



Beyond Irrigation: Harnessing the untapped potential of solar pumps

Lessons from a solar-powered
milling pilot in Uttar Pradesh

IISD REPORT



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Oorja Development Solutions (Oorja)

[Oorja](#) is a Farming-as-a-Service company delivering clean energy solutions and advisory services to smallholder farmers in northern India through an affordable pay-per-use model. By offering solar-powered irrigation and milling services, Oorja replaces diesel-based alternatives and eliminates the upfront costs of solar technology. This approach makes clean energy accessible to farmers with less than 2 acres of land and annual incomes of approximately INR 60,000.

Oorja launched its first solar-powered irrigation service, **Oonnati**, in 2018 in Bahraich district, Uttar Pradesh. In 2020, it expanded with **Oojjwal**, a solar-powered milling service, and in 2022, it introduced **Oorvar**, a climate-smart farmer advisory service. Oorja has been providing affordable solar-powered irrigation and milling services to smallholder farmers through its unique pay-per-use model for over 5 years now. Oorja has installed and integrated solar mills with the irrigation pumps to increase the utilization of the energy generated. The mills usually run when pumps are not in use by diverting the solar power generated by the pump photovoltaic (PV) panels. This effective utilization of clean energy has caught the attention of reputed organizations in the off-grid energy sector. As of August 31, 2025, Oorja is operating in five districts of Uttar Pradesh. The company has installed 256 solar pumps across 123 villages with a total capacity of 1257.2 kWp, serving over 3,700 farmers and sustainably irrigating more than 4,700 acres. Additionally, idle solar capacity powers milling services for 2,200+ community members across 17 villages.

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Executive Summary

Solar-powered irrigation pumps (SIPs) are widely used globally to increase agricultural yields, boost farmers' incomes, and reduce reliance on diesel- and electricity-powered pumps. In India, over 850,000 solar pumps have been deployed with the major government subsidy programs under Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan (PM-KUSUM) to encourage uptake. The direct benefit of these subsidies tends to be clustered among landholders and farmers. In many parts of India, solar pumps are used for irrigation only during certain periods of the year, depending on crop cycles, and remain idle otherwise. This seasonal underutilization leads to significant periods where the solar energy generated goes untapped, including in regions grappling with energy poverty. Consequently, the surplus power from these idle pumps remains an underexploited source of clean and affordable energy that could benefit poor smallholders, women, youth, and other disadvantaged groups.

This report presents an in-depth analysis of the socio-economic and behavioural impacts of grain mills powered by solar irrigation systems (as a form of “secondary use” of the solar power) in Uttar Pradesh's rural villages. The pilot was implemented by Oorja Development Solutions, a company based in India. The initiative aimed to reduce household milling costs, improve food quality, and bring value-added services closer to communities. The quantitative study consisted of allocating villages to treatment groups (with mills) and control groups (without mills). The effects of the mills were assessed with surveys of over 500 households over a 10-month period. This was complemented by qualitative interviews with women users in villages where mills had been operational for over a year.

The analysis revealed that milling is a viable secondary use of solar irrigation power, delivering benefits to treatment households. Location played a decisive role in adoption and sustained use. Mills located within or close to the village centre saw higher and more consistent usage, while those sited on farmland at the outskirts faced reduced usage, especially during the rainy season. On average, Oorja primary mill users reported travelling only ~0.5 km to access the mill, compared to ~1.1 km for users of diesel or other electric mills, indicating that proximity improves access and convenience.

While the mills were popular, there were also limitations that restricted usage. Midline survey data showed the majority of treatment households (54%) were using Oorja mills—a strong result. Use consolidated among satisfied users between the midline and endline surveys (an increase from 19% to 26% of treatment households using the Oorja mill as their primary option), while marginal users dropped off (overall usage among treatment households declined by 4 percentage points from midline to endline). The mixed results suggest differing consumer experiences with the mills.

Operational bottlenecks, such as operator unavailability, delays due to pump prioritization, and concerns about grinding quality, were cited as key barriers, alongside technical challenges like low mill capacity. These findings suggest that while integrated solar models hold promise, **operational discipline and strategic siting** might be critical for sustained adoption. Interviews revealed that households select the mill based on daily needs. As one woman explained, “We go to the solar mill for some things, but for certain grains, we go to the diesel



one.” They noted that grains like wheat, chickpeas, rice, and even spices are well-suited for the solar mill, while some other grains often require the diesel mill.

The study also highlights **shifts in gender roles and household behaviour**. With mills now within reach, women increasingly managed milling activities—tasks that traditionally required men to travel long distances. This has given women greater autonomy in food management, enabling more frequent, smaller-batch milling that reduces spoilage and enhances meal freshness. While the quantitative results did not show significant effects (as women were the primary persons responsible for milling in only 2% of treatment households at both midline and endline), qualitative interviews revealed more nuanced shifts. These differences likely reflect the short duration of the intervention (based on which quantitative data was collected) and the deeply rooted gender norms around milling, which take longer to change than the study’s time frame allowed. Moreover, qualitative interviews captured subtle attitudinal and behavioural shifts, where, in villages with longer mill exposure, women (including elderly women) and children appeared more willing to use the solar mills.

The results also showed cost savings, **dietary diversification, and new cropping decisions**. Oorja users saved about INR 45 per household per month—nearly half the milling cost of diesel/electric users (INR 38 vs. INR 82 per month). Some households also reported starting to process fresh masalas, turmeric, and coriander—ingredients they had avoided earlier due to processing constraints. In some cases, solar mills have supported small-scale value addition and reduced dependency on external markets. These behavioural shifts point toward broader, long-term gains in household agency, nutrition, and resilience.

Drawing from these insights, the report recommends **targeted policy action** to strengthen decentralized renewable energy systems in India, with a focus on maximizing the value of each solar installation. Integrated models—such as Oorja’s approach to combining irrigation with milling—demonstrate how the same solar infrastructure can serve multiple community needs, improving both economic viability and livelihood outcomes. These approaches align closely with national and state-level policies like **PM-KUSUM** and the **Uttar Pradesh Solar Energy Policy 2022**, which are expanding rural solar adoption. Policy-makers could incentivize such dual-use systems and actively support **social enterprises** that develop technical expertise, community trust, and operational sustainability.

Specifically, we recommend

- that future solar irrigation subsidy schemes include other productive uses of solar power based on local circumstances and communities;
- that gender and inclusion are considered when designing subsidy policies, including for both primary and secondary uses of solar power, with programs structured to facilitate uptake by women and under-represented groups and to make maximum use of solar power to reduce energy poverty; and
- establishing collaborative platforms for energy innovators, rural entrepreneurs, and government agencies to share lessons and co-create solutions to accelerate both learning and the scale of secondary use of solar irrigation power.



In addition to recommendations for India, the study has global implications. Globally, around 750 million people lack access to electricity, 80% of whom live in sub-Saharan Africa. SIPs are increasingly common in rural areas, given falling solar photovoltaic prices and the rise of innovative financing and business models. Our study demonstrates the feasibility of secondary use, which could be further developed by governments, technology developers, and businesses to improve the economic viability of SIP systems, boost the financial use case for consumers, and address the energy needs of energy-poor agricultural communities and households. At the same time, effective safeguards, such as ensuring sustainable groundwater extraction and complementarity with grid-based supply, are essential to prevent unintended environmental and system-level risks.



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Acronyms

FPO	farmer producer organization
GDP	gross domestic product
GESI	gender equality and social inclusion
HP	horsepower
IDCOL	Infrastructure Development Company Limited
IDRC	International Development Research Centre
IISD	International Institute for Sustainable Development
IWMI	International Water Management Institute
MNRE	Ministry of New and Renewable Energy
PM-FME	Pradhan Mantri Formalisation of Micro food processing Enterprises Scheme
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan
PRADAN	Professional Assistance for Development Action
SIP	solar irrigation pump
UIPM	Unlocking Inclusive Policy Making



1.0 Introduction

Solar-powered irrigation pumps (SIPs) are widely used globally to increase agricultural yields, boost farmers' incomes, and reduce reliance on diesel- and electricity-powered pumps. As of August 14, 2025, 853,000 solar pumps have been deployed in India with the help of the major government subsidy programs under Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyaan (PM-KUSUM) to encourage uptake (Ministry of New and Renewable Energy [MNRE], n.d.). While this marks significant progress, SIPs still represent a small share of India's roughly 32 million irrigation pumps, most of which continue to be powered by grid electricity or diesel, highlighting the large remaining potential for solarization (Chandra & Brozović, 2024).

The direct benefit of these subsidies tends to be clustered among primarily medium- to large-scale landowners and farmers, with limited trickle-down to smallholders and tenants. In many parts of India, solar pumps are used for irrigation only during certain periods of the year, depending on crop cycles, and remain idle otherwise (Kulshrestha & Pandey, 2023). This seasonal underutilization leads to significant periods where the solar energy generated goes untapped, particularly in regions grappling with energy poverty. Consequently, the surplus power from these idle pumps remains an underexploited source of clean and affordable energy that could benefit poor smallholders, women, youth, and other disadvantaged groups.

In August 2023, the International Institute for Sustainable Development (IISD) partnered with Oorja Development Solutions to assess the impact of incorporating a secondary use for the unutilized energy potential of solar irrigation pumps by setting up solar mills in the districts of Bahraich, Barabanki, and Hardoi in Uttar Pradesh. The collaboration aims to test innovative community-level models that make fuller use of existing SIP infrastructure and inform future program and policy design.

Specifically, the study seeks to

- identify the extent to which SIPs can also support “secondary uses” of the same energy source, thereby increasing value for a more diverse range of beneficiaries while also creating an incentive to use water sustainably and
- establish and road-test methods to pilot secondary uses of solar pumps in ways that maximize benefits for low-income households and disadvantaged groups, including women and youth.

Based on earlier studies, secondary-use models of SIPs have the potential to improve gender equality and social inclusion in energy use through several mechanisms. For instance, in Kenya, solar-powered community mills replaced manual grinding, saving women hours each day and enabling them to use that time for income-earning activities (Alaofè et al., 2016). In Mali, households using solar irrigation systems gained access to water for domestic chores and livestock, and farmers were able to grow vegetables in the dry season, thereby increasing household income and food security (Birhanu et al., 2023).

Secondary uses can be incorporated into business and subsidy models based on the needs and priorities of women and marginalized groups, so that additional tailored productive



uses can be supported by the SIP. Secondary use can also improve the cost viability of SIPs. While secondary uses could add additional costs to the overall SIP infrastructure (in terms of equipment purchase or wiring), using excess solar power from the SIP instead of diesel would result in net savings. If the SIP is operated as a pay-per-use service, then the project could prove more commercially viable for the provider and cheaper for the consumer if a secondary-use appliance (solar mill) is added. Users can also expand their productive use of the energy, thereby generating more income and making the SIP itself more cost-effective from the user's perspective.

While earlier studies have examined the technical feasibility of secondary uses of solar irrigation pumps, there is limited empirical evidence on their socio-economic and gender impacts. This study seeks to address that gap through a systematic mixed-methods assessment of integrated solar irrigation and milling models in rural Uttar Pradesh.

The project is part of a broader applied research study led by IISD in partnership with partners from the Global South and academic research institutions and funded by the International Development Research Centre (IDRC), Canada. The Unlocking Inclusive Policy Making (UIPM) for Clean Energy Transition project aims to create knowledge that will change the design of energy policy to achieve more inclusive and sustainable outcomes. The research addresses three key areas for energy transition where knowledge gaps are holding back inclusive change, particularly for women and youth, but also marginalized groups:

1. incubating non-fossil clean cooking solutions,
2. maximizing the social benefits of solar irrigation, and
3. ensuring an inclusive approach to just transition for coal mining communities.

The report is structured as follows. Chapter 2 presents the context and a review of existing literature on solar irrigation and secondary-use models in India and beyond, identifying gaps this study seeks to address. Chapter 3 outlines the methodology, including the research design, sampling framework, and gender equality and social inclusion (GESI) approach. Chapter 4 details the quantitative and qualitative findings from the pilot villages, and Chapter 5 discusses the key insights, behavioural patterns, and gender dynamics emerging from the analysis. Finally, Chapter 6 provides policy recommendations to guide future solar irrigation and secondary-use interventions in India and other developing contexts.



2.0 Context and Literature Review

2.1 Solar Irrigation in India

Agriculture is the cornerstone of the Indian economy, employing 46% of the workforce and contributing about 16% to the country's GDP (Government of India, 2025). It plays a vital role in ensuring food security and holds deep historical and cultural importance for the nation. However, the sector is heavily reliant on water for crop cultivation, particularly for rice, maize, and sugarcane, making irrigation indispensable for reducing vulnerability to uneven monsoons. As of 2023, 56% of the gross cultivated land in India had access to irrigation facilities, up from 47% in 2011/2012, and irrigation pumps are one of the major tools used for irrigation to improve agricultural productivity (Department of Agriculture, Cooperation & Farmers Welfare, 2024). However, the majority of these pumps are powered either by diesel or grid-dependent electricity (Government of India, 2025).

The use of diesel pumps creates dependence on price-volatile fuel and global supply chains while also contributing to heavy carbon emissions. Grid-connected electric pumps currently face challenges due to weak grid connectivity, a larger environmental footprint due to the grid being dominated by fossil fuels, groundwater depletion linked to electricity subsidies, and the unavailability of water in the daytime (most of the state electricity boards have set schedules for irrigation electricity supply, which often include night schedules). These issues underscore the need for alternative irrigation solutions that are environmentally sustainable, efficient, and provide a reliable daytime water supply.

Solar-powered micro irrigation systems are considered a suitable alternative that addresses some of these challenges and are therefore being supported by government initiatives such as the **PM-KUSUM** scheme. PM-KUSUM was launched in 2019 and currently has two main targets for solar irrigation pumps: (i) the installation of 1.4 million standalone off-grid solar water pumps and (ii) solarization of 3.5 million existing grid-connected agriculture pumps by March 31, 2026 (MNRE, 2024b). Among these targets, the off-grid component has seen the most substantial progress, currently achieving around 60% of its target, reflecting strong farmer demand and the relative ease of off-grid deployment (Dutta, 2025). This higher uptake also presents an important opportunity to promote secondary productive uses of solar irrigation pumps, especially in regions where grid integration remains limited.

A study by the Center for Science and Environment (2024) nonetheless cautions that the 2026 targets could still be missed, partly due to the centralized implementation model, highlighting the need for targeted recalibrations to accelerate both the scale-up and integration with complementary rural applications.

Although solar irrigation pumps are beneficial in various aspects, as discussed above, they come with various challenges, which are reflected in their slower uptake. Land fragmentation and small land holdings are a primary concern. According to the 2019 National Sample Survey Office survey, approximately 89% of agricultural households own less than 2 ha of land and around 70% owned less than 1 ha (Forum of Enterprises for Equitable Development, 2024). As a result, many farmers, particularly in the Indo-Gangetic plains, rely on irrigation



service markets, wherein one pump owner sells the irrigation services of one pump to multiple smallholder farmers.

Shah (2024) argues that due to highly fragmented land holdings, farmers in the Ganga basin typically use a borewell and pump only for their largest and best land parcels and buy irrigation for the rest from others. Moreover, this region has a higher number of seasonal farmers and tenants, and they invariably buy irrigation from these informal markets. Solar pump sets with larger capacities can find particular use in these situations.

The PM-KUSUM scheme currently provides financial assistance for pump sets for up to 7.5 horsepower (HP), which can irrigate around 10–12 ha of land. These large pump sets can generate cash revenues for pump owners while providing irrigation services to multiple smallholder farmers, eliminating the need for them to invest in pumps. However, such large solar pump sets result in excess and unutilized electricity generation, a problem that is particularly high during off-seasons. A report by the Sustain Plus Energy Foundation suggests that an additional 3,500 kWh of energy can be harnessed from a 5-HP pump, which typically runs only 900–1,000 hours annually, assuming optimal system parameters¹ (Sustain Plus Energy Foundation, 2021, p. 3). Although these figures cannot be generalized across contexts, they provide an estimate of the excess potential of solar pump sets.

To make use of the excess energy generated by the solar irrigation pumps in off-season periods, various activities could be undertaken. First, the excess energy could be directly supplied back to the grid. In such a scenario, the grid (via the electricity board) would procure the excess electricity from the farmer/owner of the SIP. However, this would require sufficient physical infrastructure to transmit the energy back to the grid. This option could also help the states achieve their respective renewable energy targets. Also, in regions where grid export is limited due to policy constraints such as net metering caps or the absence of feeder separation, off-grid secondary uses of SIPs become more appealing. These constraints often hinder farmers from selling surplus solar energy back to the grid, making it economically advantageous to utilize the energy locally for additional applications like milling or cooling.

Apart from this obvious solution, there are other activities that could utilize excess energy for secondary purposes. Various secondary-use activities have been piloted in India and abroad that serve as examples of optimum energy use. For example, in Bangladesh, some solar irrigation operators have started to utilize the excess energy for purposes such as rice husking, flour milling, oil milling, cold storage, etc. (Mitra et al., 2021).

In India, the PM-KUSUM guidelines provide an optional provision for the installation of Universal Solar Pump Controllers with standalone solar pumps under Component B. While not mandatory, this provision allows farmers to utilize their solar-powered irrigation systems for additional applications, such as operating chaff cutters, floor mills, cold storage units, and dryers, during periods when the pumps are not in use for irrigation (MNRE, 2024a).

¹ 5 HP \approx $5 \times 0.746 = 3.73$ kW. Operating 900–1,000 hours/year gives: $3.73 \text{ kW} \times 900 \text{ h} = 3,357 \text{ kWh}$ up to $3.73 \text{ kW} \times 1,000 \text{ h} = 3,730 \text{ kWh}$. This assumes inverter/system efficiency at approximately 90% (so net usable \approx 3,020–3,350 kWh) and that the pump is run at roughly the nominal load during those hours.



Apart from serving the purpose of energy utilization, these activities can be the cornerstone of entrepreneurial ambitions based on local contexts and advance rural economic and social development. Moreover, these secondary activities can also help mitigate the environmental impacts of allied agricultural services, such as milling, husking, refrigerating, etc. For example, milling in India is traditionally undertaken using diesel generators and therefore can be replaced with the electricity generated from the solar pump. However, these secondary activities require an adequate assessment of household and market needs to be economically feasible and socially transformative.

Three such secondary-use models were experimented with on the ground to not only understand the context in which they operate but also outline the impact they have. These are reviewed and compared in the next section. The data for this review was collected from resources on the web and internal contacts with the organization members (Sustain Plus and International Water Management Institute [IWMI], respectively) and not the entrepreneurs or operators.

2.2 Secondary Use Models and Differences

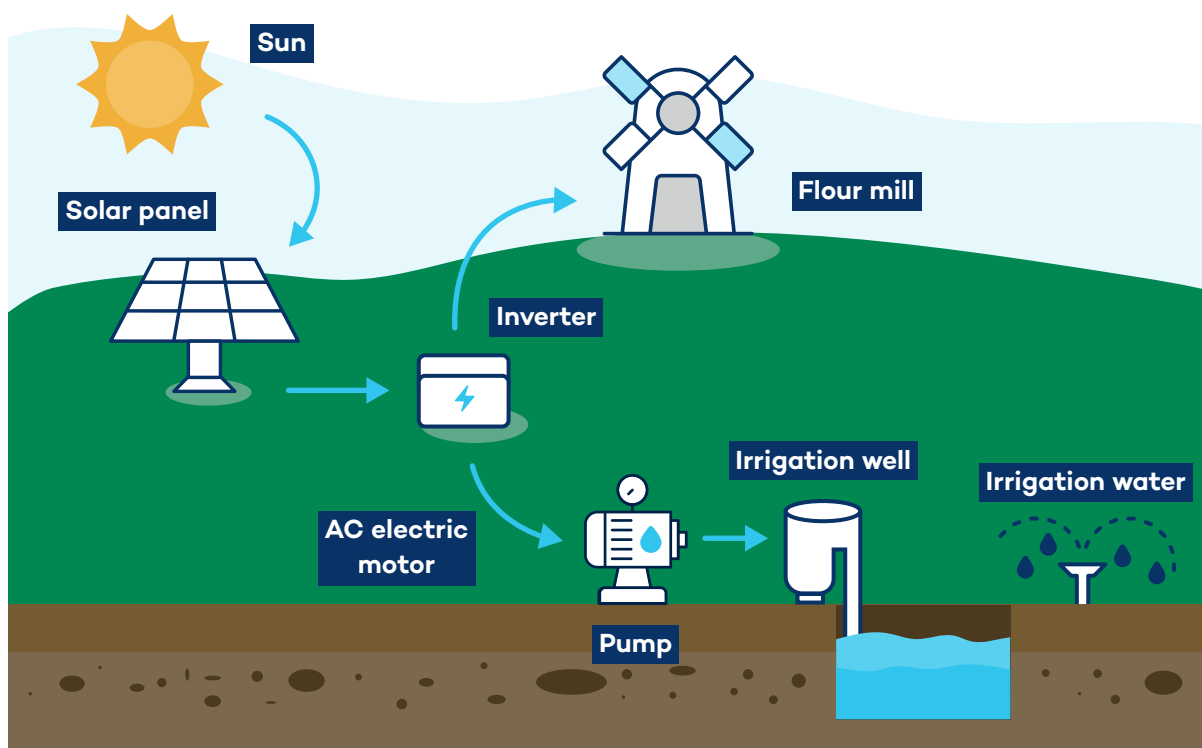
Oorja Development Solutions is a Farming-as-a-Service company in India that provides solar irrigation and milling services to smallholder farmers in Uttar Pradesh on a pay-per-use basis. The company owns, operates, and manages all the assets (primary irrigation and secondary mills) on its own, while pump operators/mill operators are paid for operating individual systems. The company raises blended capital to finance these projects, which typically includes both grants and equity investments.

As of August 31, there were 17 mills operated by Oorja in Eastern Uttar Pradesh villages. The primary motivations for operating these mills are to use the unused energy generated for solar pumps, reduce laborious efforts, and mitigate the environmental impact of milling. These mills operate using electricity when the pump is not in use for irrigation. Figure 1 shows the technical arrangement in the form of a schematic diagram.

Since these mills are based within the village, they reduce travel time to the mill for village members. With the scale and operations of the solar mill being smaller than those of the diesel mill, they can also potentially reduce the time taken in the milling process. This time saved can potentially be spent on managing the other social and economic responsibilities of household members, while also potentially impacting the distribution of tasks within the household. For instance, the vicinity of the mill could allow women who are particularly confined to domestic duties otherwise to take up this task.



Figure 1. Schematic diagram showing how solar panels power both flour mills and pumps



Source: Authors.

The Sustain Plus Energy Foundation, in partnership with Collectives for Integrated Livelihood Initiatives and Professional Assistance for Development Action (PRADAN), provided grants and technical capacity-building advisors to individual entrepreneurs to utilize the excess energy from the solar energy pumps (Sustain Plus Energy Foundation, 2024). Secondary-use activities in the form of paddy de-husking and flour milling machines, etc., are purchased by individual farmers (agri-entrepreneurs) using these grants. These machines are purchased with consideration for local requirements and contexts.

For instance, in Jharkhand, paddy is a major crop that requires de-husking to obtain rice grains. For this purpose, machines are available at specific shops located within the market or at the block level. These machines are typically run using diesel generators. The projects explored in this study were undertaken to minimize the use of fossil energy, utilize the excess energy of SIPs, and enable agri-entrepreneurship. In terms of the impacts, these initiatives led to reduced travel time and the drudgery associated with carrying paddy to the de-husking shops.

The Sustain Plus Energy Foundation and PRADAN are also implementing a group-based cluster model, where three solar pumps would trade the energy among themselves, and the total excess energy would be transmitted to a common production hub using a three-phase power transmission line. This production hub consists of a flour milling machine, an oil expeller, and a rice-hulling machine, all of which would operate on the energy drawn from the pumps. The owners/entrepreneurs of this production hub would pay a fixed fee for the energy being utilized by the water group. This approach can potentially have advantages—for



example, many allied activities could be undertaken in one place at a distance accessible to three villages. However, the challenges in operating such a venture are yet to be assessed.

IWMI analyzed the SIP program facilitated and financed by Infrastructure Development Company Limited (IDCOL), a government-owned financial institution in Bangladesh (Aariz, 2024). IDCOL provides a grant of 50% of the total solar pump set cost; the other 50% is financed using a loan (this includes a 15% down payment). The solar irrigation pumps in this case are larger (on average around 21 HP) with a command area of around 16 ha. These solar assets are owned by non-governmental organizations and SIP companies that provide irrigation services to individual farmers. Since these are large pump sets (with larger panel sizes), they also generate large amounts of surplus energy, given the pump is in use only around 30% of the time in a year. To utilize this excess energy, some SIP companies started to use secondary agricultural machinery to earn extra revenue.

The primary motivation from the SIP companies is to earn additional revenue to be able to pay off loan instalments. The secondary activities included flour milling, rice husking, oil expelling, cold storage, poultry farms, etc. Poultry farming below the solar panels was an interesting use case where both electricity and water demands were met by the pump set; in addition, the solar panel roof protected the birds from heat, which would have required additional investments otherwise.

A conversation with an IWMI official, however, indicated that such secondary businesses were adopted by only around 10–15 SIP projects out of a total of around 1,500. The focus of IDCOL and the Bangladeshi government is now to facilitate the transmission and sale of excess electricity back to the grid. However, the sale of electricity is permitted only one way under current regulations, meaning the irrigation electricity demand could only be met from on-site solar generation and not from the grid.

Similarly, in India, regulatory constraints, such as feeder separation initiatives and agricultural net metering limits in several states, can restrict the ability of farmers to export excess solar energy back to the grid (Uttar Pradesh Solar Energy Policy, 2022). These limitations make off-grid secondary uses of SIPs, such as operating mills or cold storage units, more practical and economically viable. By utilizing solar energy for multiple applications beyond irrigation, farmers can maximize the benefits of their solar investments, especially in regions where grid connectivity is unreliable or export options are constrained.

**Table 1.** Comparing three different excess energy utilization models

Aspect	Oorja	Sustain Plus and Collectives for Integrated Livelihood Initiatives	IWMI-IDCOL
Location	Eastern Uttar Pradesh, India	Jharkhand, India	Western Bangladesh
Ownership	Company-owned assets	Owned by individual entrepreneurs	Owned by SIP companies
Financing	Blended capital (equity and grants)	Sustain Plus grant: 80% Farmers' share: 20% For secondary use: 10% additional grant from external funder	IDCOL Grant: 50% Loan: 35% SIP companies: 15% downpayment For the secondary-use assets, SIP companies need to pay and procure
Organizational functions	Oorja: Owns, operates, and manages the assets. Farmers: Employed as operators	Implementing organizations - training and capacity building, business planning	IWMI: Analysis of groundwater and pump utilization IDCOL: Financing SIP company: Operating the pump and secondary use
Number of secondary-use systems	17	25 (18 owned and operated by males, six by females), one owned by Gram Sabha	10–15
Secondary-use activities	Flour milling	Paddy de-husking ² and milling (flour)	Poultry farming, flour milling, oil expellers, and paddy de-husking
Motivation	To reduce the laborious effort and environmental impact of milling; secondary use of solar energy	To optimize the use of solar pumps and develop agri-entrepreneurs	To generate additional revenue from the pumps; the focus has now shifted to grid integration due to lower uptake
Socio-economic benefits	1. Potential time savings in the milling procedure and redistribution of domestic duties within households 2. Entrepreneurial skill development 3. Additional income and a new source of income	1. Time savings and reductions in drudgery linked to paddy de-husking. 2. Entrepreneurial skill development 3. Additional income and a new source of income 4. Inclusive ownership and gender participation	1. Potentially creating additional employment in the village 2. Providing a one-stop centre for the agricultural needs of farmers in the village

Source: Authors' compilation based on literature review and interviews with respective organizations.

² Husking and de-husking are essentially the same process: removing the outer husk or hull from a grain or seed. De-husking is a more formal term that is used in grain or rice processing to describe the mechanical removal of husks from the harvested crop.



While these secondary-use cases provide an opportunity to realize both socio-economic empowerment and environmental benefits at the rural level, existing evidence has largely remained descriptive. No study has systematically evaluated their actual social, economic, and gender impacts, or the conditions under which such models can succeed and scale. In fact, all the assessments of secondary use of solar pumps have focused on technical feasibility or anecdotal benefits rather than quantifying outcomes for different user groups or understanding behavioural dynamics. This study seeks to fill that gap by conducting one of the first mixed-methods evaluations of a live secondary-use model in India that integrates solar-powered milling with irrigation pumps to assess not only cost savings and utilization patterns but also broader effects on gender roles, inclusion, and community welfare.



3.0 Methodology

The study adopted a mixed-method approach drawing on baseline, midline, and endline surveys of over 500 households across treatment sites (villages with mills) and control sites (without mills),³ alongside qualitative interviews with women users in villages where mills had been operational for over a year. These provided insights into longer-term impacts compared to the approximately 10-month operational window in the quantitative survey sites.

3.1 Gender Equality and Social Inclusion

This study assessed the impact on GESI-related components within the villages. Each aspect of the study was thoroughly examined to identify which elements of GESI are being addressed and to ensure inclusivity across all activities through necessary interventions. Specifically, it examined women's involvement in decision making; enhanced mobility and access to services; saved time through easier access to services; and improved affordability and economic accessibility for marginalized groups.

Oorja conducted baseline, midline, and endline surveys of 50 households in each of the 10 villages with the goal of understanding the current socio-economic conditions of the communities and their milling practices. Gender and inclusion were a cross-cutting factor for Oorja across all its operations. Over 90% of Oorja's customers are from historically discriminated-against communities, mainly Scheduled Castes and Other Backward Classes, and 100% are classified as bottom-of-the-pyramid farmers. By intentionally targeting these populations, Oorja ensures that its economic and productivity benefits reach those who have traditionally been excluded from access to capital. Moreover, Oorja addresses systemic gender inequalities by improving women's access to agricultural resources and empowering them with greater decision-making power.

Once the respondent gave their consent, the enumerator continued with the survey questions and terminated when the respondent declined to participate in the survey or left midway (see Appendix A for details on consent and research ethics).

3.2 Research Design

This study employed a **matched-pair cluster randomized design** at the village level to evaluate the effects of introducing solar-powered grain milling services as a secondary use of Oorja's solar irrigation systems. All study villages had previously been selected by Oorja for SIP deployment through a standardized site selection process, applying uniform criteria such as groundwater availability, agro-ecological suitability, demographic profile, and agricultural production patterns. This ensured that the sample villages shared similar pre-intervention characteristics relevant to solar technology adoption.

³ Sample size (N) = 527 (Baseline); 494 (Midline); 503 (Endline). Total number of villages = 10 (five each in treatment and control groups).



3.2.1 Village Selection and Pairing Process

A needs assessment was conducted in 19 villages across Bahraich, Barabanki, and Hardoi districts. From these, 10 villages were shortlisted based on community demand for solar milling and their alignment with Oorja’s operational model.⁴ To ensure comparability between treatment and control villages and increase statistical power, matched pairs of villages were formed using **Mahalanobis distance**⁵ based on pre-treatment characteristics. These included household wealth, ownership of agricultural and productive assets, access to infrastructure, and indicators of agricultural activity. Matching was stratified into two categories:

1. **new SIP villages** – Four villages that had recently qualified for SIP installation
2. **existing SIP villages** – Six villages with SIPs already in place

Within each stratum, a greedy matching algorithm paired villages to minimize Mahalanobis distance. Two matched pairs were formed from the new SIP villages and three from the existing SIP villages. Within each pair, one village was randomly assigned—using a uniform random number generator—to receive the solar-powered mill (treatment), while the other served as a control. This yielded **five treatment villages** and **five control villages**, ensuring each control was closely matched to a treatment site across observable baseline characteristics.

3.3 Quantitative

The quantitative part of the study focused on assessing the impact of solar mills using a pair-wise matching methodology. In each of the 10 villages, **50 households** were surveyed at baseline (February 2024), with a small buffer resulting in a total of **527 households** (see Appendix A for details on survey timelines, villages, and the number of households surveyed at each stage). Sampling was stratified to include:

- **15 households** per village that were registered SIP users in the village (mandatory inclusion), which were included in both treatment and control villages (a total of 150 registered SIP users).
- **35 households** selected to ensure diversity by house type (*kachcha* vs. *pucca*), caste group, and proximity to the proposed mill location (near/far) to assess potential spillover effects.

⁴ Community demand and alignment were determined through a structured pre-selection process conducted by Oorja before the baseline survey. The process combined qualitative field assessments and quantitative screening criteria. Community demand was assessed through village-level consultations, focus group discussions, and interviews with farmer collectives, women’s groups, and local operators to gauge interest in milling services, willingness to pay, and existing reliance on diesel or electric mills. Alignment with Oorja’s operational model was evaluated based on technical and logistical feasibility, including solar pump availability, proximity of potential mill sites to existing SIP infrastructure, reliability of solar generation, and the presence of a potential active local operator. These parameters ensured that selected villages were both socially receptive and technically suitable for piloting secondary use interventions.

⁵ Mahalanobis distance is a multivariate distance measurement that accounts for the scale and correlation among covariates. Unlike Euclidean distance, it uses the inverse covariance matrix so that differences on highly correlated or high-variance variables do not dominate. In matching, pairs with the smallest Mahalanobis distance are the most similar on all pre-treatment characteristics jointly.



This methodology aligns with prior research on solar irrigation pumps, such as by Burney et al. (2010). Mills were installed in the five treatment villages in March 2024. The **midline and endline surveys** were conducted five and nine months after the installation (in August and December 2024), respectively. Attrition was minimal, with **494 households** tracked at midline and **503 households** at the endline, maintaining statistical significance in each village. Data was collected using digitized questionnaires via KoBo Toolbox, enabling real-time monitoring and quality checks.

Key variables studied included:

- **food consumption and stocks:** assessed whether improved milling access led to more frequent, smaller-batch processing and better dietary diversity, especially for women and marginalized households.
- **expenditures:** examined if solar mills reduced milling costs for bottom-of-the-pyramid and excluded groups.
- **women's use of time:** explored if proximity to mills reduced women's time burden and increased flexibility.
- **resilience to shocks:** assessed if local, affordable milling strengthened household coping capacity, particularly for vulnerable groups.

3.4 Qualitative

To capture longer-term impacts and GESI dimensions, qualitative surveys were conducted in **10 villages** where solar mills had been operational for **over a year**—a longer exposure period than the quantitative sample. A total of **120 female respondents** (~80% mill users, ~20% non-users) were selected from Oorja's sales and usage records to reflect varied engagement levels. Semi-structured interviews, conducted by an external professional agency, followed a conversational format to build trust and encourage candid responses. All interviews were audio-recorded and transcribed for detailed analysis.

The qualitative component explored changes in household roles, decision making, food processing practices, expenditure patterns, and perceived benefits and barriers, offering a rich context to the quantitative results.

This combined design—grounded in rigorous matching, randomized assignment, and complementary mixed methods—enabled robust estimation of the causal impact of secondary-use solar-powered mills on rural livelihoods, while also uncovering nuanced, longer-term social and economic shifts.



3.5 Integrating Qualitative and Quantitative Evidence

While we prioritize reporting survey results (levels/changes; treatment vs. control), we integrate qualitative mechanisms (wherever relevant data is available) to explain why a pattern occurs and when it is likely to hold.

- **design link:** Quant modules (distance, costs, frequency, decision making) map to predefined qualitative themes (proximity/siting, operator reliability, perceived quality, women's mobility/safety).
- **analysis link:** For each primary outcome, a joint display aligns (a) treatment–control estimates/means with (b) 2–3 salient themes and an illustrative quote from matched villages.
- **interpretation:** While convergent findings between quantitative and qualitative data strengthen inferences, we also document divergences and use them to infer mechanisms/boundary conditions (exposure time, siting, reliability, etc.).
- **weighting:** Quantitative results determine magnitude/direction; qualitative insights inform mechanisms and policy design (pricing, siting, operator key performance indicators, GESI targeting, etc.).

3.6 Data Cleaning and Analysis

The quantitative survey data underwent a rigorous cleaning process in **STATA** to ensure accuracy and consistency across all survey rounds. Data from the baseline, midline, and endline surveys were merged to form a final, panel-style dataset, enabling direct comparison of households over time. Descriptive statistics, including frequency counts, proportions, means, and medians, were generated to compare treatment and control groups across key outcomes, such as milling expenditures, unit milling prices, milling frequency, distance to the nearest mill, and time spent on milling activities.

To estimate program impacts, an **ordinary least squares regression framework** was employed, taking advantage of the random assignment within matched village pairs. The models included fixed effects for village pairs and survey stages, with standard errors clustered at the village level to account for intra-village correlation.

This approach allowed the analysis to isolate the causal effects of introducing solar-powered milling services while controlling for confounding factors, such as infrastructure rollout timing, seasonal variation, and unobserved village characteristics.

For the qualitative component, interview transcripts from 120 women respondents were coded using qualitative analysis software. A **deductive thematic analysis** was applied, guided by the interview questionnaire and informed by emerging themes during the coding process. This approach provided deeper insights into household decision making, gender roles, food consumption patterns, and financial behaviours linked to solar mill adoption. By triangulating quantitative results with qualitative narratives—especially from villages where mills had been operational for over a year—the analysis captured both measurable outcomes and longer-term behavioural shifts.



3.7 Assumptions

The study was designed with the following key assumptions:

1. **sustained community need:** Villages included in the study will maintain a consistent demand for solar mills throughout the study period.
2. **gendered impact of mill location:** Female household members, being the primary users of milling services, will experience significant benefits from the convenient location of solar mills within the village.
3. **operational efficiency:** The solar mills used in the study will remain operationally efficient and capable of meeting the community's daily milling needs.
4. **consistent respondent participation:** The same respondents, or members from the same households, will participate in the baseline, midline, and endline surveys to ensure a statistically significant and consistent dataset across all phases.
5. **female respondent engagement:** Enumerators will successfully engage female household members and encourage their participation, particularly in sections of the survey focused on women's perspectives and experiences.
6. **respondents' responses:** The in-depth interviews conducted three times within a time span of 12 months will not create fatigue and will not significantly affect the integrity of responses.

3.8 Limitations of the Study

1. **exposure and timing:** While we conducted the endline survey ~9 months post-installation, some behavioural/GESI outcomes (such as usage of milling among women) likely need longer.
2. **power and clusters:** Only five matched pairs (villages) limit precision and heterogeneity tests.
3. **generalization:** Sites were pre-screened for Oorja's model, so the results may not extrapolate to different geographies with different milling tariffs and operators.
4. **measurement:** Key outcomes are self-reported. So, we used shorter recall, cross-round checks, and triangulation with qualitative data to validate the self-reported responses (wherever possible).
5. **spillovers:** Access to nearby non-Oorja mills in some controls may attenuate effects.
6. **operational variation:** Siting, operator availability, and milling quality varied by village/season, mediating impacts.



4.0 Results

This section presents an analysis of the results of the quantitative and qualitative surveys to assess the impact of Oorja solar mills installed across 10 villages in Eastern Uttar Pradesh. The key takeaway messages are provided below, followed by detailed results in the subsequent sections.

- **Adoption consolidates among core users.** Overall usage dipped slightly from midline to endline, yet primary adoption strengthened (from approximately 19% to 26%), indicating consolidation among satisfied users, while some secondary users and non-users churned.
- **Barriers are operational and not limited to cost.** The most cited drop-off reasons were operator unavailability, perceived flour quality issues (e.g., coarseness/burning), and delays/queues; siting on village outskirts and poor monsoon access compounded frictions.
- **Accessibility gains are clear.** Oorja primary users travel ~0.5–0.6 km versus ~1.1 km for diesel/electric users.
- **Affordability is context-specific.** Average tariffs at solar mills are generally lower than diesel/electric, but village-level price dispersion and competing providers shape perceived value; price alignment to the local markets matters.
- **Financial flexibility helps the vulnerable.** Short-term credit/deferral at the solar mill is used by a meaningful minority and eases household cash flow.
- **Dietary diversification and processing enable behavioural shifts.** Closer, cheaper milling enables smaller, more frequent batches; reduces storage losses; and encourages processing of diverse products.
- **Gender inclusion shows incremental, place-based gains.** Quantitative decision-making measures remain flat, but qualitative evidence suggests greater mobility/autonomy for women (and elderly/children) where mills are centrally sited and reliably operated.

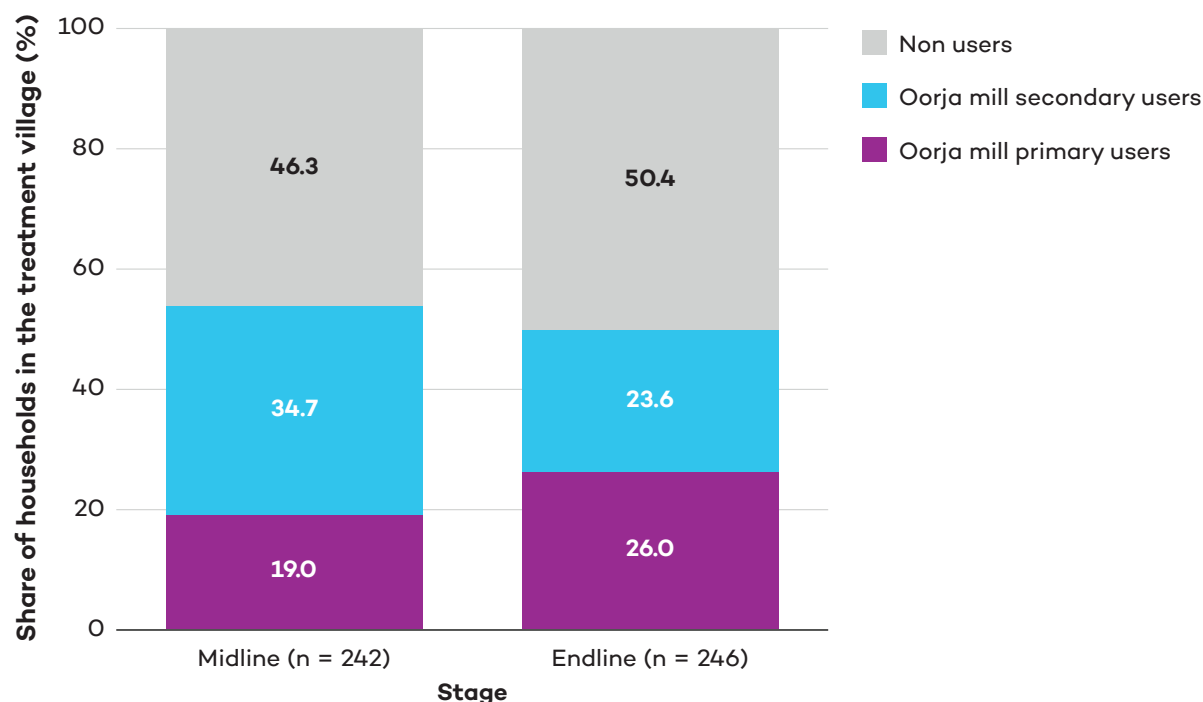
4.1 Adoption Pattern

An analysis of adoption patterns across the treatment group (Figure 2) reveals a noticeable shift in the use of Oorja's solar mills between the midline and endline surveys ($p=0.03$). The proportion of households reporting Oorja as their primary milling source increased from 19% during midline to 26% during the endline survey, indicating a positive trend in primary adoption (Figure 2). A primary mill refers to the milling option that a customer prefers and uses as their first choice.

Secondary usage of the mill declined from 34.7% during the midline to 23.6%, indicating that some users either shifted to primary use or discontinued usage. A secondary mill refers to a backup or alternative option that the customer uses only occasionally, relying on other milling methods, such as diesel, electric, or another solar mill, for their main processing needs.



Figure 2. Household distribution by solar mill usage



Note: Primary users are households that selected Oorja's solar mill as their primary milling option. Secondary users are those who selected the Oorja mill as their second or third choice. Non-users are those who opted for diesel, electric, or a combination of both across their primary, secondary, and tertiary milling preferences.

Source: Authors.

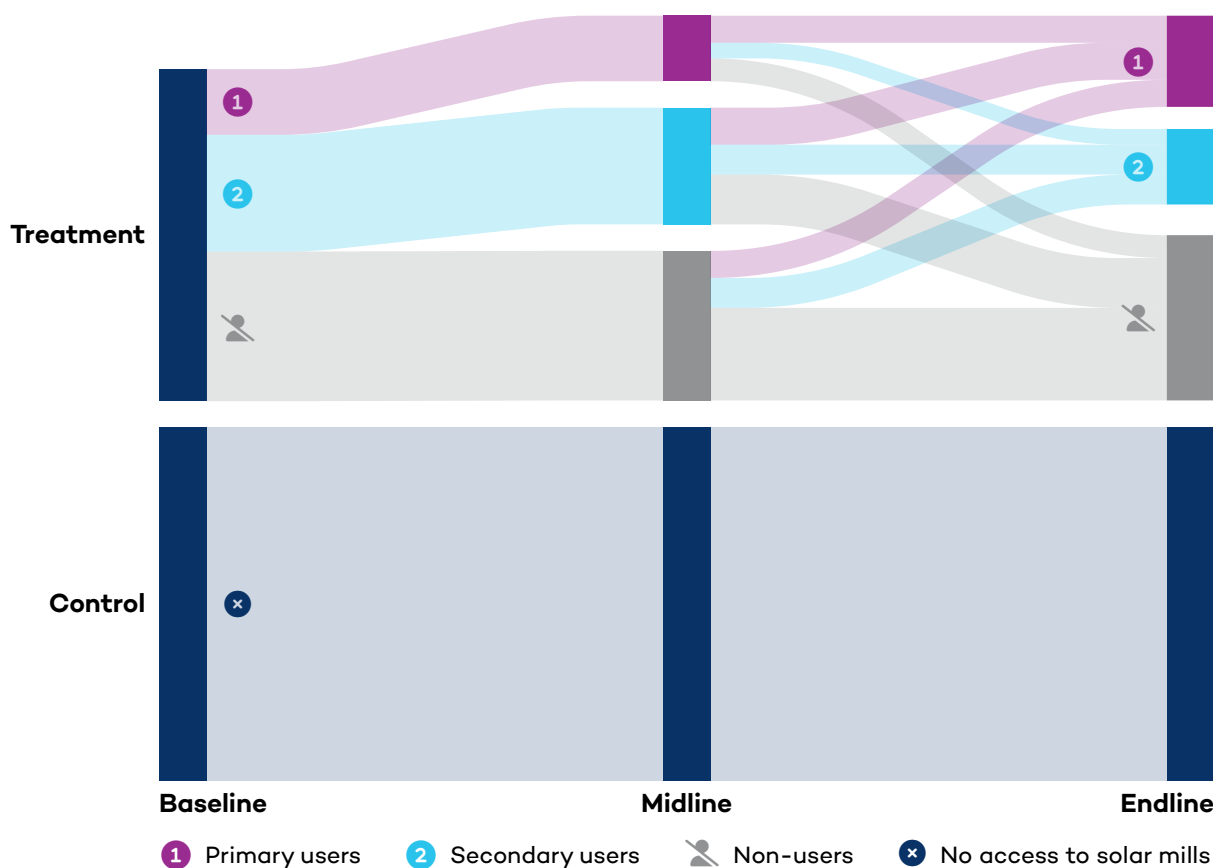
However, it is also important to highlight that the overall proportion of households using the Oorja mills declined by around 4 percentage points from midline to endline. A deeper look at the transition of user categories from midline to endline highlights important shifts in the adoption behaviour toward Oorja's solar mills among treatment households. At midline, 20% (n=46) were primary users, 35% (n=82) were secondary users, and 45% (n=105) were non-users. Tracking these groups into the endline (N=233) reveals the following transition patterns:

- Among the 46 primary users at midline, 41% (n=19) remained primary users at endline, 24% (n=11) became secondary users, and 35% (n=16) discontinued use and became non-users. Reasons for drop-off included operator unavailability, high milling cost, poor grinding quality, low output, and distance to the mill (Figure 5).
- Of the 82 secondary users at midline, 32% (n=26) transitioned to primary users by endline, 26% (n=21) remained secondary users, and 43% (n=35) became non-users. Many of those who discontinued usage cited reasons such as irregular operator presence, poor flour quality (e.g., burnt smell, coarseness), long wait times, high costs, and limited trust in service reliability. Some also reported switching to home-based milling or faced physical access issues like poor road connectivity.
- Among the 105 non-users at midline, 16% (n=17) adopted Oorja as their primary milling source by endline, 20% (n=21) used it as a secondary option, and the majority (62%, n=65) remained non-users.



Figure 3 illustrates the transitions in user categories between midline and endline, highlighting the shifting adoption patterns of Oorja’s solar mills over time.⁶

Figure 3. Transitions in user categories between midline and endline (N=233)



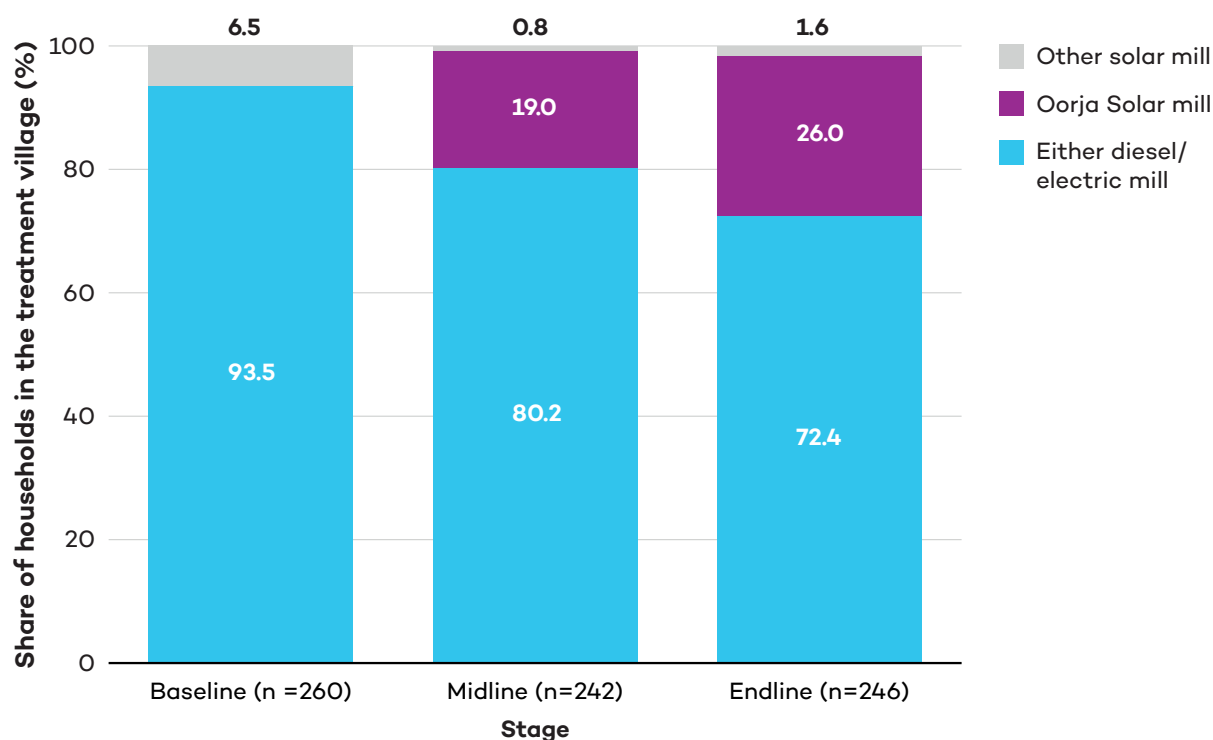
Source: Authors.

A deeper analysis of primary milling usage across the treatment group (Figure 4) reveals a gradual shift in household preferences over time in the treatment villages. At baseline, 94% of households relied on either diesel or electric mills. By midline, following the introduction of Oorja solar mills, the milling landscape began to shift. Usage of diesel or electric mills dropped to 80%, and other solar mills to 0.8%. At the same time, in the endline, the share of diesel/ electric mill usage declined further to 72%, and other solar mill usage slightly rose to 2%.

⁶ The sample sizes for the full treatment group were different across different survey stages (N=260 [baseline], N=242 [midline], and N=246 [endline]) due to routine attrition (temporary unavailability, migration) and data cleaning (logic checks/outlier removal). However, to maintain the exact comparability across rounds in Figure 3 (Sankey diagram), we only considered 233 treatment respondents who were consistently surveyed across the baseline, midline, and endline rounds (balanced panel).



Figure 4. Distribution of primary mill type in the treatment villages: Baseline, midline, and endline



Source: Authors.

While the above analysis (including Figures 2, 3, and 4) highlights household-level transitions in adoption behaviour, Appendix B provides a village-level perspective, showing how these shifts played out across different treatment villages between midline and endline.

4.2 Reasons for Not Using the Solar Mills

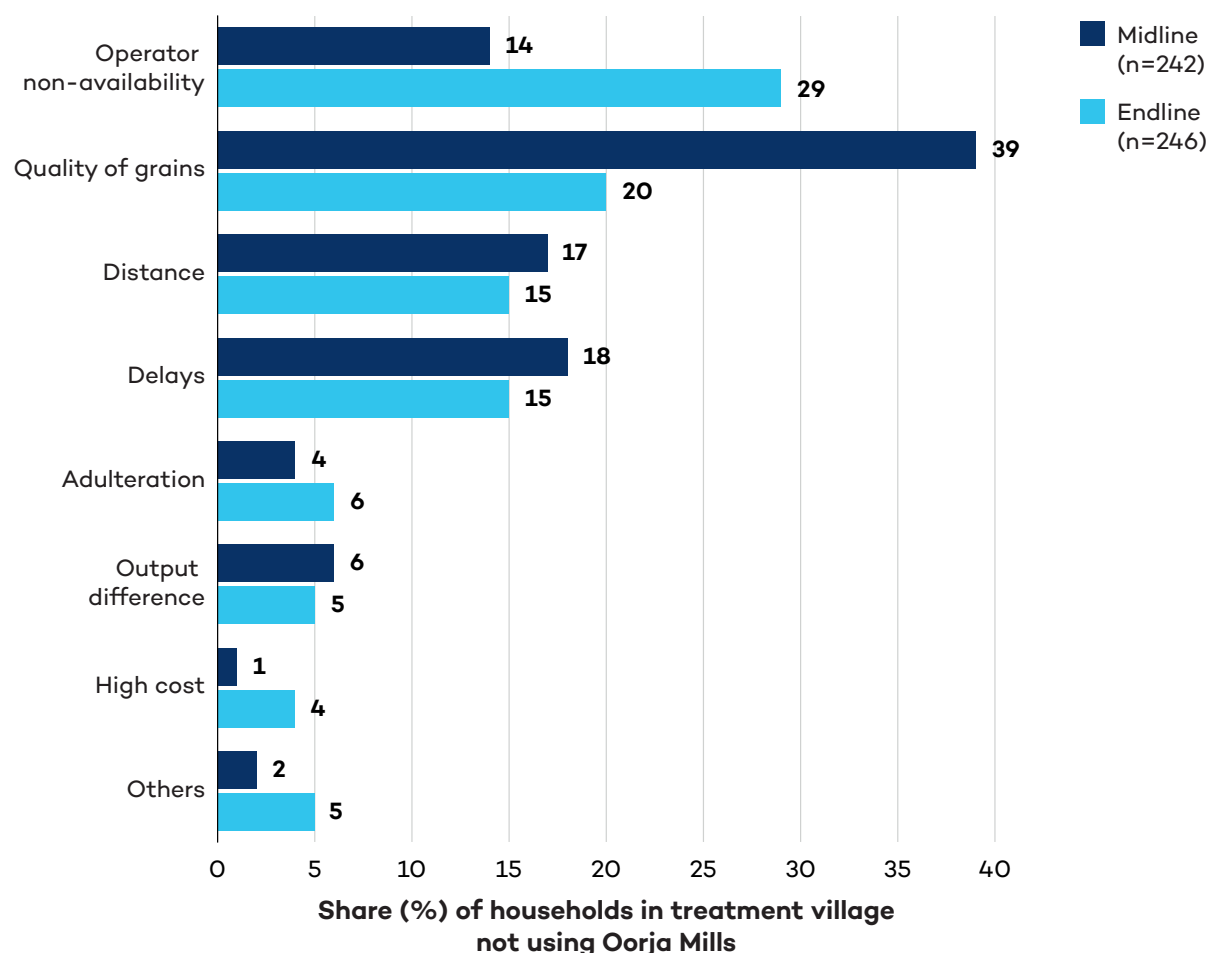
Figure 5 highlights the primary reasons cited by households in treatment villages for not using Oorja’s solar mills, based on midline and endline data. At both stages, the most prominent barrier was the quality of grain, cited by 39% of households at midline and 20% at endline. Other persistent challenges included the unavailability of operators (14% midline and 29% at endline) and delays in service (18% midline and 14% at endline), both of which remained significant deterrents. While distance (17% midline and 14% at endline) and cost (1% midline and 4% at endline) were also cited, these appeared to be relatively less concerning compared to service-related issues. Notably, concerns around adulteration and other unspecified reasons remained consistent, indicating ongoing apprehensions that may require further qualitative exploration. Overall, the data suggests that improving operational reliability and grinding quality could enhance adoption and trust in Oorja’s solar mills.

An analysis of the “other” responses further revealed a few recurring themes. A lack of information given to households was a barrier—several reported being unaware of the solar mill’s existence or its location. Accessibility challenges, particularly for women, also emerged strongly. Phrases like “*the road is not proper*” highlighted the physical difficulties faced in



reaching the mill. In a few cases, respondents mentioned that they already had a home-based flour mill, reducing the need to use Oorja's services.

Figure 5. The distribution of major reasons for not using the solar mills (treatment households only; multiple responses allowed)



Source: Authors.

These findings are echoed in the qualitative interviews, where users shared both positive feedback and areas of concern. Several respondents appreciated the grinding quality at Oorja's solar mill. One user noted: *"The quality is good. It is smooth. The grind quality is good,"* while another mentioned: *"The flour from the electric mill was coarse, but here at the solar-powered mill, it is finely ground."* However, similar to the survey responses, issues like flour burning were also raised: *"The problem is that they burn the atta,"* one user mentioned.

Concerns around reliability and accessibility were reiterated in qualitative narratives as well. One user remarked, *"If the solar mill does not operate, I need to go to the diesel mill,"* while another explained the operational challenges tied to weather, *"If there is no sunlight, the atta [wheat] will not be grinded. The sunlight on the panel helps manage this."* Cost was another recurring theme, particularly in Gandhaura, where a respondent suggested, *"If the cost is reduced, it would be very good."* These qualitative insights reinforce the patterns observed in the quantitative data



and highlight the importance of addressing operational gaps, enhancing service reliability, and improving user awareness and accessibility to increase the sustained adoption of solar milling solutions.

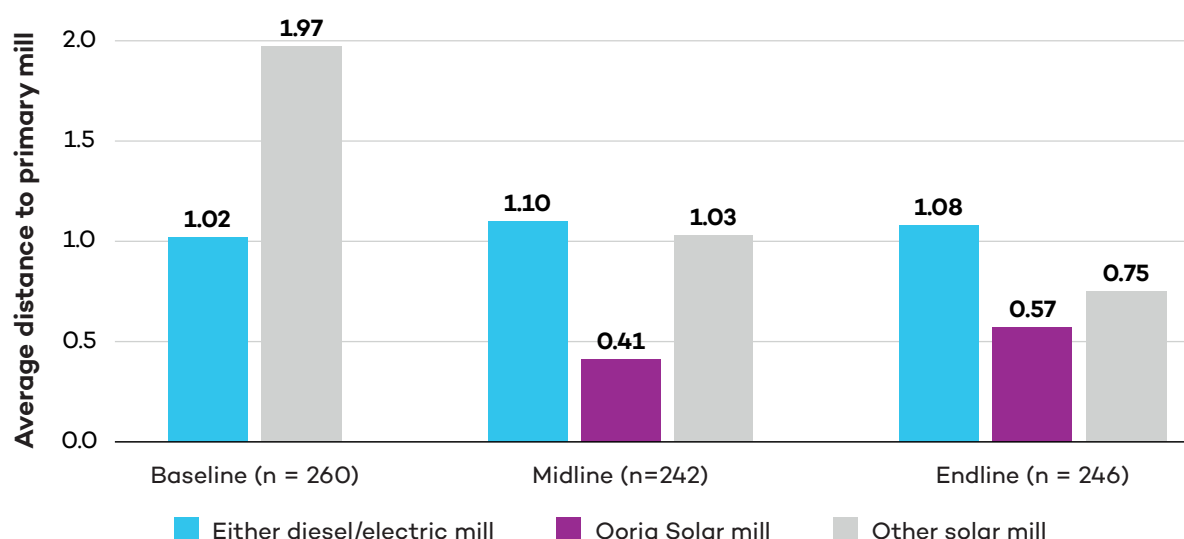
These findings point to clear action areas for improving solar mill adoption. Key performance indicators could include service uptime and operator availability, consistency in flour quality, speed of service, and user awareness levels. Addressing these concerns through regular monitoring and community feedback loops can strengthen reliability and user trust in Oorja's milling services.

4.3 Benefits of Solar Mills

4.3.1 Distance Travelled

Analysis of the average distance to the primary mill by the type of primary mill found that households using Oorja solar mills had a clear advantage. At midline, those who selected Oorja as their primary mill reported travelling only 0.41 km on average, which is at least ~0.6 km less than primary users of other mills (who travelled an average distance of more than 1 km in the midline) ($p < 0.001$ when comparing Oorja mill to any other type of mill). This pattern persisted at the endline, with Oorja primary users reporting a distance of 0.57 km, compared to 1.08 km for diesel or electric users and 0.75 km for other solar mill users ($p < 0.001$). These findings suggest that Oorja solar mills were generally located closer to households, improving physical access to milling services. Figure 6 illustrates these differences in average distance across user groups.

Figure 6. Average distance to the mills (in km) reported by the user group



Source: Authors.

The qualitative data also underscores the transformative impact of improved accessibility to Oorja's solar mills—particularly for women, who are often the primary users. With the



mill located closer to their homes, they no longer need to rely on others for transportation or dedicate an entire day solely to milling. One woman from Sarvantara shared that *“The solar mill is closer to our home,”* while another noted, *“Since the mill is in our village, we can get our grains milled quickly.”* This convenience saved time and effort, allowing women to manage household tasks more flexibly: *“Now, if I hear the sound of the mill, I leave whatever job I am doing and go to the mill for wheat grinding.”*

At the same time, accessibility varies within villages. Some households, particularly on the outskirts, still faced challenges: *“It is far from here. There’s no one to take it till there to get the grinding done.”* Others said, *“It is far from our house, so we don’t always go there. If we find a mill nearby, we go there instead.”* Long queues and waiting times are also reported, with one user noting, *“Sometimes the queue is too long, and we have to wait before our turn comes. If we are in a hurry, it is difficult.”*

The reduced need for long-distance travel has saved time, effort, and transport costs for many households. Previously, users often relied on others or spent money travelling to diesel mills: *“The diesel mill is far, and if we take the vehicle, we have to spend on fuel.”* Overall, the findings suggest that proximity, operational reliability, and ease of access are critical for sustained adoption of solar milling services. These findings point to clear operational levers: adopt central siting criteria, post and adhere to scheduled operator hours (particularly during non-irrigation seasons), and manage queues through tokens to maximize accessibility and sustain adoption, especially for women.

4.3.2 Mobility Patterns

Given the varying distances to mills, it was important to examine how this influenced mobility patterns, particularly the use of non-motorized transport. It was expected that shorter distances would encourage walking or cycling, while longer distances might discourage walking.

Across all user groups, non-motorized transport remained the dominant mode of travel to access milling services. Among Oorja’s primary and secondary users in particular, the availability of nearby solar mills made walking or cycling both feasible and preferred. Among Oorja’s primary mill users at endline, 47% walked or cycled to the mill, while 11% relied solely on motorized transport. Secondary mill users reported even higher reliance on non-motorized travel, with 74% walking or cycling. By comparison, 65% of non-users travelled using non-motorized modes. This finding highlights an indirect environmental benefit of solar mills.

By opting to walk or cycle to the mills, users significantly reduced their reliance on motorized vehicles, leading to a reduction in carbon emissions from transportation. This shift toward more sustainable modes of commuting not only contributes to lowering the overall environmental impact but also reinforces the broader sustainability goals of solar-powered solutions, making them an even more valuable resource for rural communities.



4.3.4 Milling Quantity and Expenditure

A comparative analysis of the average quantity of wheat milled and the corresponding rates across primary mill types reveals that Oorja mill users (Figures 7 and 8) continue to benefit from more cost-effective milling than those using conventional or other solar mills.

Wheat was chosen for this analysis as it was the most commonly milled item across all households, making it a representative indicator for comparing milling trends and expenditures.

At midline, households using Oorja solar mills as their primary mill milled an average of 21.5 kg of wheat per household at a lower average rate of INR 1.8 per kg, amounting to an approximate expenditure of INR 37.6 per month. For consistency, these figures were calculated only on the primary milling option for wheat, which captures households' main milling behaviour and avoids distortion from smaller or occasional uses of other mills or crops. In contrast, those relying on diesel or electric mills milled 35.2 kg per household at INR 2.3 per kg, resulting in a much higher average cost of INR 82.4 per month. Users of other solar mills also experienced a relative cost advantage, milling 19.3 kg per household at INR 1.5 per kg, leading to an expenditure of INR 28.99 per month.

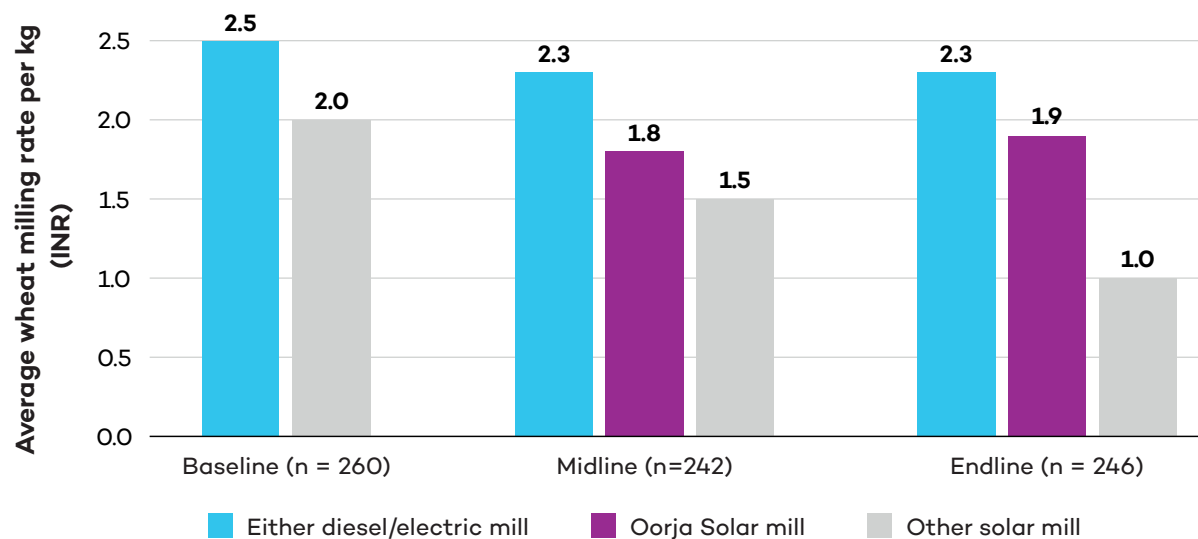
By the endline, although the quantity of wheat milled decreased for most groups, the cost advantage of Oorja users remained. Oorja primary mill users milled 25.7 kg at INR 1.9 per kg, spending about INR 49.78. Meanwhile, users of diesel/electric mills milled 30.43 kg at INR 2.33 per kg, incurring a higher cost of INR 70.90. Households using other solar mills milled 24 kg (average per household) at a significantly lower rate of INR 1 per kg, resulting in the lowest expenditure of INR 24.⁷

Lower wheat volumes at Oorja mills likely reflect behaviour and capacity. With the mill nearby and cheaper, households mill smaller, more frequent batches. As one user said: *“Before the solar mill, I would grind 20–30 kg at once; now I grind as needed.”* Seasons and weather also shape batch size: *“If there is good sunlight, I grind more; if not, less.”* On the supply side, machine capacity, limited operating hours, queues, and early quality/trust issues can hold down totals; some households also shifted part of milling to spices/maize.

⁷ Quantity and price are calculated using the average wheat milling rate and quantity for the primary milling and crop choice only. This reflects households' main milling behaviour, avoids dilution from secondary options, and ensures consistency across the sample, as milling quantities and costs may vary widely across different choices, sticking to the primary option maintains uniformity and relevance in comparison metrics. For milling quantities, the midline data covers a 6-month recall period, while the endline data covers 5 months. To allow valid comparison between these two periods, quantities have been normalized to average per month.

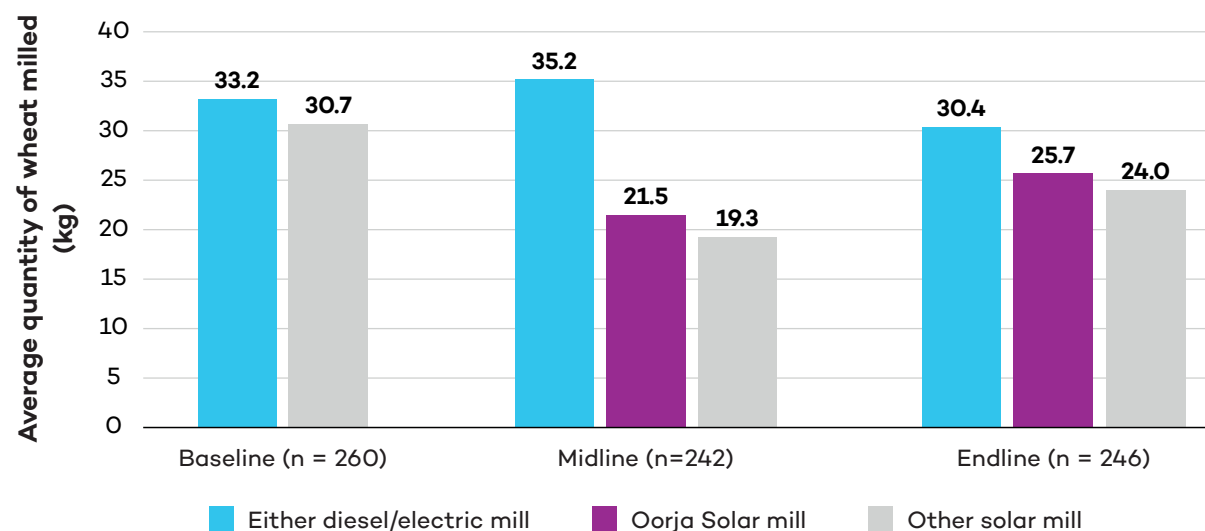


Figure 7. Milling rates by user and non-user groups



Source: Authors.

Figure 8. Milling quantity by user and non-user groups



Source: Authors.

In addition to the quantitative trends, qualitative insights further reinforce the perception of the solar mill as a more affordable and accessible option. Several users clearly highlighted the cost advantage of Oorja’s solar mills over traditional diesel and electric alternatives. For instance, one respondent noted, “*Sunil (solar mill operator) takes 2 rupees per kg, and Jaswal (diesel/electric mill operator) charges 2.50 rupees,*” while another user from Gandhaura village emphasized, “*The solar mill charges only 1 rupee per kg, whereas the diesel mill costs Rs. 2.50 per kg. If I needed to grind 20 kg of wheat, it would cost me 20 rupees at the solar mill, but at the diesel mill, it would cost me double.*” These experiences illustrate a tangible cost saving that makes the solar mill a preferred choice for many, especially when processing larger quantities.



Therefore, smaller monthly wheat quantities at Oorja mills appear to reflect smaller, more frequent batches enabled by closer siting and lower prices. Batch sizes may also vary by season and weather. Where volumes remain modest, the reasons could be practical, such as machine capacity, limited operating hours, queues, and early quality/trust concerns. These could be addressed through higher-capacity machines, extended hours, simple queue systems, and standardized quality checks; we note these as hypotheses consistent with the qualitative evidence, not definitive causal claims.

Table 2. Average milling rates and quantity of wheat in treatment villages by primary milling type

Stage	Village	Either diesel/ electric mill		Oorja solar mill		Other solar mill	
		Average quantity milled per month (in kg)	Average milling rate per kg (INR)	Average quantity milled per month (in kg)	Average milling rate per kg (INR)	Average quantity milled per month (in kg)	Average milling rate per kg (INR)
Midline	Baksha Kheda	36	1.89	18	1.71	30	1.00
	Chaukhandil	35	2.03	28	1.00	-	-
	Gumdapur	44	2.73	30	2.00	-	-
	Imaliya	29	2.51	15	2.00	9	2.00
	Padritara	32	2.53	23	2.00	-	-
Endline	Baksha Kheda	31	1.83	33	1.70	-	-
	Chaukhandi	25	2.04	0	-	24	1.00
	Gumdapur	28	2.66	21	2.22	-	-
	Imaliya	37	2.50	21	2.00	-	-
	Padritara	32	2.58	17	2.13	-	-

Source: Authors.

However, perceptions of affordability vary across locations. In Basantpur, for instance, where electric mills charge INR 1 per kg, one user remarked, “*The solar mill is expensive,*” drawing attention to the relative differences in pricing across different types of mills. Affordability is therefore relative to local alternatives. Where INR 1/kg electric mills exist, an Oorja mill may not be the cheapest option even if it is cheaper than diesel. This sentiment is further reflected in village-level data (Table 2), which shows variation in average milling rates at Oorja’s solar mills. At midline, users in Gumdapur and Imaliya villages paid higher average rates of INR 2.6/kg and INR 2.4/kg, respectively, compared to INR 1.8/kg in Baksha Kheda. While rates slightly declined at the endline, the disparity persisted—with Gumdapur still at INR 2.5/kg



and Padritara at INR 2.5/kg, both significantly higher than Baksha Kheda's INR 1.8/kg. These differences likely shape community perceptions of cost, even though the absolute rates remain competitive or lower than conventional diesel mills. It underscores the need for localized communication strategies to help users understand cost-benefit trade-offs, particularly in villages where lower-cost alternatives exist or are perceived to be more affordable.

Affordability, even in small increments, can make a meaningful difference in daily life. As one user put it, *"The money we save here, we can use for something else in the house,"* emphasizing how reduced milling costs can ease household expenses. However, preferences continue to vary based on factors beyond just price. Some villagers still opt for the diesel mill due to its speed or suitability for specific grains. As one woman explained, *"We go to the solar mill for some things, but for certain grains, we go to the diesel one."* This reflects the complementary role that solar mills can play, offering an affordable, accessible alternative without fully replacing conventional options. Instead, they expand the range of choices available, allowing households to balance cost, convenience, and grain type according to their needs.

4.3.5 Credit Facility

The availability of a credit facility at the solar mill has emerged as a critical support mechanism for financially constrained households. At the endline, a total of 38 households in the treatment group reported using credit at the mill in the past 12 months. Out of these, 13 accessed credit specifically from Oorja mills. Among these users, half considered the option of credit important, while 45% remained neutral. This indicates that while not widely deemed essential, the availability of credit could play a meaningful role for a significant portion of users, especially in situations where immediate cash flow is a challenge. However, we cannot generalize these findings due to the smaller sample size.

The qualitative findings reinforce this perspective. The option to defer payments has made the solar mill an accessible choice for many villagers, especially those facing financial constraints. One respondent shared, *"Either we pay cash, or if there is a shortage of money, then we pay later."* This flexibility has eased the financial burden on households that may not always have enough cash on hand. The mill operator's willingness to accommodate delayed payments is highly appreciated, with another user adding, *"If I fall short of money, they accept payments even after a week."* This understanding and leniency from the operator provide significant relief, particularly in times of economic uncertainty.

One respondent explained that with diesel and electric mills, payment is required upfront, and without the necessary money, milling services cannot be provided, since diesel and electricity are costly. In contrast, the solar mill offers flexibility. With the solar mill, they can pay within 10 to 15 days, which helps when they do not have money immediately.

Beyond helping individual households, this kind of flexible credit has wider relevance. In many rural areas, smallholders still struggle to access formal loans and often depend on informal lenders who charge high interest. By allowing short-term payment deferrals, solar mills fill part of that gap, offering a practical form of financial flexibility that aligns with the goals of rural credit and financial inclusion efforts.



4.3.6 Food Consumption and Storage

The presence of the solar mill inside the village has led to a noticeable transformation in food consumption and processing patterns within the village. Its proximity and ease of access have enabled households to shift away from bulk milling toward smaller, more frequent batches. This has encouraged a growing preference for freshness in daily meals. As one respondent noted, *“If we grind less quantity, it will be fresh,”* reflecting how access to on-demand milling is influencing food preparation choices. Another shared, *“Rice and lentils, whenever we need to cook them, we now grind in smaller amounts,”* highlighting the convenience the mill brings to everyday cooking.

This shift from bulk to periodic milling marks a change in both household routines and preferences. *“Earlier, we would take a large amount at once to be milled. But now, with the solar mill here, we grind a little at a time and return after a few weeks or a month to do it again,”* said one respondent, indicating a broader behavioural shift toward frequent and need-based usage.

Moreover, the convenience of local milling has led to greater dietary diversification. Some households have started consuming food items they previously avoided due to the lack of nearby milling options. *“Earlier, we didn’t eat corn flour, but now we have started using it,”* shared one user. Others have begun growing new crops like coriander, chili, and turmeric, now confident they can process these at the village mill.

Food processing practices have also broadened. *“Before, we used to get our grains milled in the village, but now we can process wheat, besan, rice, and more,”* one villager explained. Previously, spice processing was limited due to the effort required to grind them manually or the cost of external mills. However, as one user pointed out, *“Before, we never used to grind masala, but now, with this mill, we have started grinding masala as well,”* showing how the solar mill has made value-added food processing more accessible.

In addition to changes in consumption, the solar mill has influenced household storage practices. When milling facilities were distant, families were compelled to grind in bulk to avoid repeated travel. This led to challenges with storing large quantities of flour, often resulting in spoilage or pest infestation. *“Earlier, the flour would go bad, or small insects would get into it,”* said one respondent. With the solar mill now nearby, families are opting to grind as needed, reducing long-term storage needs. *“Before, when the mill was far, we had to grind a huge quantity at once to avoid frequent trips. But this caused issues in storing the food, as it might get ruined.”* The result is improved food quality and hygiene, as well as reduced household wastage.

Frequent, smaller-batch milling, enabled by local processing, can reduce aflatoxin and mycotoxin risk by avoiding prolonged storage of grain and flour (Kumar et al., 2022; Sacco et al., 2020). Furthermore, by enabling dietary diversification through access to new processing methods and local value addition, households can achieve better overall nutrition (Langer et al., 2024; O’Malley et al., 2024; Yadav et al., 2024b).



4.3.7 Gendered Access and Roles Around Milling

The introduction of the Oorja solar mill has made milling more accessible, especially for women. Traditionally, the task of transporting grain to distant mills was managed primarily by men, given the physical effort required and the need to travel by bicycle or cart. However, the installation of solar mills within the village has significantly changed this dynamic.

Now, with the mill located nearby, women could make the trip themselves in smaller, more frequent batches that fit around other household tasks. They no longer need to rely on male family members to carry large quantities of grain over long distances, which has given women more autonomy in managing daily food processing.

As one woman shared, *“I go whenever I feel the need. There is no need to ask anyone.”* For her and many others, milling has become part of their everyday responsibilities, like cooking or cleaning, removing the need for consultation or permission. This change has allowed women to have greater flexibility in planning their household chores and diets.

Quantitative findings from the project support this shift. In treatment villages, where the solar mill was introduced,

- at midline, women were primarily responsible for milling in 2% households, based on data from 242 treatment households;
- even by endline, this figure remained consistent (2%) across 246 treatment households.

It is important to highlight that (i) this indicator captures who decides, not who travels; (ii) the exposure window (~9 months) may be too short for intra-household decision norms to shift; and (iii) with a small base rate (2%) and village-level clustering, the study has limited statistical power to detect small changes. This helps explain the apparent contrast with the stronger qualitative accounts, which were more encouraging. With the mill now accessible, even young girls and elderly women are taking on this responsibility. *“Now even small kids can do it. Even a 9-10-year-old girl can go,”* shared a respondent. Another added, *“Now that it is close by, even elderly people go when needed,”* illustrating the democratization of access brought about by proximity.

The qualitative evidence points to reduced mobility barriers and wider participation in milling trips: women, adolescent girls, and elderly women go more often when the facility is close and hours are predictable. This is best interpreted as broader access rather than a measured shift in formal decision making within households. Some women also reported that men still choose where milling happens (*“My husband decides where we should go for milling”*), underscoring that norms on who decides may lag behind improvements in who can go.

Proximity clearly lowers gendered mobility barriers. Women, girls, and elderly women are more able to mill independently when the facility is sited inside the village with predictable hours. At the same time, deeper decision-making norms may not shift automatically.

Complementary measures should therefore include awareness and safety messaging, women-first queue tokens, and partnerships with self-help groups for outreach and feedback. There are currently no women operators at the study sites. So, creating pathways for women



operators (recruitment, basic operations and maintenance training, etc.) can further increase women's comfort and willingness to use the service, consistent with evidence that engaging women in energy service delivery helps access female customers in hard-to-reach locations and improves targeting of services. This aligns with evidence and sector toolkits that recommend stronger roles for women in frontline energy delivery and customer-facing posts (Energy Sector Management Assistance Program, 2025).

At the same time, shifting routine trips to women could add to unpaid work, and the time impact will vary by season and workload. To keep time costs low, mills should use simple token/appointment systems to shorten queues and maintain reliable posted hours. Future interventions should also include a short time-use diary to measure any change in unpaid work more clearly.



5.0 Discussion

The study reveals that secondary use of SIP power is feasible and can provide an innovative solution for rural households in terms of economic savings, food-related practices, autonomy, and decision making. As with any intervention, the impact is shaped by both enabling conditions and persistent structural challenges. Below, we explore the patterns that emerge across cost, usage behaviour, gender dynamics, and long-term service uptake.

Overall, the findings show that solar mills cut milling costs and travel time, making energy access more affordable and convenient. They also support livelihood diversification and small but meaningful gains in women's decision making and mobility. However, long-term success depends on tackling challenges like maintenance, operator availability, and user retention, which ultimately shape the sustainability of solar-powered milling.

5.1 Lower Milling Costs and Eased Household Budgets

Findings from this study confirm that solar-powered mills can deliver tangible cost savings compared to diesel or electric alternatives. At the endline, users reported an average cost of INR 1.94/kg, compared to INR 2.33/kg for non-users, translating into savings of roughly INR 100 per wheat milling season for the average household (assuming 250 kg per season). These savings, while modest in absolute terms, are significant in rural household budgets where milling is a recurring expense. The magnitude of savings aligns with evidence from Tanzania and Kenya, where integrated solar milling programs reduced operating costs by 10%–25% compared to diesel-based systems (IWMI, 2024).

However, these benefits were not evenly distributed. In Gumdapur and Padritara, higher Oorja mill rates eroded the price advantage, underscoring the importance of aligning pricing with local market rates to maintain competitiveness. Lessons from Bangladesh's solar irrigation-to-processing transition highlight that flexible tariff-setting and community engagement in price decisions can help sustain cost advantages over time.

From a policy perspective, India's PM-KUSUM framework—which already subsidizes irrigation—could integrate secondary uses like milling into its capital support and tariff design, maximizing returns from each solar installation.

5.2 Proximity

Proximity emerged as an equally critical factor. Oorja mill users travelled around 0.5 km on average, compared to more than 1 km for those using diesel/electric alternatives. Proximity also has important implications for women's safety and mobility: shorter distances reduce exposure to risks associated with travelling long routes or in early morning/evening hours, especially when non-motorized transport is used. These results point to the need for siting strategies that prioritize high-density user clusters and integrate with broader rural infrastructure planning (such as rural road expansion programs).



5.3 Changes in Milling Behaviour and Food Practices

The accessibility of Oorja's mills encouraged a shift from bulk to need-based milling, improving freshness and hygiene while potentially reducing spoilage. Some households also diversified processing to include maize, coriander, and turmeric—foods they had previously avoided due to the lack of local processing options.

Such diversification mirrors experiences from solar agro-processing initiatives in Kenya and West Africa, where versatile milling capacity revitalized traditional food practices and contributed to dietary diversity (Efficiency for Access, 2024). In India, aligning such interventions with nutrition-oriented rural programs could help embed solar milling within broader health and food security strategies.

5.4 Small But Symbolic Shifts in Gender Roles

Quantitative data shows that only around 2% of women independently decided where to mill grain, yet qualitative narratives indicate incremental gains in mobility and autonomy. The ability to visit mills without needing male permission was a recurring theme, particularly among elderly women and younger household members.

These patterns parallel Nepal's solar processing experience, where closer proximity to facilities increased women's participation in household decision making (Grid Alternatives, 2019). While decision-making power remains largely male-dominated, targeted GESI measures—such as involving women in operator roles or ownership models—could strengthen these gains. IISD's policy engagement with MNRE, informed by this study's findings, has already led to discussions on incorporating gender-responsive features in subsidy models.

5.5 One More Option, Not a One-Size-Fits-All

Oorja's solar mills have complemented rather than replaced diesel or electric mills. Households often alternated between services based on grain type, urgency, and pricing, reflecting a pluralistic service ecosystem. This ecosystem poses a challenge for scaling solar mills, but the insights gained in this study could position solar mills as a core service that delivers substantial benefits to users.

Kenya's rural milling sector demonstrates that such diversity improves resilience to downtime and seasonal demand shifts (Efficiency for Access, 2024). For India, multi-service solar hubs integrating irrigation, milling, and other productive uses could improve asset utilization and community resilience.



5.6 Factors Influencing Drop-Offs and Sustained Use

Only 41.3% of households that initially used Oorja as their primary mill maintained that preference at the endline. The main drivers of attrition were

- **technical limitations:** perceived lower flour quality and slower speeds
- **operational priorities:** operators focusing on irrigation, which offers higher income
- **accessibility issues:** outskirts location and poor road conditions during monsoons.

Comparable programs in Tanzania addressed similar issues by deploying higher-capacity, battery-supported mills and linking operator incentives to service reliability (Government of the United Republic of Tanzania, n.d.)—measures that could be considered in India alongside others, such as performance-linked contracts, service-level benchmarks, or viability gap funding.

5.7 Village-Level Dynamics and Parallel Adoption of Solar Mills

Retention patterns varied widely across villages. Padritara retained 65% of midline users at endline, likely due to consistent operator presence and competitive pricing, while Chaukhandi retained fewer than 30%, losing users to a competing solar mill offering faster service at INR 1.00/kg.

Such patterns mirror East African agro-processing hubs, where service quality, competitive pricing, and peer influence shape consumer decisions. Scaling in India will require adapting service design and operator engagement to each village context.

5.8 Policy Influence and Opportunities for Integration

India's current solar irrigation strategy under PM-KUSUM does not explicitly integrate secondary uses like milling, nor does it embed GESI considerations into design. However, IISD's engagement with MNRE as part of this project has already led to promising openings: MNRE has expressed interest in expanding subsidy frameworks to include other productive uses of solar power and has requested input on alternative subsidy delivery models.

Moreover, a new bilateral Germany–India program is set to prioritize GESI in decentralized clean energy, creating a strategic opportunity to align India's solar policy with global best practices. Coordinated action across ministries—renewable energy, MSME, agriculture, and rural development—will be key to breaking down existing policy silos and enabling integrated planning. Embedding productive uses into subsidy design could unlock greater economic returns, improve gender inclusion, and strengthen rural value chains.



6.0 Policy Recommendations

India's rapid expansion of decentralized solar irrigation—through programs like PM-KUSUM and state-level policies such as the Uttar Pradesh Solar Energy Policy 2022—has significantly improved agricultural energy access. Yet, when solar assets are designed for *multi-use* rather than single-purpose applications, they can deliver stronger economic returns, higher utilization rates, and broader benefits to the wider community, including women and marginalized groups. The following recommendations primarily relate to India, but most also apply to other governments considering policies to promote secondary use of SIP power.

Promote Secondary and Tertiary Uses of Solar Energy While Addressing the Challenges Highlighted in this Report

- Broaden PM-KUSUM's definition of *productive use* to include post-harvest processing, storage, and rural enterprise applications.
- Provide capital top-ups or zero-interest loans to retrofit existing solar assets with secondary-use equipment.
- Pilot *solar agri-hubs* that combine irrigation, milling, storage, and value-addition equipment, like East African agro-processing clusters.

Foster Collaboration Through Cross-Sector Platforms

- Establish national and state-level *productive-use solar platforms* involving government, social enterprises, agri-tech startups, farmer producer organizations, and financiers.
- Encourage joint pilots in high-priority districts, refining integrated models before national scale-up.
- Share operational and adoption data across sectors to improve decision making and monitoring.

Recognize and Support For-Profit and Social Enterprise Models

- Offer blended finance and viability gap funding to social enterprises delivering productive-use services.
- Facilitate carbon credit access for enterprises that enhance renewable energy utilization in rural areas, noting that carbon credit access is complex for small enterprises and pooled or aggregated approaches via industry associations or state nodal agencies could reduce bureaucratic burdens.
- Recognize and fast-track such enterprises under the Pradhan Mantri Formalisation of Micro food processing Enterprises Scheme (PM-FME), Startup India, and similar schemes.

Strengthen Local Ownership and Operations

- Introduce performance-linked incentives for operators who effectively manage both irrigation and processing.



- Train women's self-help groups, youth collectives, and farmer producer organizations to operate multi-use solar systems.
- Form *village energy committees* for oversight, maintenance planning, and grievance redress.

Align Solar Policy With Post-Harvest and Microenterprise Needs

- Explicitly include post-harvest processing and rural enterprise services in solar energy policies.
- Leverage schemes like Rashtriya Krishi Vikas Yojana, PM-FME, and the Agriculture Infrastructure Fund to co-finance solar-compatible productive-use appliances.
- Develop standardized procurement and technical guidelines for solar-compatible processing tools.

Ensure Accessibility and Inclusive Infrastructure Planning

- Use Gram Panchayat Development Plans to site mills in more central, accessible locations.
- Fund access improvements through the Mahatma Gandhi National Rural Employment Guarantee Act or rural development schemes.
- Promote mobile or cart-based processing units for remote or seasonal locations.

Tailor Interventions to Village-Level Dynamics

- Allocate district innovation funds for locally adapted business and service models.
- Document and share successful operational approaches for replication.
- Build adaptive and simple feedback loops (such as village scorecards or operator logs) into solar policy to respond to community-level differences.

Invest in Research and Development

- Fund research and development to support next-generation solar milling, incorporating battery storage and more efficient solar-compatible appliances. With technology costs declining, these technologies are becoming increasingly feasible for rural deployment.



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Appendix A. Methodology Details

Consent and Research Ethics

The following key considerations were considered while planning and executing the activities under the survey:

1. The survey was in accordance with the International Development Research Centre's Corporate Principles on Research Ethics.⁸ Additionally, the team of survey agency, including enumerators and supervisors, were provided orientation and training on the Prevention of Sexual Harassment (PoSH) at Workplace policy of Oorja in accordance with The Sexual Harassment of Women at Workplace (Prevention, Prohibition and Redressal) Act, 2013 of India⁹ to ensure their safety as a part of this study.
2. In accordance with the Canadian Tri-Council Policy Statement on Ethical Conduct of Research Involving Humans ("TCPS2"),¹⁰ the following key measures were adopted:

Inclusion:

- i) **Respondents** – The questionnaire was drafted with the objective of being inclusive of female participation as respondents. The section includes time use in household chores and women's bargaining power in decisions related to household work and expenses. Similarly, efforts were made to have equal representation from different income categories based on the construction materials of their homes (high-quality, permanent materials being a proxy for relative wealth and cheaper, less durable construction materials being an indicator of lower incomes).
- ii) **Enumerators** – The enumerators involved in the survey were in the age group of 20–30 years and belonged to the rural areas in the districts of the project locations in Uttar Pradesh. In addition to this, out of 10 enumerators, at least 40% were female. Youth and female enumerators were hired to ensure the inclusion of individuals from underrepresented groups, such as females, youth, and minority groups.
- iii) **Consent** – Before starting each survey, all enumerators were required to obtain consent from the respondent to proceed with the survey, as outlined below. This was to ensure that the respondent is aware of the survey objectives and their right to abort the survey if they do not feel comfortable. A sample note for consent (for baseline survey) is as follows:

“Oorja is providing Pay Per Use solar based irrigation services in your village. To benefit the community further, we are planning to provide milling services that can help you in getting your produce milled conveniently and in a sustainable manner. With an objective to provide these services, Oorja is conducting a survey to understand the current situation of the community and the mill requirements in the village.”

⁸ The principles are outlined here: <https://idrc-crds.ca/en/idrcs-advisory-committee-research-ethics>

⁹ See the text of the act here: https://doe.gov.in/files/inline-documents/DoE_Prevention_sexual_harassment.pdf

¹⁰ See the TCPS2 here: https://ethics.gc.ca/eng/policy-politique_tcps2-eptc2_2022.html



Consent – “This survey will ask some personal and farm related questions. Information collected will be restricted to Oorja and will only be used for analysis within Oorja. Please answer the questions as accurately and honestly as possible as this will allow Oorja to provide the best services to you. Your participation in this survey is entirely voluntary and declining participation will not affect your access to any Oorja services. At any time, if you do not wish to answer a question or wish to terminate the interview, please tell the interviewer. The duration of this interview is approximately fifty minutes. If you consent to this study, please convey your acceptance to the interviewer.”

A separate Non-Disclosure Agreement was signed with the knowledge partners, research intern, and the survey agency involved in the process of data collection and analysis to ensure that the privacy of the respondents is protected and the collected information is used only for analysis under this study and shall not be shared with any other individual or organization. Similarly, for quoting the statement(s) of a respondent(s) in the report, permission will be sought from them to ensure their identity is kept confidential unless permitted.

Survey Timeline and Village Details

Table A1. Survey rounds and timelines

Phase	Month of data collection	Purpose
Baseline survey	February 2024	Sampled solar pump users and households near/far from the potential mill site to evaluate potential spillover effects
Mill installation	March 2024	Mills installed in five out of 10 villages based on the analysis of baseline data
Midline survey	August 2024	Conducted 5 months after mill installation to measure early outcomes
Endline survey	December 2024	Conducted 9 months after installation to capture longer-term impacts

Source: Authors.

Table A2. Details of sample size across survey rounds

Survey round	Total households surveyed	Treatment group	Control group	Notes
Baseline (February 2024)	527	265	262	Included 27 buffer households to ensure statistical significance
Midline (August 2024)	494	242	252	Decline due to seasonal migration and initial duplications
Endline (December 2024)	503	246	257	Maintained statistical significance across villages

Source: Authors.

**Table A3.** District-wise list of control and treatment villages

District	Treatment village	Control village
Bahraich	Gumdapur	Sitapur
Bahraich	Padritara	Mahru
Bahraich	Imaliya	Siswara
Bahraich	-	Bhaggadawa
Barabanki	-	Bachrauli
Hardoi	Baksha Kheda	-
Barabanki	Chaukhandi	-

Source: Authors.



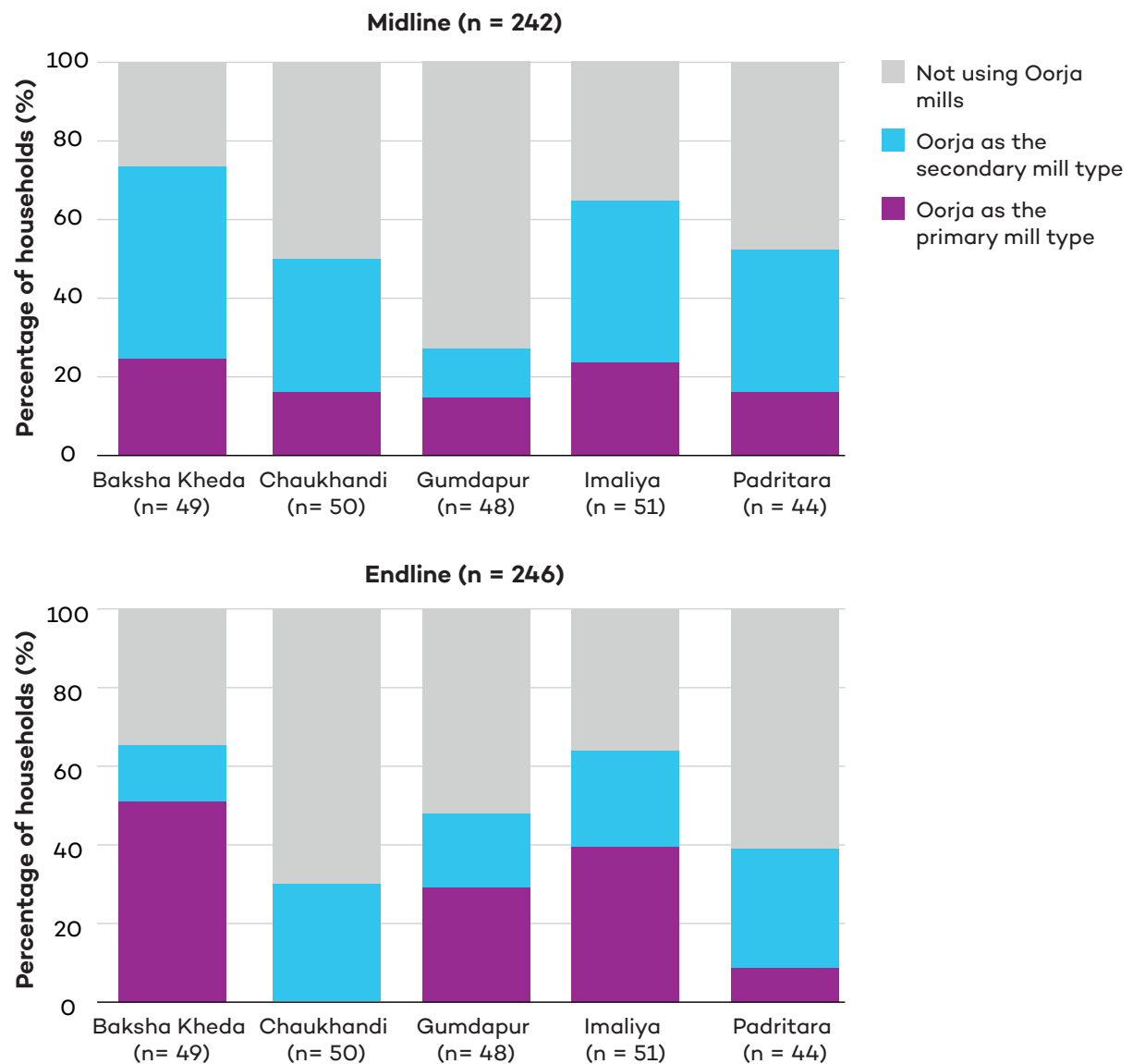
Appendix B. Village-Level Shifts in Mill Adoption

When comparing the adoption of Oorja mills as primary and secondary mill types across treatment villages (Figure B1), a clear shift from secondary to primary usage is evident between the midline and endline surveys. In Baksha Kheda, for instance, the share of households using Oorja as their primary milling option more than doubled, rising from 24.5% at midline to 51% at endline, while secondary usage dropped sharply from 49% to 14.3%, indicating a significant consolidation of trust in Oorja's services. A similar trend is observed in Imaliya, where primary usage increased from 23.5% to 39.6%, accompanied by a slight decline in secondary use.

In Gumdapur, we also noted a positive shift, with primary usage doubling from 12.1% at midline to 24.1% at endline, and a modest increase in secondary usage. Conversely, Chaukhandi saw a decline in primary usage, dropping from 16% to 0%, while secondary usage remained relatively stable, suggesting a potential loss of engagement. This was mainly due to the installation of a 10 HP solar mill in the village, which was providing milling services to the community at lower tariffs. In Padritara, primary usage declined slightly from 15.9% to 8.7%, with a modest change in secondary users due to another solar mill becoming operational at a distance of less than a km.



Figure B1. Oorja mills as the primary and secondary mill types in treatment villages



Source: Authors.

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