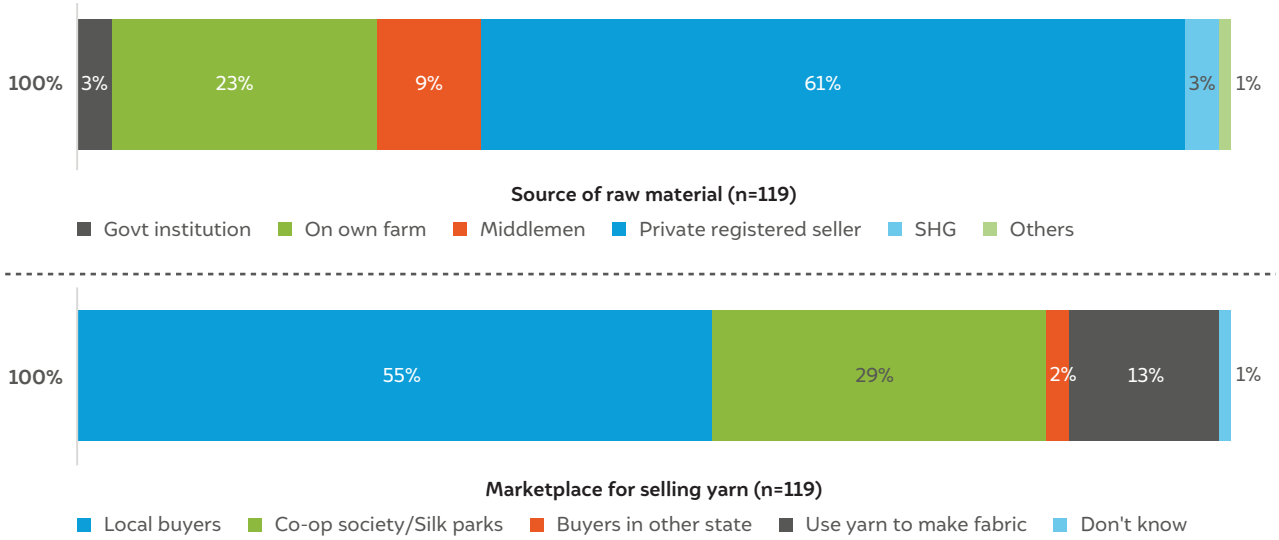


Distribution of users across product usage categories

Source: Authors' analysis

Productivity Impact

2x increase in productivity compared to earlier reeling practices	**120%** Increase in average selling price of yarn	**97%** Users reported increase in quality of reeled silk	**10** Average number of months of reported usage per year



Source: Authors' analysis

- Users experienced significant productivity gains, with the average daily reeling output increasing from **92 g** to **185 g**.
- We observed significant variations in how the raw material was sourced across different geographies. For instance, users from Assam and Meghalaya reported procuring cocoons from their farms, whereas most users in West Bengal and Odisha procured from privately registered sellers.
- Since users from Assam and Meghalaya procure raw materials from their farms, over **85 per cent** of them reported actively using the solution during the survey.

7.2 Small horticulture processors

The small horticulture processor extracts juices, pulp, and essential oils from vegetables, fruits, herbs, and flowers to make jams, candies, and squashes. Using 100 units of solar-powered small horticulture processors for 3 hours daily for 180 days a year can abate 11.6 MT of CO_2

Image: CEEW/Emotive Lens

States surveyed (share of respondents)

Rajasthan	38%
Uttar pradesh	25%
Uttarakhand	12%
Others	25%

Respondents

Total	32
Male	84%
Female	16%

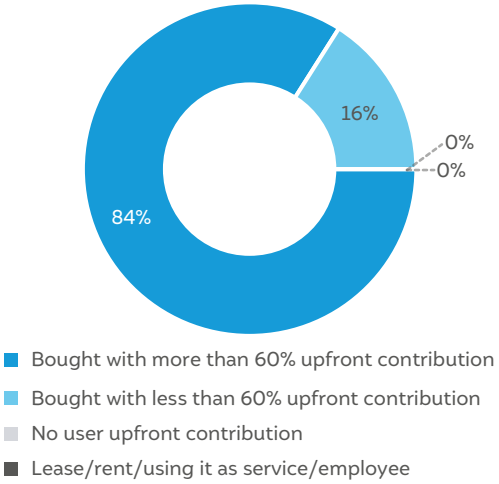
Caste category

General	66%
SC/ST	31%
OBC	3%

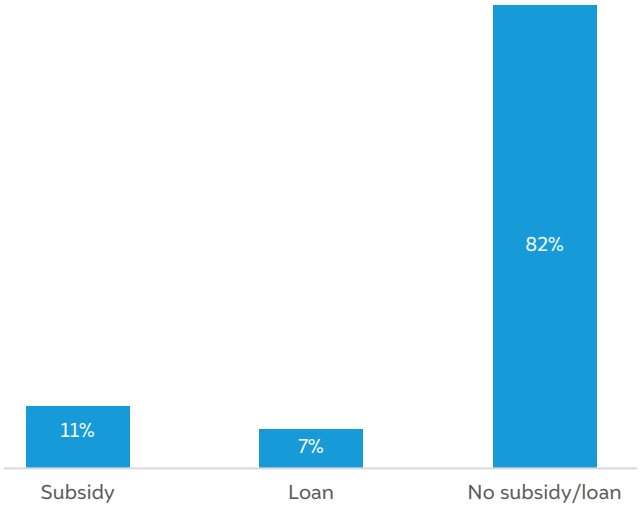
Primary income

Non-farm	50%
Farm	50%

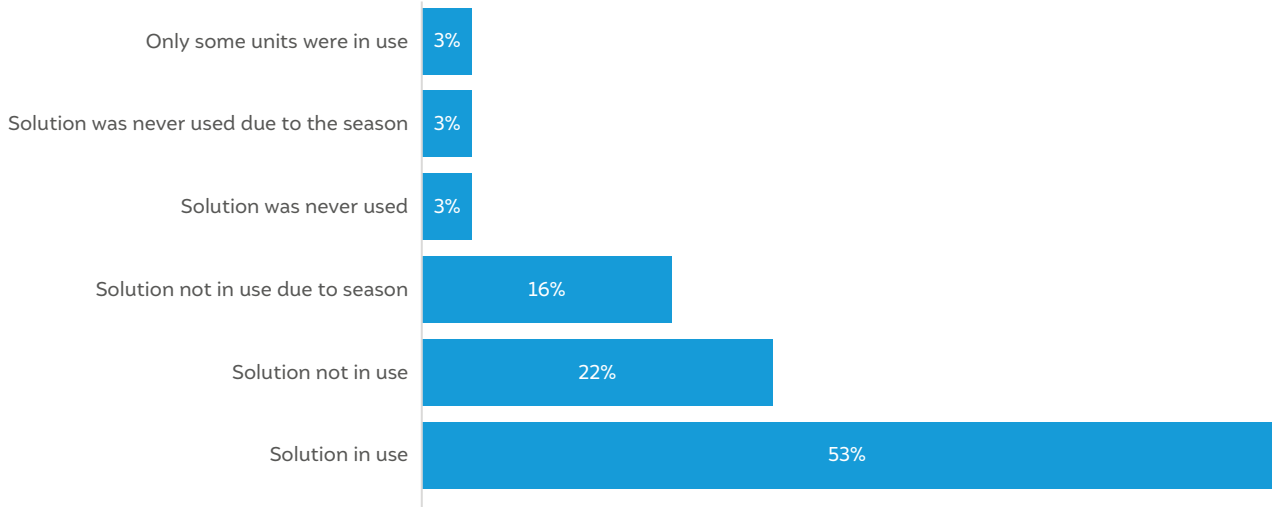
Users' upfront contributions to access small horticulture processor



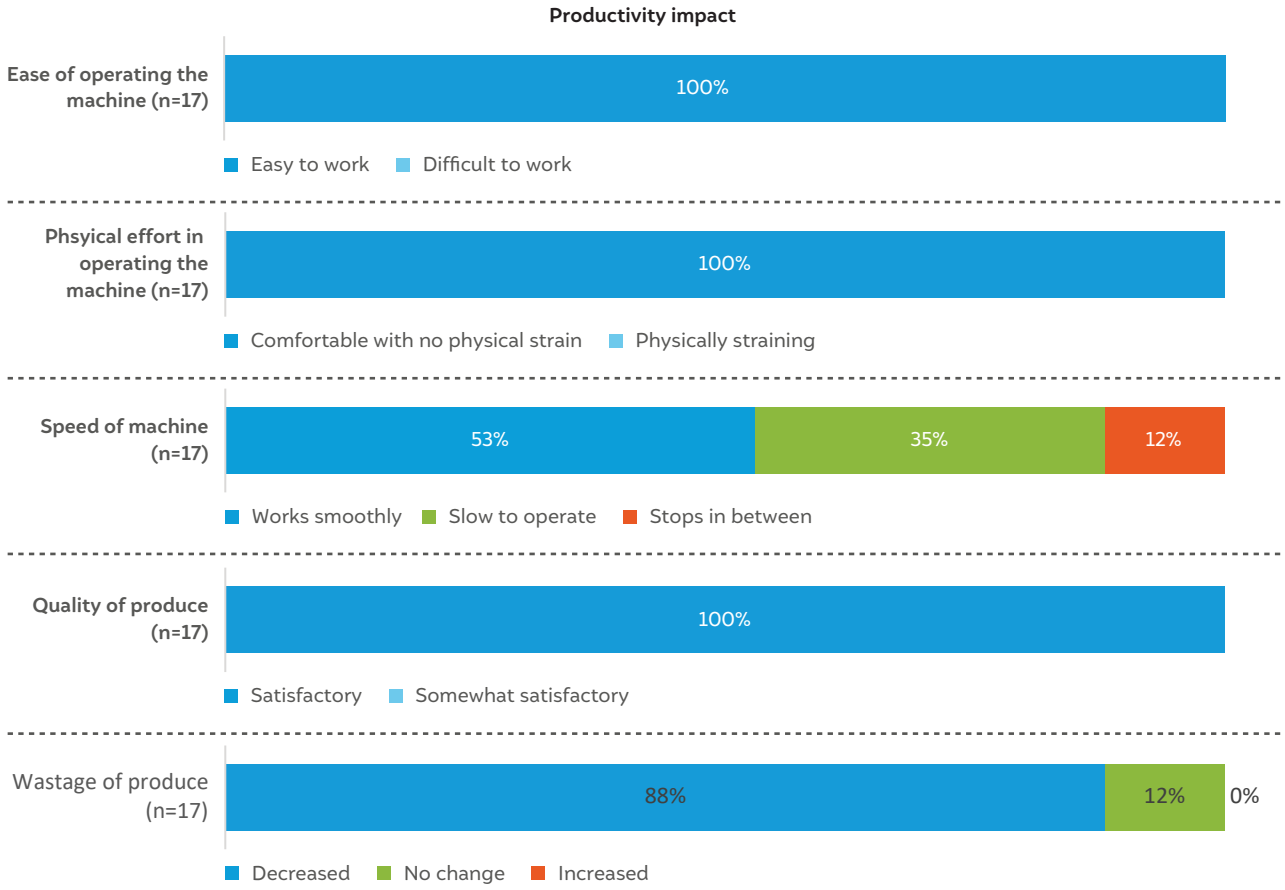
Source of capital for individual purchase and ownership (n=27)



Distribution of users across product usage categories



Source: Authors' analysis



Source: Authors' analysis

- Most (88 per cent) users use small horticulture processors to make **fruit, vegetable, and herbal juice products**.
- Almost **94 per cent** of users report no previous experience in processing. Given this, establishing productivity impact becomes challenging.
- **Capital cost** (37 per cent) and **operational cost** (18 per cent) are the top two reported challenges for users of small horticulture processors.

7.3 Solar refrigerators

The energy-efficient, solar-powered DC refrigerator provides reliable cooling for a wide range of commodities. By using 100 solar refrigerators for 21 hours daily for 250 days a year, about 29.4 MT of CO_2 could be abated.

Image: CEEW/Emotive Lens

States surveyed (share of respondents)

Uttar pradesh	60%
Rajasthan	29%
Karnataka	11%

Respondents

Total	169
Male	69%
Female	31%

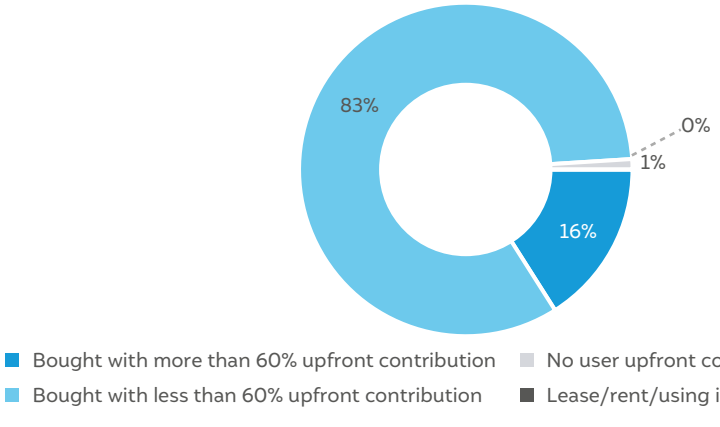
Caste category

SC/ST	40%
OBC	36%
General	23%
Others	1%

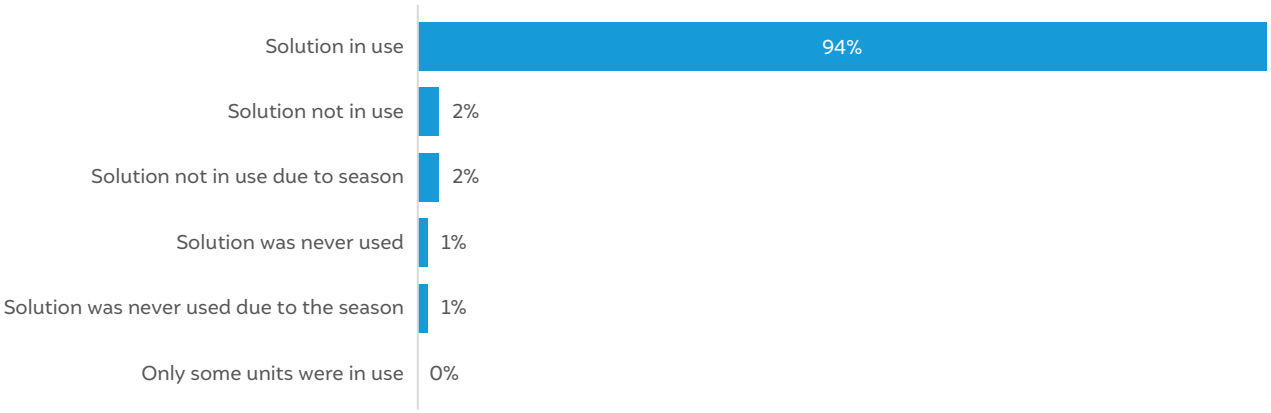
Primary income

Non-farm	60%
Farm	40%

Users' upfront contributions to access solar refrigerator

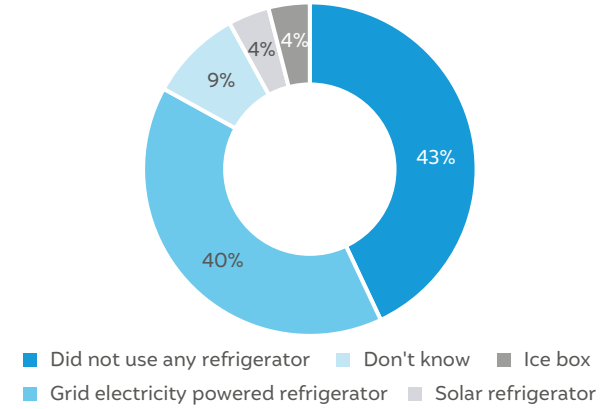


Distribution of users across product usage categories

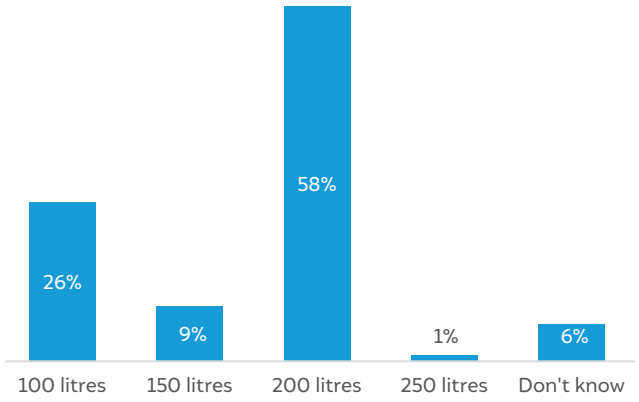


Source: Authors' analysis

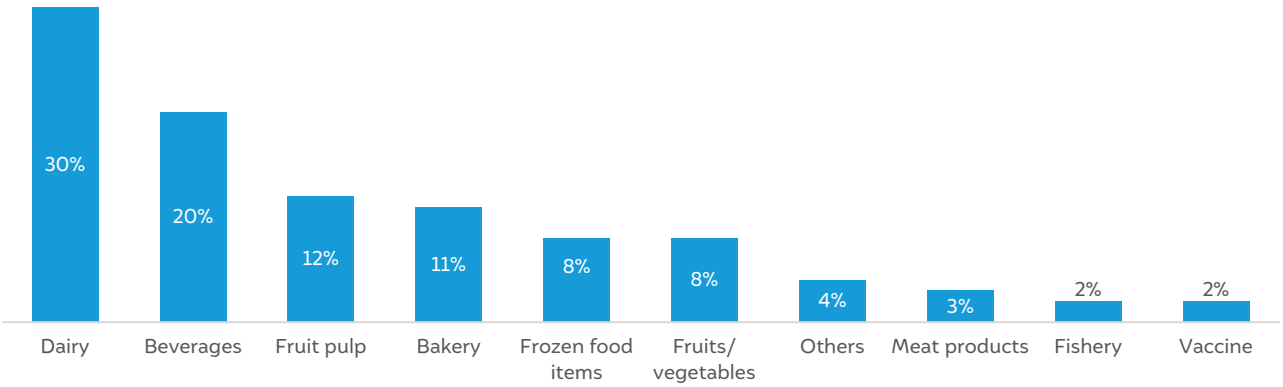
Distribution of responses on previously used refrigerator (n=162)



Solar refrigerator variant distribution (n=169)



Type of commodities stored in the solar refrigerator (n=149)



Source: Authors' analysis

Productivity Impact

12	24	28%	INR 450
Number of months of reported usage per year (median value)	Number of hours of reported usage per day (median value)	Users reported savings from electricity bill	Average monthly savings on electricity bill

- Almost **half** of the respondents (43 per cent) are first-time users of solar refrigerators.
- The majority of the solar refrigerator users owned a **200-litre refrigerator**. Of all the users, about 15 per cent preferred a higher-capacity refrigerator.
- More than **85 per cent** of respondents purchased the refrigerator for business use. Among them, 31 per cent indicated their business as a '**food outlet/*dhaba*/restaurant**'.

7.4 Solar vertical fodder grow unit

A solar-powered, microclimate-controlled hydroponics unit allows users to harvest 25 kg of fresh green fodder daily. Using 100 solar vertical fodder growing units for 225 days a year can abate about 15.4 MT of CO_2

Image: Selvaprakash Lakshmanan/Swiss Re Foundation/Fairpicture

States surveyed (share of respondents)

Karnataka	38%
Andhra pradesh	28%
Telangana	26%
Others	8%

Respondents

Total	39
Male	38%
Female	62%

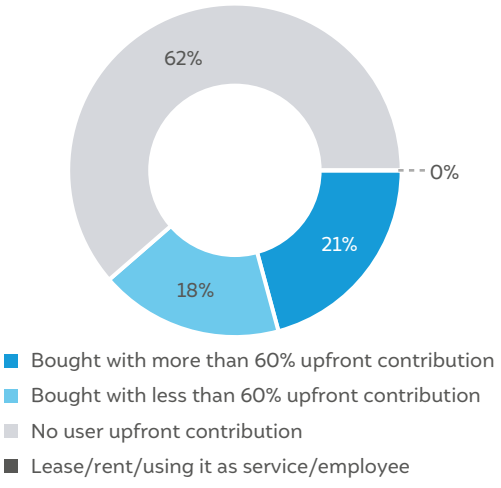
Caste category

OBC	62%
General	28%
SC/ST	10%

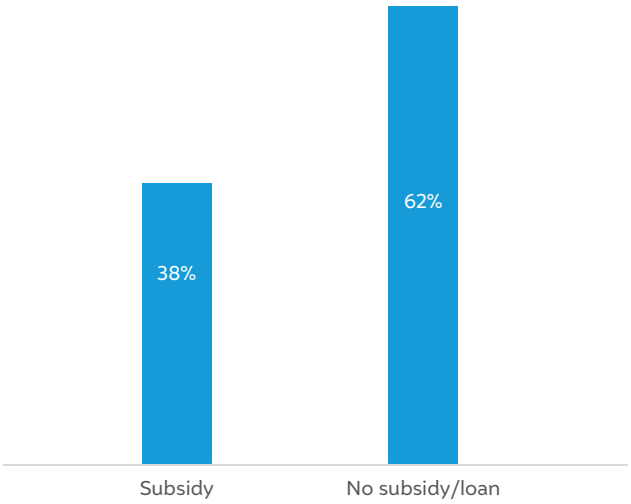
Primary income

Non-farm	21%
Farm	79%

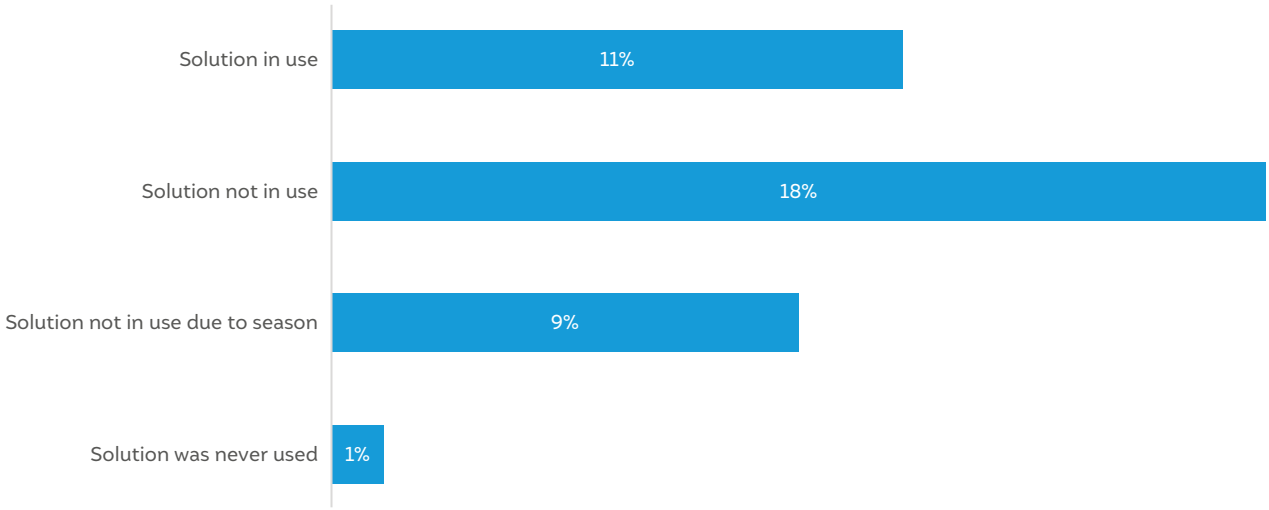
Users' upfront contributions to access solar vertical fodder grow unit



Source of capital for individual purchase and ownership (n=15)



Distribution of users across product usage categories

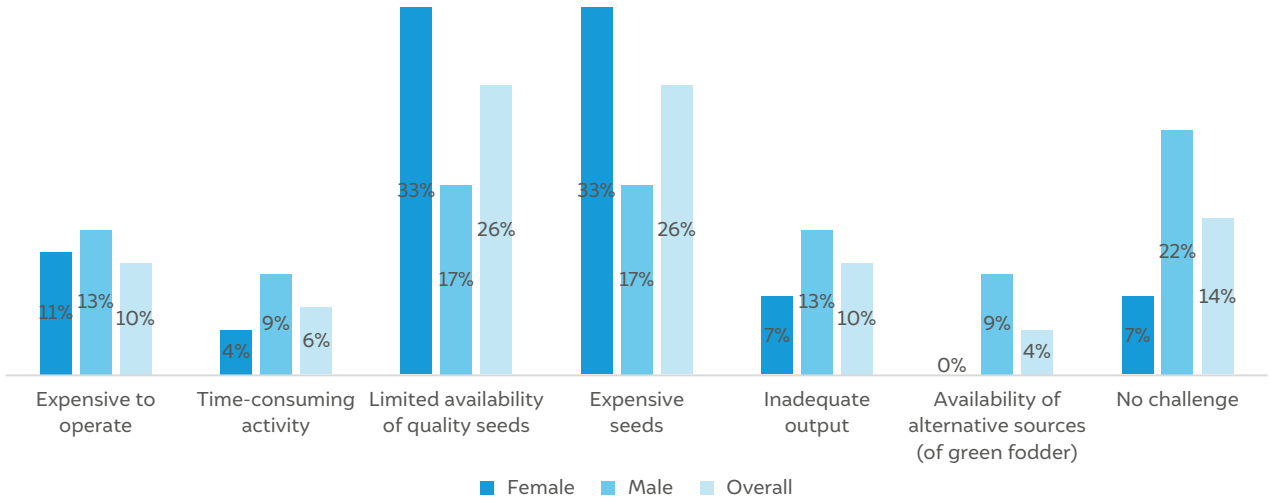


Source: Authors' analysis

Productivity Impact

2 hrs	59%	47%	INR 2/litre
Average reported time saved in fodder collection & feed preparation	Users reported reduced physical effort with fodder collection & preparation	Users reported reduced concentrate feed purchase	The average reported increase in the price of milk

Challenges with operating the solar vertical fodder grow unit (n=34)



Source: Authors' analysis

- Before adopting the vertical fodder grow unit, most users reported procuring green fodder by walking (62 per cent). These users typically walked a distance of less than 1 km (79 per cent).
- Most male household members (80 per cent) undertook this responsibility; about 58 per cent of female household members reported that they would collect green fodder.
- The availability of quality seeds and seed expenses were the top two challenges reported by the users.

7.5 Micro solar pump

A hyper-efficient, portable, open-well submersible pump system helps small farmers (land holding <2 acres) increase their irrigation area. About 11.4 MT of CO_2 could be abated with 100 units of micro solar pumps used for irrigating 2 acres on average across 6 months of a year.

Image: Khethworks

States surveyed (share of respondents)

Madhya pradesh	35%
Jharkhand	10%
Odisha	55%

Respondents

Total	159
Male	40%
Female	60%

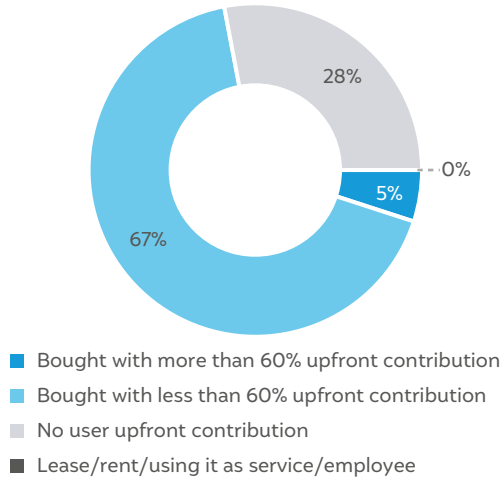
Caste category

SC/ST	79%
OBC	16%
General	4%
Others	1%

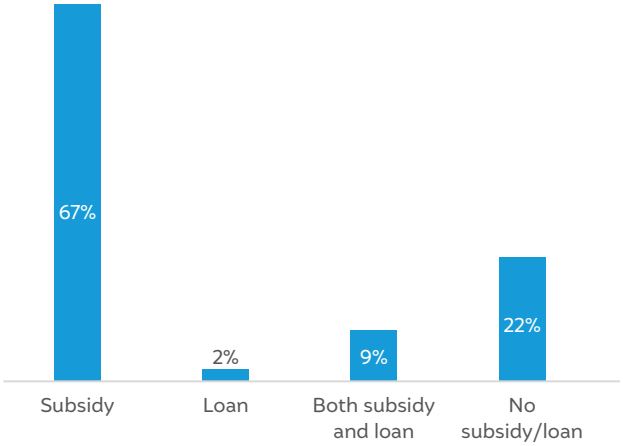
Primary income

Non-farm	8%
Farm	92%

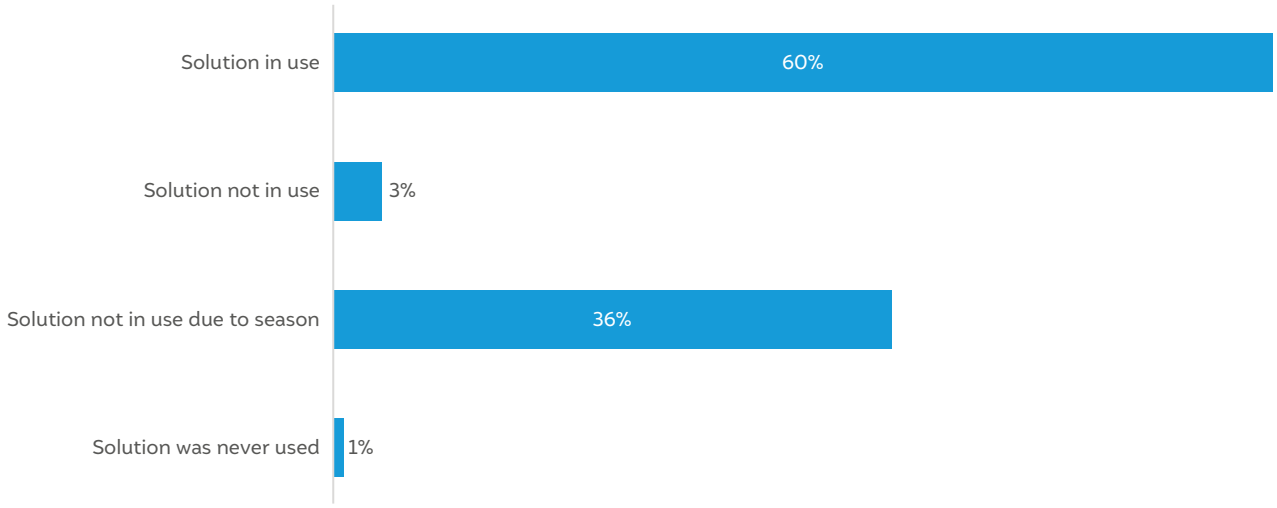
Users' upfront contributions to access micro solar pump



Source of capital for individual purchase and ownership (n=46)



Distribution of users across product usage categories

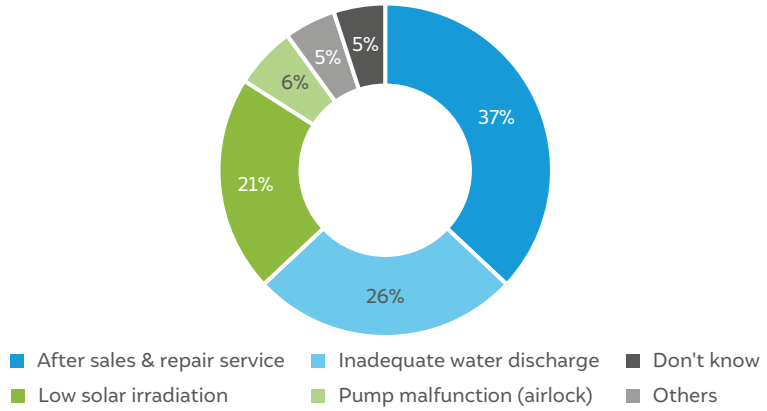


Source: Authors' analysis

Productivity Impact

123	5.3 hrs	81%	84%
Average number of irrigation days using the micro solor pump	Average number of hours of irrigation per day	Users reported an increase in irrigated area post the adoption of a micro solar pump	users reported a reduced cost of irrigation post the adoption of a micro solar pump

Reported challenges with the use of micro solar pump (n=19)



Source: Authors' analysis

- Among those who experienced decreased irrigation costs, the average savings on irrigation costs were **INR 14,623**.
- About **39 per cent** of farmers practised rainfed irrigation before adopting a micro solar pump. Post-adoption, farmers reduced their dependency on rainfed irrigation, with micro solar pump-based irrigation displacing earlier practices.
- **Eighty-two per cent of** users mention the discharge quality from the micro solar pump as 'very good'.

7.6 Solar dryer

A portable solar dryer helps farmers increase the shelf life of perishable agricultural produce, thereby enabling savings from food loss and better value for farmers. Solar dryers are commonly used for drying fruits, vegetables, spices and grains in bulk. Ten units of 100 kg solar dryers can abate about 20.3 MT of CO_2 through drying 60 batches per year and avoiding 15 kg of food loss per batch

Image: CEEW/Emotive Lens

States surveyed (share of respondents)

Maharashtra	17%
Odisha	24%
Andhra Pradesh	30%
Others	29%

Respondents

Total	87
Male	62%
Female	38%

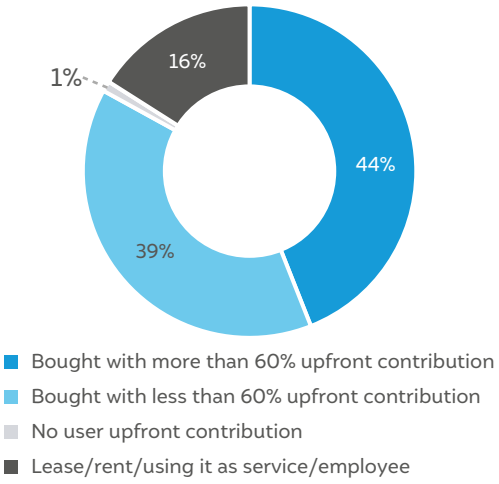
Caste category

OBC	40%
SC/ST	38%
General	16%
Don't know	6%

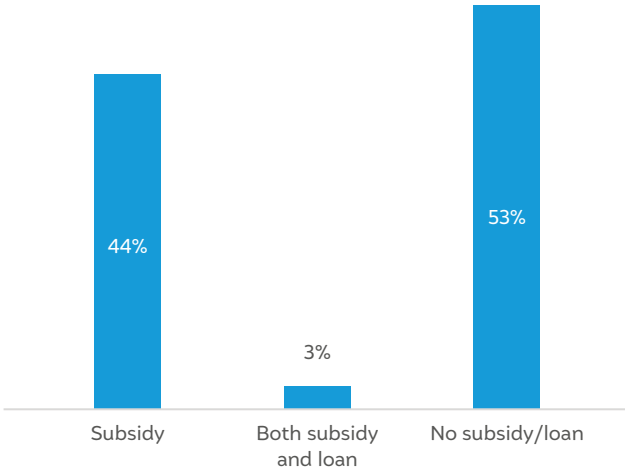
Primary income

Non-farm	15%
Farm	85%

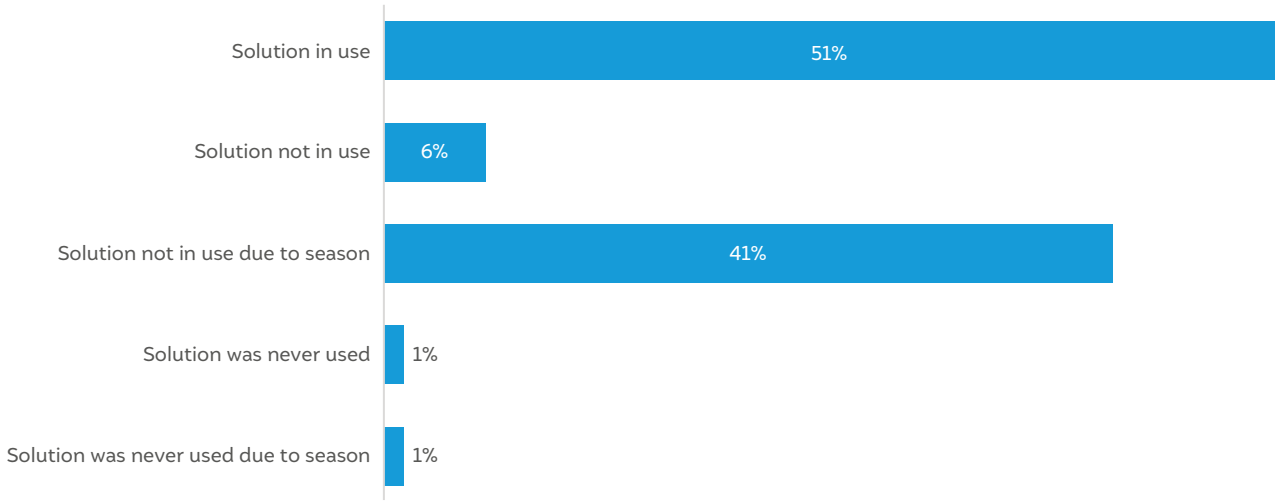
Users' upfront contributions to access solar dryer



Source of capital for individual purchase and ownership (n=47)



Distribution of users across product usage categories

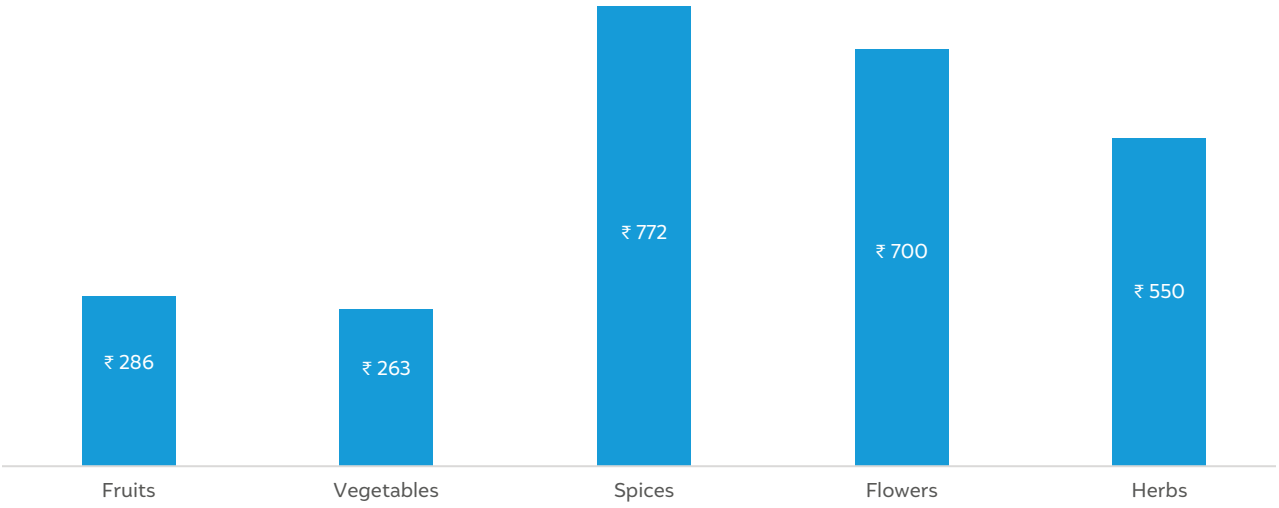


Source: Authors' analysis

Productivity Impact

35%	52%	41%	88%
Users reported **'low operating cost'** as the reason for adopting a solar dryer.	of users process dry fruits in the solar dryer; 35% process vegetables	Users market their dried produce to other states through traders.	Users reported increase in quality of dried produce.

Reported average price realised per kg of dried produce



Source: Authors' analysis

- About **91 per cent** of users acknowledged that they had no previous experience with dryer technologies. All users had previously followed **'open sun drying'**.
- Ten per cent of users reported availing of the buyback option from the manufacturer. According to them, 'ease in securing the order' and 'timely payment' were the top two advantages of the buyback option.

7.7 Solar dehydrator

A portable solar dehydrator helps farmers increase the shelf life of perishable agricultural produce, thereby enabling savings from food loss and better value for farmers. Designed for small-scale use, solar dehydrators effectively remove moisture from food items to ensure preservation. Ten units of 100 kg solar dehydrators can abate about 20.3 MT of CO_2 through drying 60 batches per year, avoiding 15 kg of food loss per batch.

Image: Priyatam Yasaswi/CEEW

States surveyed (share of respondents)

Maharashtra	100%

Respondents

Total	75
Male	4%
Female	96%

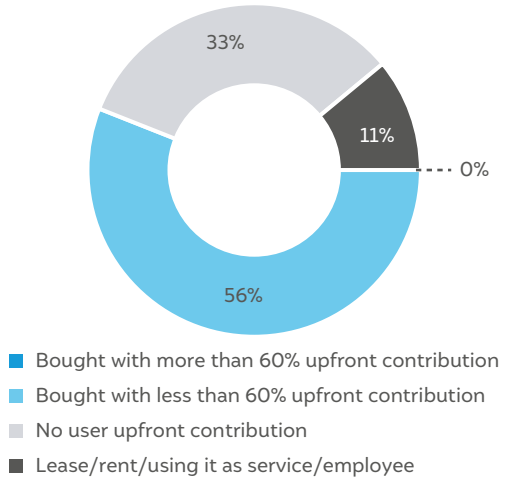
Caste category

General	67%
SC/ST	27%
OBC	3%
Don't know	3%

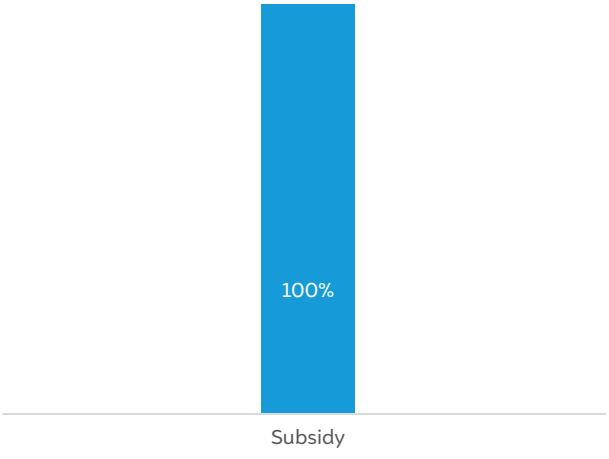
Primary income

Non-farm	60%
Farm	40%

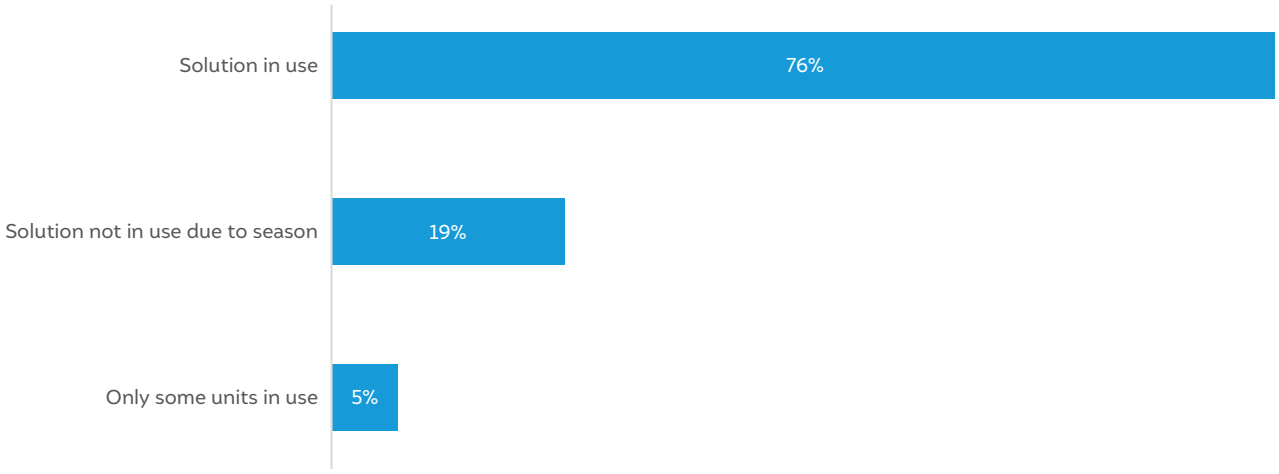
Users' upfront contributions to access solar dehydrator



Source of capital for individual purchase and ownership (n=23)



Distribution of users across product usage categories

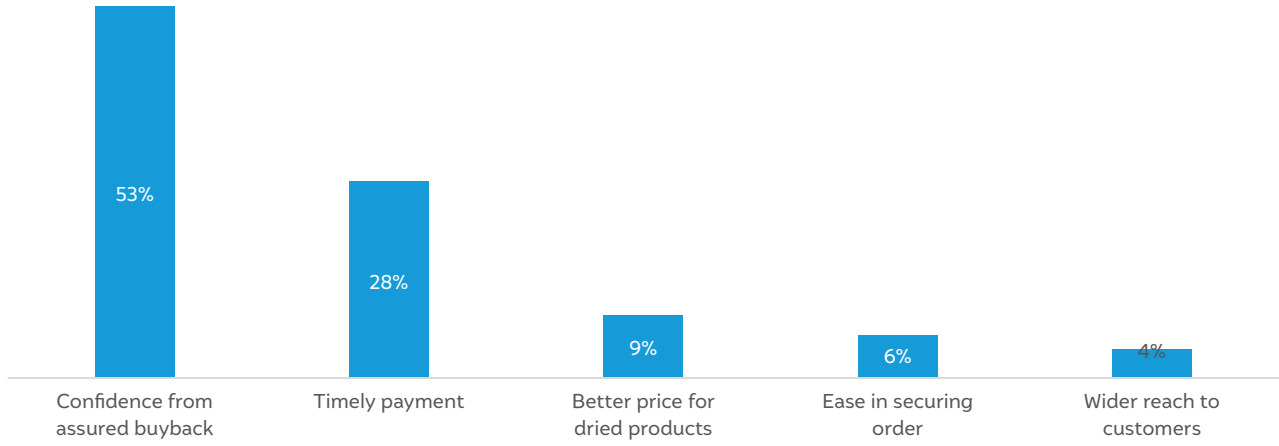


Source: Authors' analysis

Productivity Impact

19 litres/day	INR 1.5/litre	6hrs	92%
The average quantity of milk supplied by a user to the collection centre.	Average increase in price realised for supplying milk to the collection centre.	Average time spent on dehydrator per day by the user.	Users reported a decrease in physical effort from earlier activities.

Reported advantages of working at the Khoya processing centre (n=32)



Source: Authors' analysis

- All solar dehydrator users accessed the solution through credit enabled for the village-level collection centre. The manufacturer purchases the processed and dried end product from the user. The user's monthly repayment is deducted from this amount to repay the loan.
- On average, there were 10 members in a village collection centre.
- Users report that they supply almost 19 litres of milk per day to the village collection centre, which processes an average of 120 litres per day.
- The dehydrator is used an average of six months per year, with up to 28 days of average use per month.

7.8 Biomass-powered cold storage

The biomass-powered cold storage offers reliable cooling to farmers for storing their agricultural products at minimal running cost. It utilises the waste biomass available at the farm gate. Each biomass cold storage unit (15 MT capacity) can abate about 65 MT of CO_2, for 15 batches in an year avoiding an average produce loss of 15 per cent per batch.

Image: CEEW

States surveyed (share of respondents)

Maharashtra	100%

Respondents

Total	51
Male	92%
Female	8%

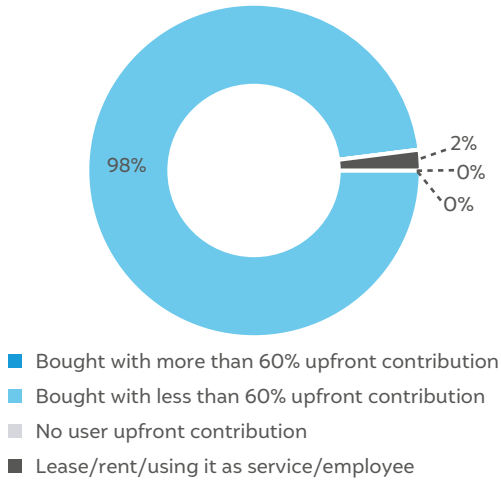
Caste category

SC/ST	53%
General	35%
OBC	12%

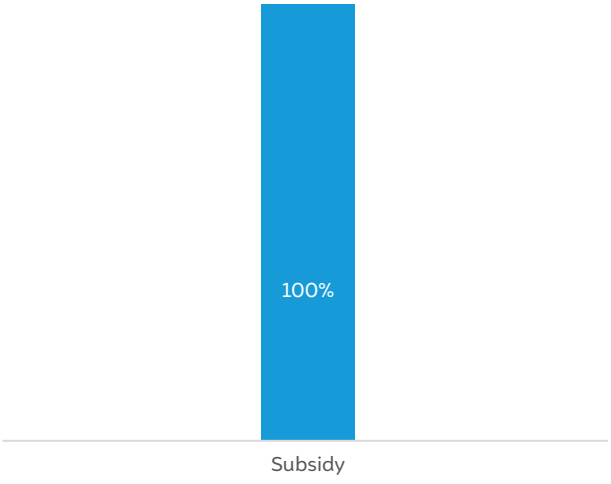
Primary income

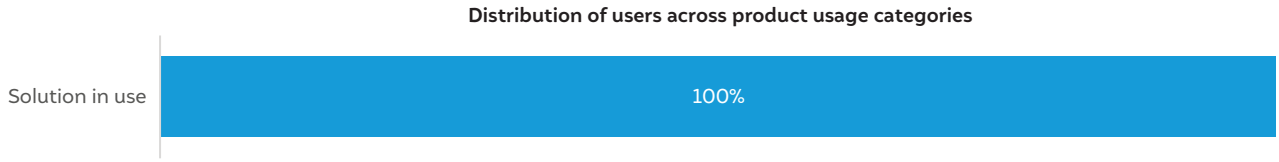
Farm	100%

Users' upfront contributions to access biomass powered cold storage



Source of capital for individual purchase and ownership (n=23)

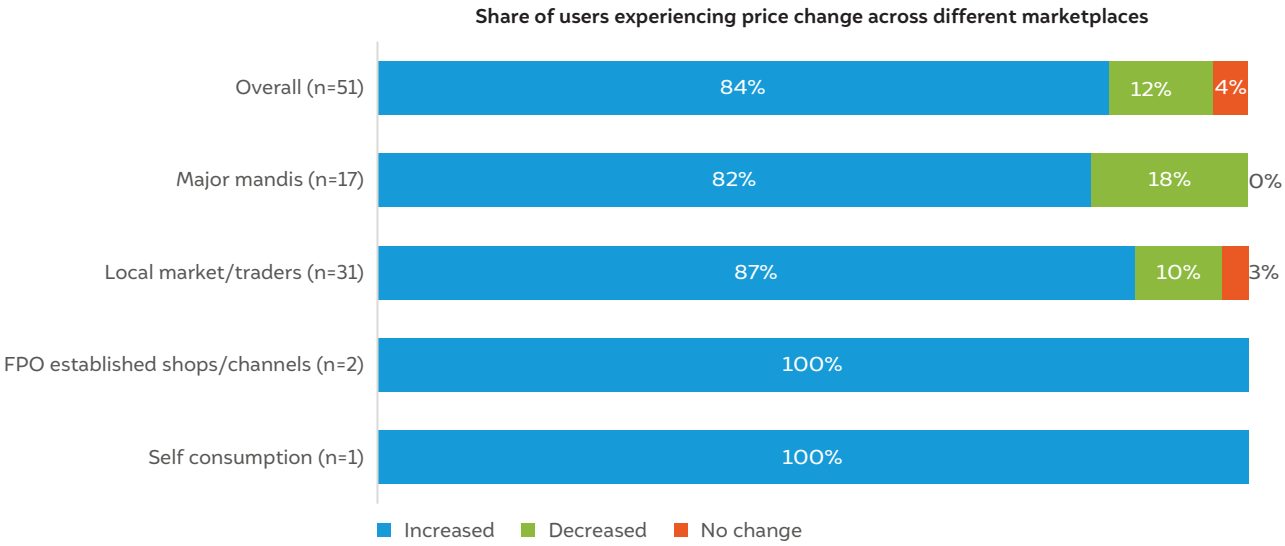




Source: Authors' analysis

Users' Experience

56%	73%	84%	73
Users reported 'utilisation of waste biomass' as the biggest advantage of biomass- powered cold storage.	Users store fruits in cold storage; 23% store vegetables	Users report improved price realisation for commodities with the use of cold storage.	Average number of days of storage of fresh produce (fruits) in the cold storage.



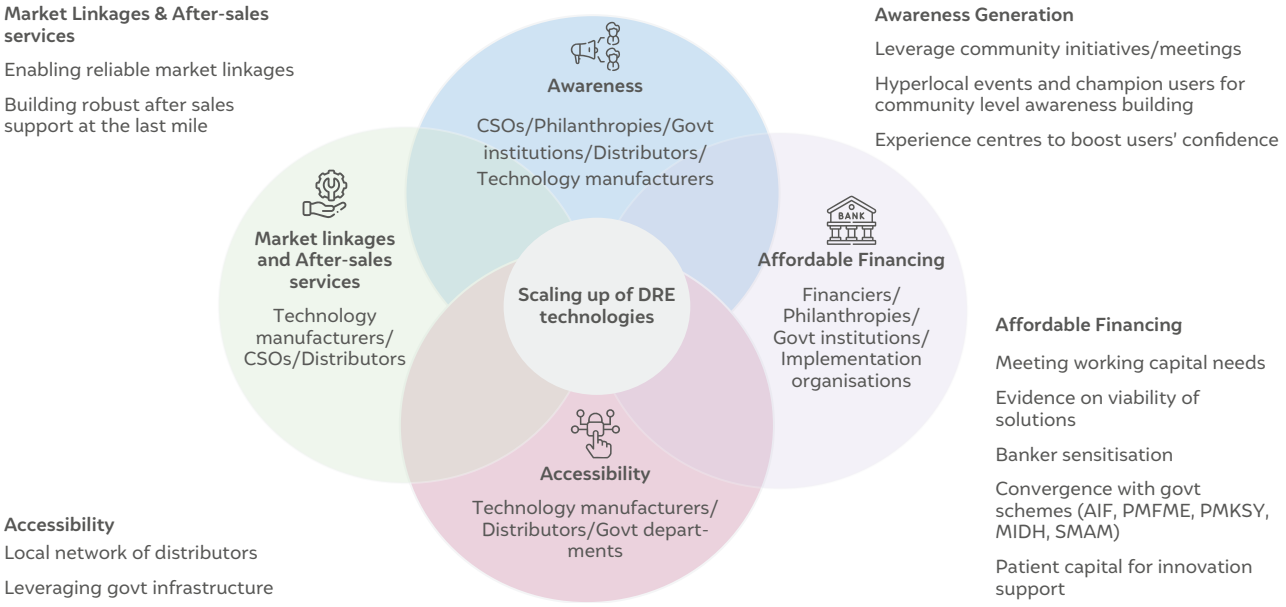
Source: Authors' analysis

- Almost **72 per cent** of users were first-time users of cold storage. The rest reported previously using 'grid-based and warehouse-type cold storage'.
- Most users (61 per cent) reported selling their produce to **local markets or traders**, and 32 per cent sold it to major *mandis*.
- About **84 per cent** of users experienced better price realisation after using cold storage. Nearly 30 per cent of users highlighted that 'low price during harvest' was one reason for adopting cold storage.

A farmer in rural Maharashtra organises crates of lemons inside a biomass-powered cold storage.

Image: CEEW/Emotive Lens

8. Recommendations



The DRE for livelihoods sector continues to grow in India. There are now diverse technologies in the market beyond solar water pumps, as was the case a few years ago. This growth is primarily due to the work done in this space by philanthropic organisations, clean energy technology manufacturers, and government stakeholders. However, a few gaps need to be addressed to unlock this sector's true potential and ensure that sustainable livelihoods are created at the grassroots level. Drawing insights from both the impact research and programme experience, this section outlines targeted recommendations for each stakeholder group, emphasising their critical roles in fostering a thriving DRE ecosystem. These recommendations aim to accelerate adoption, overcome barriers, and maximise the socio-economic and environmental benefits of DRE technologies.

- **DRE livelihood technologies can be targeted towards SHGs and FPOs to enable group ownership and the creation of micro/nano-enterprises**

  Our data reveals that 60 per cent of self-selected DRE technology adopters are members of Self-Help Groups (SHGs) or Farmer Producer Organisations (FPOs). These groups utilise technologies like silk reeling machines, solar dryers to generate income through value-added activities. Further, some of these users are also owners of solar micropumps and biomass powered cold storage.

  From Powering Livelihoods experience, financiers demonstrate a stronger preference for lending to groups rather than individuals, making DRE solutions more affordable. This group-centric approach has fostered numerous successful enterprise creation and scaling stories, with SHGs and FPOs effectively leveraging government community investment/ revolving funds to expand their micro-enterprises. One such story is of Anju Bisht from Chamoli, Uttarakhand, who collaborates with three SHGs and procured solar dryers for processing Buransh flowers, Malta, lemons, and more. The SHGs utilised an INR 20,000 revolving fund at 0 per cent interest for two years, along with INR 20,000 from group savings as working capital. With earnings of INR 60,000–70,000 over 9–10 months of using the solar dryer, they now plan to invest in higher-capacity solar dryers to scale production and further enhance their livelihoods.

- **Commercial scale-up of technologies should be incentivised to reduce subsidy-heavy deployments for long-term usage**

  The research shows that 15 per cent of the respondents have contributed more than 60 per cent towards the technologies. Further, our regression analysis shows a strong and statistically significant relationship between user upfront contribution and usage of the solution at the time of the survey (p-value=0.00). Therefore, user upfront contribution is crucial to ensure long-term usage, and so commercial models of deployments should be advanced.

  Our programme experience and field-based qualitative research reveal key drivers for successful commercial deployment: demonstrating economic viability, quantifying socio-economic and environmental benefits, and building stakeholder confidence through compelling case studies. This report contributes to this evidence base. Furthermore, establishing local sales networks is vital. The programme has onboarded over five such partners on-ground working across 10 states to reach millions of groups/farmers/nano-entrepreneurs for awareness generation and unlocking commercial sales. To achieve scale, philanthropies should prioritise investments in models that incentivise commercial deployments, and governments must mainstream credit-linked subsidies and interest subventions for DRE technologies.

- **Facilitate sustained use of DRE solutions by strengthening market linkages and ensuring access to working capital to maximise user benefits**

  DRE solutions are often considered in terms of deployment numbers or sanctioned numbers. However, these solutions can benefit the user and the community only through sustained usage. Without efforts to ensure sustained usage, there is a significant risk that most of these deployments will remain unused. Non-utilisation also poses a considerable risk to cash flows, which are key indicators for financiers when assessing the creditworthiness of a solution. Therefore, ensuring sustained usage is important when designing interventions involving DRE livelihood solutions.

  Our findings indicate that approximately 18 per cent of users have never used the solution, while about 5 per cent have stopped using it at the time of the survey. Although the reasons for non-usage may vary across different technologies, we found that a lack of working capital is the primary barrier for 86 per cent of respondents who have never used the solution. Additionally, 30 per cent of those who stopped using the solution cited the unavailability of raw materials or inputs as a significant constraint.

  - **Working capital**

  Most DRE solutions today are subsidised by philanthropic organisations or government departments (Gaur, Yasaswi, and Jain 2023). This support, often in the form of grants and upfront subsidies, helps bridge the affordability gap for users. However, in some instances, even though the solution was nearly fully subsidised, it was not utilised by users. The primary reason is the users' inability to cover raw material costs. This is because considerable emphasis is placed on the initial capital required to acquire the DRE solution in implementation strategies without recognising the working capital needs. Therefore, fully subsidising DRE solutions is not an effective mechanism to realise the impact of DRE livelihood solutions. Users must be educated about working capital requirements before they adopt the solution.

- **Market linkages**

The impact of DRE solutions that require market linkages—both forward and backward—strongly depends on the strength of these connections. For instance, solar silk reeling and spinning machines rely on robust supply chains (backward linkages), while solar dryers and small horticulture processors depend on market access (forward linkages). Our interactions with users revealed that the unavailability of cocoons (backward linkages) led to the underutilisation of solar silk reeling machines in Bihar, while, in some cases, the lack of favourable prices for dried produce limited the use of solar dryers.

The Powering Livelihoods programme, in collaboration with Raheja Solar, a solar dryer manufacturer, tackled market access challenges faced by rural women entrepreneurs in Andhra Pradesh by building an end-to-end value chain. Through a buy-back guarantee for dried products—where enterprises commit to purchasing at a fixed rate—120 women farmers across six FPOs earned guaranteed incomes. This success gained support from Samunnati, a financing institution, which increased loan coverage for additional solar dryers from 20 per cent to 80 per cent. The initiative ensures income stability, enables financing, provides training, and strengthens market linkages, fostering sustainable women-run micro-enterprises

The following recommendations by stakeholder groups are aimed at facilitating a well-informed and effective scale-up of DRE livelihood technologies.

Central ministries should come together for convergence and integrate DRE livelihood solutions in their existing schemes and initiatives

Policymakers

- **Central ministries such as the Ministry of New and Renewable Energy (MNRE), Ministry of Agriculture and Farmer Welfare (MoA&FW), Ministry of Rural Development (MoRD), and Ministry of Tribal Affairs (MoTA) focusing on livelihoods and rural development**. Schemes such as *Pradhan Mantri Formalisation of Micro Food Processing Enterprises* (PMFME), *National Agri Infra Financing Facility* (AIF), and *Start-up Village Entrepreneurship* programme are some high potential central government schemes offering support through upfront capital subsidies, credit-linked backend subsidies, and interest subvention among others.
- Providing targeted capital support for DRE solutions by converging existing government schemes and policies is crucial. This targeted capital support needs to be determined after careful consideration of the business ecosystem of each DRE solution as well as an assessment of the needs and market conditions of potential users. Targeted capital support will ensure that solutions are not arbitrarily deployed and will, more importantly, unlock sectoral momentum.

Manufacturers

- **Including operational requirements, working capital, and overall viability would give users and financiers a realistic estimate of the required capital**. Additionally, designing training and capacity-building sessions for users, financiers, and government departments—focused beyond upfront costs and subsidy coverage ensures stakeholders fully understand the long-term economic benefits of DRE solutions.
- For processed goods, manufacturers could establish buyback initiatives that guarantee pricing for users, encouraging active uptake of these solutions at the last mile. Financiers and philanthropies are urged to support these initiatives, as they play a vital role in enabling sustainable incomes for users, extending beyond their typical focus on facilitating the adoption of DRE solutions.

Implementing organisations

- **Implementation organisations and manufacturers must assess users' needs and market conditions to identify gaps in access to backward and forward linkages**. Addressing these gaps should be prioritised through well-devised plans before deploying solutions on the ground. These plans can involve collaborations among manufacturers, implementation organisations, government departments, and research institutions.
- **A data-based approach to help match potential users with relevant stakeholders, such as DRE solution manufacturers and government departments, can ensure the long-term sustainability of interventions**. Key decisions, including setting upfront subsidies, evaluating economic viability, and meeting market and operational requirements, must be informed by this approach. This ensures subsidies and deployments are strategic, unlocking sectoral momentum.

Financiers

- **Financial institutions disbursing credit to rural consumers must actively include DRE livelihood solutions in their portfolio in addition to conventional farm and non-farm equipment**. Evidence shows that users have the ability to repay loans taken for DRE solutions through the increased incomes generated using the adopted DRE livelihood solution (Jha, Patnaik, and Jain 2019). In this study, we find that among users who experienced income gains and bought (made some upfront contribution) the solution, almost half (46 per cent) could pay for the initial loan using their increased incomes. This number further increases if loan tenures are extended, making it viable for even more users (68 per cent).
- Financiers should consider the solution's working capital and upfront capital requirements before disbursing credit. Credit support is often not extended to DRE solutions owing to their small-scale nature. However, our findings show that some solutions' capital requirements extend beyond the upfront capital. A lack of working capital to purchase raw materials or sell produce is a real challenge for some users. Supporting this through affordable credit can address the challenges many potential users face in adopting DRE solutions owing to its capital requirements.

9. Way forward

Image: CEEW/Emotive Lens

DRE is poised to significantly contribute to India's transition to a net-zero-emissions-based economy by 2070. It is also hold significant potential to improve productivity, community incomes, and the overall rural economy. Beyond improving incomes, these solutions enable a wider social impact. We find that 84 per cent of female users reported increased participation in public/community events, and 77 per cent of users cited an improved perception of clean energy sources after using DRE solutions.

To scale up these solutions effectively, a holistic approach is crucial.

- This involves raising awareness, ensuring affordability, training key stakeholders, fostering partnerships, and generating evidence on their impact and challenges in procurement and usage.
- Implementing partners, policymakers, last-mile distributors, think tanks, financiers, and philanthropies must collaboratively work in the ecosystem to enable this holistic support.
- Interministerial convergence is key to scaling up support for DRE livelihoods. Integrating technologies into existing government schemes and leveraging the strengths of grassroots organisations can significantly enhance the sustainability and impact of these initiatives.

DRE-based livelihoods need a national focus to accelerate their penetration on the ground, enhance affordability, and create strong linkages for a people-centred energy transition. This report provides relevant evidence to help inform strategies to develop sustainable livelihoods and secure a resilient and inclusive future through the adoption of DRE-based livelihoods.

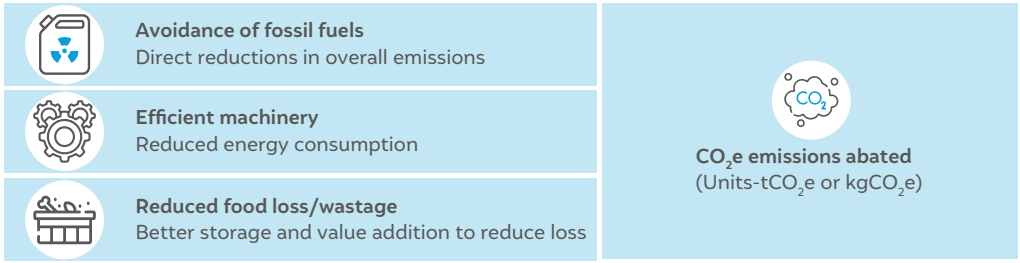
Solar dryers offer immense potential for farmers to increase the value of their produce.

Image: CEEW/Emotive Lens

Annexure 1: Environmental impact

Decentralised renewable energy (DRE)–powered livelihood solutions impact the user's economic and social indicators and reduce carbon emissions that would be emitted using conventional technologies. DRE solutions generally cut emissions as they operate on clean energy sources. They also enable environmental impact primarily through three pathways (Figure A1).

Figure A1 Pathways for DRE livelihood solutions to enable environmental impact



Source: Authors' compilation

Solutions such as solar-powered irrigation pumps ensure that conventional solutions, including diesel or petrol pumps, are not used, avoiding using fossil fuels such as diesel and petrol in running irrigation systems. This results in the total abatement of emissions involved in the base case of operating diesel/petrol-run water pumps. Secondly, efficient machinery in motorised applications reduces energy consumption, reducing the total emissions involved compared to relatively inefficient motorised applications. For instance, a grain processing mill comprising energy-efficient brushless direct current (BLDC) motors would consume less energy than conventional AC motors. Additionally, post-harvest management solutions such as dryers, dehydrators, and cold storage powered by renewable energy sources such as solar and biomass help reduce loss of food (agri produce/harvest). DRE solutions, therefore, create environmental impact by abating emissions associated with reduced food loss. While only one pathway might be relevant for any given DRE solution, there might be cases where a combination of more than one would be applicable. A solar dehydrator involving energy-efficient components would consume reduced energy while reducing food loss.

Based on these pathways, this study estimates the environmental impact of the technologies covered in the survey. While the technology-specific section (Section 6) highlights the findings, this section explains the approach and rationale behind arriving at these numbers for each technology. We obtained the solutions' specifications from the respective manufacturers and sourced the usage data from the users' responses for the analysis. We used the carbon emission factor published by the Central Electricity Authority.

1. Solar silk reeling and spinning machine

Description: A solar silk reeling and spinning machine is a small-scale portable appliance that assists users in reeling silk from cocoons (*tussar*, *eri*, etc.). The machine abates emissions by drawing its power from solar energy. The theoretical power rating of the variant (*Buinyaad*) considered for the analysis is 30 W. A typical use case was found to be 250 days per year with 5 hours of usage per day. Emissions from a typical use case involving grid electricity have been considered the baseline (Table A1).

Table A1 Calculation of the environmental impact of solar silk reeling and spinning machines for a typical use case

Formula	Unit	Emissions abated annually (for 100 units)
(Annual energy consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	1.1

Source:Authors' analysis

Note - The theoretical carbon abatement is about 200 kg of CO_2e per 200 days of usage.

2. Small horticulture processor

Description: A small horticulture processor is a small-scale food processing machine that enables users to process a variety of fruits, vegetables, herbs, and flowers. A solar-powered small horticulture processor abates emissions by drawing its power from solar energy. The theoretical power rating of the variant (120 litres/hour) considered for the analysis is ~597 W. A typical use case was 180 days per year with 3 hours of usage per day. Emissions from a typical use case involving grid electricity have been considered the baseline (Table A2).

Table A2 Calculation of the environmental impact of solar-powered small horticulture processors for a typical use case

Formula	Unit	Emissions abated annually (for 100 units)
(Annual energy consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	11.6

Source: Authors' analysis

3. Solar refrigerators

Description: The solar refrigerator considered in the analysis is an energy-efficient and reliable cooling solution for storing fruits, vegetables, and dairy products. It abates emissions by drawing its power from solar energy and displacing the emissions involving a conventional refrigerator. Emissions from a typical use case involving grid-based refrigerators have been considered the baseline. The grid refrigerator variant (200 litres) considered for the analysis has a 5-star rating and an annual energy consumption of 430 units. A typical use case was found to be 250 days per year with 21 hours of usage per day (Table A3).

Table A3 Calculation of the environmental impact of solar refrigerators for a typical use case

Formula	Unit	Emissions abated annually (for 100 units)
(Annual energy consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	29.4

Source: Authors' analysis

4. Solar vertical fodder growing unit

Description: The solar vertical fodder unit considered in the analysis allows farmers to grow up to 25 kg of fresh green fodder per day for cattle. It abates emissions by drawing its power from solar energy. The variant (25-30 kg/day) considered for the analysis has a theoretical power rating of 40 W. A typical use case was 225 days per year with less than 1 hour of actual pump usage per day. Emissions from a typical use case involving grid-powered fodder grow units have been considered the baseline (Table A4).

Table A4 Calculation of the environmental impact of solar vertical fodder grow units for a typical use case

Formula	Unit	Emissions abated annually (for 100 units)
(Annual energy consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	15.4

Source: Authors' analysis

Note: The theoretical carbon abatement is about 200 kg of CO_2e per 200 days of usage.

5. Micro solar pump

Description: The micro solar pump allows farmers to irrigate their fields without relying on expensive fuels such as diesel or kerosene. The variant (0.3 HP) considered for the analysis has a theoretical rated flow of 3600 Lt/hr at 10 m head. A typical use case was ~ 6 months per year, and the average land irrigated ~ 2 acres. Emissions from a typical use case involving a diesel-powered irrigation pump have been considered the baseline (Table A5).

Table A5 Calculation of the environmental impact of micro solar pump for a typical use case

Formula	Unit	Emissions abated annually (for 100 units)
(Annual avoided diesel consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	11.4

Source: Authors' analysis

6. Solar dryer

Description: A solar dryer enables the processing of fresh agricultural produce, such as fruits, vegetables, and flowers, at the farm gate, cutting down food loss for small and marginal farmers. The variant considered for the analysis can dry up to 100 kg of commodities at a time. Emissions abated were considered a combination of avoided food loss and the savings from electricity consumption needed for drying commodities. A typical use case was found to involve 60 batches per year (Table A6).

Table A6 Calculation of the environmental impact of solar dryer for a typical use case

Formula	Unit	Emissions abated annually (for 10 units)
(Avoided food loss × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey) + (Annual electricity consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	20.3

Source: Authors' analysis

7. Biomass-powered cold storage

Description: A biomass-powered cold storage provides reliable cooling to fresh agricultural produce, such as fruits, vegetables, and flowers, at the farm gate, reducing food loss for small and marginal farmers. The variant considered for the analysis can store up to 15 MT of commodities at a time. Emissions abated were considered a combination of avoided food loss and the savings from electricity consumption needed to provide reliable cooling to the commodities. A typical use case was found to involve 15 batches per year (Table A7).

Table A7 Calculation of the environmental impact of biomass-powered cold storage for a typical use case

Formula	Unit	Emissions abated annually
(Avoided food loss × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey) + (Annual electricity consumption × carbon emission factor)/1000 × (per cent of users who reported using the solution at the time of the survey)	MT	94

Source: Authors' analysis

Limitations

While the real-world applications of these solutions might involve various components that would influence the environmental impact (manufacture, transport/logistics, etc.), this analysis only considers the user-solution interaction based on the three primary pathways listed earlier in this section (Figure A1).

The unique offering the studied solutions provide has proven challenging in benchmarking energy consumption or emissions generated by identical alternative solutions available on the market. Therefore, to establish the environmental impact of some of these DRE solutions, we considered a hypothetical case in which a similar solution runs on grid electricity.

Additionally, the usage patterns (hours/day, batches/month, days/year, etc.) of some solutions vary depending on the use case or commodity involved. Assuming a typical use case might not accurately measure their impact. Real-time monitoring can offer crucial data to accurately assess the environmental impact of these solutions.

Acronyms

CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DC	Direct current
DRE	Decentralised Renewable Energy
EMI	Equated Monthly Installment
FPC	Farmer Producer Company
FPO	Farmer Producer Organisation
GDP	Gross Domestic Product
IRENA	International Renewable Energy Agency
MoAFW	Ministry of Agriculture and Farmers Welfare
MoFPI	Ministry of Food Processing Industries
MNRE	Ministry of New and Renewable Energy
MoRD	Ministry of Rural Development
MoTA	Ministry of Tribal Affairs
MT	Metric tonnes
OBC	Other Backward Class
PL	Powering Livelihoods
SC	Scheduled Caste
SHG	Self Help Group
ST	Scheduled Tribe

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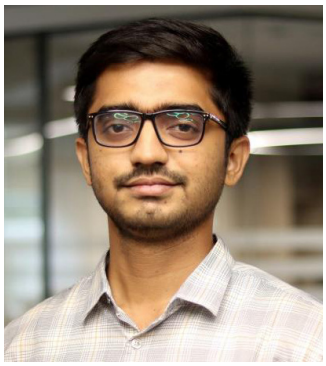

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