Survey to Understand the Pattern of Energy Financing in Rural Areas and Preparedness for Financing Energy Transitions in Selected States

Report

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Executive Summary

A collaborative effort led by the Ashoka Centre for People-Centric Energy Transition (ACPET) and Sambodhi undertook a comprehensive study to understand the pattern and preparedness of energy transition financing in rural areas. This project is a pivotal initiative in understanding and facilitating people-centric energy transition in India, with an emphasis on the distributive aspects of energy transition finance across selected states. The project's focus extends to micro-grids, mini-grids, grid-based electricity supply, aiming to establish a framework for prioritizing clean energy transition financing in Indian districts aligned with development goals and state capacities.

This project is designed to comprehensively examine the distribution aspects of energy transition finance within specific states of India, with a focus on both the demand and supply sides. This includes a detailed assessment of current prioritization gaps in energy transition finance and the development of strategies to bridge these through effective policies and decision-making processes within districts of Uttar Pradesh, Bihar, and Jharkhand. The project's methodology integrates the analysis of secondary and primary data to gauge the readiness of these states in harnessing and distributing energy transition finance across various societal segments.

The primary survey was conducted in aspiring and laggard districts in the selected states, based on the Niti Aayog classification and backed by the secondary data-based machine learning analysis. The survey covered a broad spectrum of stakeholders including village representatives, mini grid operators, households, as well as commercial and institutional consumers. Furthermore, qualitative interviews with implementing agencies provided insights into ground-level dynamics of energy transition. The demand-side assessment focused on understanding consumer preferences, awareness, energy utilisation, quality and reliability of electricity services, knowledge regarding energy transition financing, and the willingness to pay for service improvements involving the analysis of the collected data from the demand side. The supply-side assessment focused on evaluating existing financing options and mechanisms for rural renewable energy projects, as well as the actual cost of services vis-à-vis the charges, allowing for a comprehensive view of the supply side aspects.

The key finding at the village level was that, although the main grid remains the dominant source of electricity, both aspiring and laggard districts show a significant reliance on solar energy as a last-mile solution, highlighting its role as a key enabler of energy access and resilience in remote geographies and indicating diversification of energy sources. Electricity services from the mini grid were found to be more reliable and adequate in terms of daily availability, continuity, duration, voltage adequacy and overall satisfaction, as reported across consumer categories in both aspiring and laggard districts. Challenges persist in terms of regularity of billing and payment, and overdue payments were reported in both main grid and mini grid connections. Overall, consumer preference leans towards a combination of both main grid and solar mini grid supply. The general perception is that solar energy will be more desirable in the long run, as it is environment-friendly and cost-effective, especially if subsidized for rural domestic consumers. Mini grid connections and solar pumps have brought massive benefits to farmers in terms of reduction of time and cost of irrigation as well as ease of repair and maintenance. They have also greatly benefitted small scale commercial enterprises and village level institutions such as Anganwadi centres, Panchayat Bhawan, and schools with a stable and steady source of electricity supply.

Across all categories, the desired service improvements include 24/7 supply of electricity or more than 18 hours of supply per day, voltage stability, reduced power outages, increase in load capacity, and quick redressal of technical issues. Upon probing, most of the respondents across all consumer categories agreed that they were willing to pay an additional amount of 5-10% for service improvements in main grid and mini grid connections.

The study proposes a range of recommendations to enhance access to clean and reliable electricity in rural areas, encompassing the encouragement of supportive policies and regulatory frameworks, increasing access to finance, fostering innovation and collaboration among key stakeholders, encouraging capacity building and skill development, and strengthening monitoring and evaluation frameworks in the sector. At the policy level, initiatives such as designing specific programmes on rural enterprise development centered around mini grids, preparedness and potential business models for grid-interactive mini grids, and financing the transition through innovative mechanisms such as blended financing, crowdfunding, and carbon trading may be explored. Financing gaps can be addressed through identification of load drivers, integrating job creation and the rural digital with commercial and institutional load centres, provision of grant-based CAPEX and minimum interest-based OPEX support,

In conclusion, the study underscores the complex landscape of electricity access and reliability in rural areas, with both opportunities and challenges across aspiring and laggard districts. Prioritizing infrastructure upgrades, promoting renewable energy adoption, streamlining billing processes, and fostering community engagement, can collectively pave the way for a resilient and sustainable energy future.

1. Introduction

1.1. Project Background and Context

Energy financing in rural areas, both globally and in India, is essential for sustainable development. Globally, approximately 675 million people lack access to electricity, and around 2.3 billion rely on traditional fuels for cooking. India mirrors these global challenges, with a substantial portion of its rural population experiencing energy poverty, highlighting the importance of sustainable energy solutions (World Bank, n.d.)[1].

India, with its rapidly growing population and economy, faces a significant challenge in meeting its increasing energy demands sustainably. As the world's second-most populous country, India's energy consumption is projected to be the fastest growing among all major economies by 2040. The country has made substantial progress in renewable energy, becoming the second-largest source of domestic power production, with a projected increase in renewable energy consumption from 17 Mtoe in 2016 to 256 Mtoe by 2040 (Kumar. J & Majid, 2020)[2]. This rapid expansion underscores the necessity for a sustainable and equitable energy transition, especially in rural areas where access to reliable and clean energy remains a challenge. In rural communities like Keragam in Odisha, the introduction of solar-powered solutions has significantly improved livelihoods, highlighting the transformative impact of renewable energy technologies (Fuchet, 2022)[3].

In India, energy financing in rural areas is not just about electrification but encompasses broader aspects like gender equality and economic empowerment. Reliable energy access relieves women from energy-intensive tasks, enabling them to participate more in education and economic activities, thereby transforming entire communities (Chandra, 2023)[4]. This holistic approach to energy access and utilisation in rural India forms a crucial part of the global effort to achieve sustainable energy goals.

India's transition to renewable energy in rural areas is marked by substantial growth in solar and wind energy capacity. As of May 2023, renewable energy sources, including hydro, contribute 41.4% to the total installed electricity capacity. This shift highlights India's commitment to clean energy sources and its role in the global renewable energy landscape (Ministry of Power, 2023)[5]. The Ministry of New and Renewable Energy (MNRE) has issued frameworks to boost the sector, focusing on areas like textile, agriculture, and green job creation through renewable energy. Solar-powered irrigation systems, for example, have become increasingly prevalent, providing a reliable and sustainable energy source for farming. This not only aids in agricultural productivity but also helps in conserving water resources, demonstrating the multifaceted benefits of renewable energy in rural economies (Kumar, 2023)[6]. The budgetary allocation for MNRE in FY 2023-24 was Rs. 10222 crores, a 48% hike from the previous budgetary allocation of Rs. 7033 crores, which underscores the government's commitment to the promotion of renewable energy. The government has allocated Rs. 35000 crore for priority capital investments towards energy transition and net zero objectives, as well as energy security (Ministry of New and Renewable Energy, 2023)[7].

Despite advancements towards a just energy transition, rural communities face significant barriers in accessing financial services, with about 70% of marginal farmers lacking a bank account and 87% having no access to credit, often due to the lack of adequate formal financial institutions and infrastructure. To address these challenges, several initiatives like the $125 million loan from the Asian Development Bank (ADB) to L&T Finance support financing in rural and peri-urban areas, with a focus on women borrowers and small businesses (Devdiscourse)[8], have been started. Although grid

[1] World Bank (n.d.). *Energy*. Retrieved from https://www.worldbank.org/en/topic/energy/overviewc
[2] Kumar. J, C. R., & Majid, M. A. (2020). Renewable energy for sustainable development in India: Current status, future prospects, challenges, employment, and investment opportunities. *Energy, Sustainability and Society*, *10*(1), 2. https://doi.org/10.1186/s13705-019-0232-1
[3] Fuchet, A. (2022). Access to Energy: Empowering India's Rural Communities. Schneider Electric Blog. Retrieved from https://blog.se.com/sustainability/2022/06/15/access-to-energy-empowering-indias-rural-communities/
[4] Chandra, R. (2023). Empowering rural India through sustainable energy. *ET Edge Insights*. Retrieved from https://etinsights.et-edge.com/empowering-rural-india-through-sustainable-energy/
[5] Ministry of Power (2023). *Power Sector at a Glance ALL INDIA | Government of India | Ministry of Power*. Retrieved from https://powermin.gov.in/en/content/power-sector-glance-all-India
[6] Kumar, M. (2023). Decentralised solar is transforming rural India, needs an extra push. *Mongabay Series: Clean Energy.* Retrieved from https://india.mongabay.com/2023/02/decentralised-solar-is-transforming-rural-india-needs-an-extra-push/
[7] Ministry of New and Renewable Energy (2023). PROMOTION OF CLEAN ENERGY - Major steps taken by the Government to accelerate the Indian economy's transition to one powered by green energy – Union Power & NRE Minister. Retrieved from https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1907698
[8] Devdiscourse (2023). *ADB signs $125M loan with L&T Finance to support financing in rural and peri-urban areas in India | Business.* Retrieved from https://www.devdiscourse.com/article/business/2723131-adb-signs-125m-loan-with-lt-finance-to-support-financing-in-rural-and-peri-urban-areas-in-india

electrification and coverage are high among rural households, the literature indicates that gaps are prevalent among rural micro-enterprises, with only 65% of enterprises having grid electricity connections, while 16% of households and 40% of enterprises use non-grid sources such as solar home systems, rechargeable batteries, mini-, of grids, and diesel generators to meet their energy requirements (The Rockefeller Foundation, 2019)[9]. The main barriers consist of affordability issues due to high connection cost and inflated bills due to gaps in electricity meter coverage and billing efficiency, unreliable power supply, and long duration of power cuts.

Even with current challenges, the renewable energy sector in India, including solar, is expected to continue its growth trajectory. This optimism is based on the belief that current challenges will ease in the short-to-medium term as current supply chain disruptions due to geopolitical tensions and COVID-19 ease out and average prices stabilize, and the industry has enough cushion to absorb downside risks (Srivastava & Saboo, 2022)[10]. Renewable energy projects in India have the potential to enhance returns through various means, such as bond market refinancing, EPC margins, stake sales in operational projects, and carbon credits trading. These methods not only increase the viability of the projects but also provide cushioning against risks (Srivastava & Saboo, 2022)[11]. The current landscape of renewable energy financing in India, particularly focusing on solar energy, showcases a dynamic and evolving scene with various models including revenue-based, philanthropic, equity-based, and public finance models. The diversity in financing models reflects the multi-dimensional approach India is taking to bolster its renewable energy sector, positioning itself as a key player in the global transition towards cleaner energy sources.

In this context, the Ashoka Centre for People-Centric Energy Transition (ACPET) has launched the Energy Transition Financing Project. ACPET is a transdisciplinary centre with a vision to guide India, and potentially the world, towards a sustainable, secure, and equitable energy path. This project is a pivotal initiative in understanding and facilitating the energy transition in India, with an emphasis on the distributive aspects of energy transition finance across selected states. The project's focus extends to micro-grids, mini-grids, grid-based electricity supply, and various renewable energy options, aiming to establish a framework for prioritizing clean energy transition financing in Indian districts aligned with development goals and state capacities.

This project, as part of ACPET's initiative, is designed to comprehensively examine the distribution aspects of energy transition finance within specific states of India, with a focus on both the demand and supply sides. This includes a detailed assessment of current prioritization gaps in energy transition finance and the development of strategies to bridge these through effective policies and decision-making processes within districts of Uttar Pradesh, Bihar, and Jharkhand. These states have 36% of the aspiring districts of India, and the sample of 4 aspiring districts in each state represents 30% of the total aspiring districts in these states and 11% of the aspiring districts in the country overall (NITI Aayog)[12]. Thus, the performance of the renewable energy solutions in the sample aspiring districts will be critical to understanding the potential energy transition and the financing aspects in the aspiring districts of the country, especially the equity aspects and the livelihood opportunities it creates for women and the marginalized. The project's methodology integrates the analysis of secondary and primary data to gauge the readiness of these states in harnessing and distributing energy transition finance across various societal segments.

The significance of this project is amplified by India's ambitious goals for clean energy, including achieving net-zero emissions by 2070 and meeting fifty percent of installed capacity from renewable sources by 2030. These targets highlight the country's commitment to a sustainable energy future, emphasizing the importance of projects like the Energy Transition Financing Project by ACPET in navigating the challenges and harnessing the opportunities presented by this transition (Birol & Kant, 2022)[13].

Motivation behind the study:

The motivation of the study stems from a dual focus: firstly, it aims at understanding the macro-level DISCOM reforms aimed at financing the transition towards clean energy, and secondly, it requires a broader examination and understanding of micro-level district specific rural households and other stakeholder issues to facilitate clean energy transition financing.

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[9] The Rockefeller Foundation (2019). *Rural Electrification In India: Customer Behaviour And Demand*. Retrieved from https://www.rockefellerfoundation.org/wp-content/uploads/Rural-Electrification-in-India-Customer-Behaviour-and-Demand.pdf

[10] Srivastava S. & Saboo A. (2022). Renewable Energy Assets in India: A Project Finance Perspective. *Institute for Energy Economics and Financial Analysis (IEEFA).* Retrieved from https://ieefa.org/sites/default/files/2022-06/Renewable%20Energy%20Assets%20in%20India.pdf

[11] Ibid.

[12] NITI Aayog (2022). *List of Aspiring Districts*. Retrieved from https://www.niti.gov.in/sites/default/files/2022-09/List-of-Aspiring-Districts.pdf

[13] Birol, F., & Kant, A. (2022). *India's clean energy transition is rapidly underway, benefiting the entire world – Analysis.* International Energy Agency (IEA). Retrieved from https://www.iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

At the macro level, the study aims to analyse and decode the complex mechanisms and policies that drive DISCOM reforms specifically in the context of clean energy transition financing. By gaining an insight into the broader landscape of DISCOM operations, frameworks and financial structures, the aim was to identify key issues and challenges influencing the integration of renewable energy sources into the power sector.

Respectively, the study aims to delve into the micro-level intricacies within districts in rural areas to uncover and study the challenges and opportunities households and other local stakeholders face in adopting clean energy initiatives. Zooming in on the district-level dynamics will provide an insight into the preparedness of the targeted states and districts in Uttar Pradesh (UP), Bihar, and Jharkhand with regard to utilising the energy transition finance and allocating and distributing it across the various societal segments.

1.2. Objectives and Scope of the Study

The overarching objective of the assignment is to provide accurate, timely, and actionable insights into energy financing and preparedness, facilitating evidence-based decision-making and policy formulation to support the transition towards sustainable, secure, and equitable energy paths in the selected states. The overarching objective has been further broken down into specific objectives for a more granular understanding of the study that needs to be undertaken:

- **Objective 1:** To explore the current state of infrastructure and identify energy usage patterns along with supply, distribution and utilisation of clean energy transition finance, and the drivers and barriers impacting energy financing from representative consumers.
- **Objective 2:** To explore the interaction effect (moderation and mediation) of drivers, barriers, and other relevant parameters.
- **Objective 3:** To assess the energy sufficiency of representative rural consumers (domestic, institutional, and commercial) and identify the challenges in the current electricity supply service.
- **Objective 4:** To assess the key improvements in electricity services from a consumer perspective and the willingness to pay for improved electricity services.
- **Objective 5:** To understand the supply-side aspects – electricity generation, operation and maintenance, distribution, billing, and revenue generation – from agencies/committees operating mini-grids and micro-grids, as well as the cost of the project in terms of total investment, subsidies, sources and terms of funding, and recovery of costs from consumers.
- **Objective 6:** To assess the involvement of the village community, Panchayat, and other community-based organizations in aspects related to electricity delivery, meter reading, billing, and revenue collection.
- **Objective 7:** To explore the nature of demand, the differentiated nature of demand constitution, and what drives demand, including electricity demand required for livelihood-related activities.

The scope of the study is as follows:

- **Examine Distributive Aspects of Energy Transition Finance:** The project is designed to conduct a comprehensive examination of how energy transition finance is distributed. This involves studying the flow of financial resources towards micro-grids, mini-grids, and renewable energy options in selected Indian states, and analysing the efficiency and equity of this distribution.
- **Develop a Framework for Prioritizing Clean Energy Financing:** One of the key goals is to establish a robust framework to prioritize clean energy financing in Indian districts.
- **Identify Gaps and Develop Strategic Approaches:** The project aims to identify existing gaps in energy transition finance from both demand and supply perspectives. It will develop strategic approaches, policies, and action plans to effectively bridge these gaps.
- **Assess Infrastructure and Energy Usage Patterns:** The project includes a thorough assessment of the current state of infrastructure and energy usage patterns. This involves understanding the supply, distribution, and utilization

of clean energy transition finance, as well as the barriers and drivers impacting energy financing from the perspective of consumers.

- **Evaluate Energy Sufficiency for Rural Consumers:** A critical objective is to evaluate the energy sufficiency of rural consumers, including domestic, institutional, and commercial users. This will involve identifying challenges in the current electricity supply service and suggesting possible improvements.

- **Understand Supply-Side Aspects of Energy:** The project will assess the supply-side aspects of energy, including electricity generation, operation, maintenance, distribution, billing, and revenue generation, especially in the context of mini-grids and micro-grids. An exploration of barriers, opportunities, and the way forward of grid-based and off-grid battery and storage solutions will also be attempted to the extent possible.

- **Analyse Community Involvement in Electricity Services:** Assessing the involvement of village communities, Panchayats, and other community-based organizations in electricity delivery is a major objective.

- **Explore the Nature and Drivers of Electricity Demand:** The project will explore the nature of electricity demand in rural areas, particularly the demand for livelihood-related activities. It aims to understand what drives this demand and how it can be sustainably met through renewable energy sources.

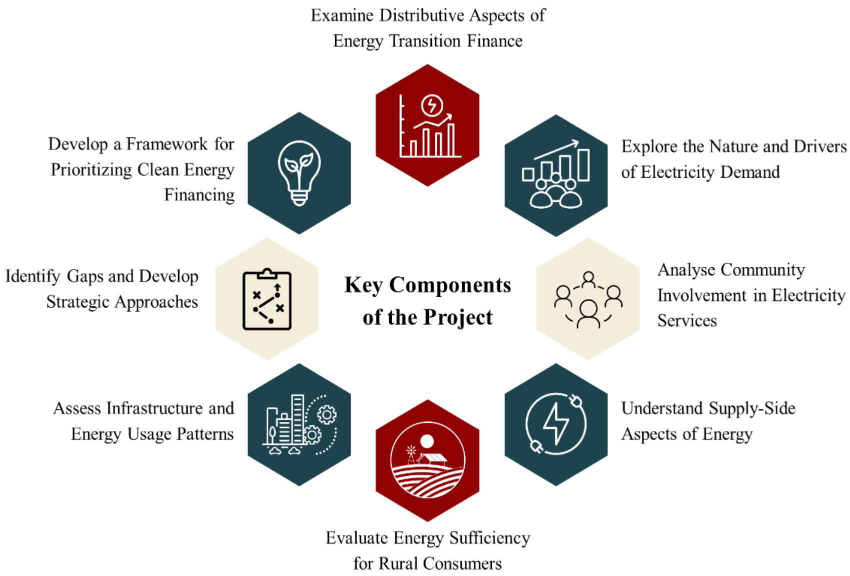

Figure 1: Key components of the study

These components are crafted to provide a comprehensive understanding of the energy transition landscape in rural India, focusing on the financial and infrastructural aspects critical for sustainable development. In addition, the study outputs sought to establish core and peripheral linkages between energy transition financing and Sustainable Development Goals (SDGs). While the core goals of the project are aligned with SDG 13 – climate action and SDG 8 – inclusive and sustainable economic growth; immediate connections can be established with SDG 1 – no poverty, SDG 7 – affordable and clean energy, SDG 9 – industry, innovation and infrastructure, and SDG 10 – reduced inequalities. Critical linkages can be drawn with SDG 3 – good health and well-being, SDG 4 – quality education, SDG 5 – gender equality, SDG 11 – sustainable cities and communities, and SDG 12 – responsible consumption and production; while the wider foundations of the study can be traced to SDG 2 – zero hunger, SDG 6 – clean water and sanitation, SDG 14 – sustainable use of marine ecosystems, SDG 15 – sustainable use of terrestrial ecosystems, SDG 16 – peace, justice and strong institutions, and SDG 17 – global partnerships. The diagram below forms the framework for building on these linkages.

Figure 2: Framework for core and peripheral linkages with SDGs

Following the narrative of the scope of the study Sambodhi devised a series of broad activities to meet the project goals. A thorough approach and methodology, involving mixed-method design was comprehensively developed for data collection. This process began with the development of a suitable methodology and submission of an inception report outlining its scope, objectives, methodology, and initial plan. This was followed by formative research visits to Uttar Pradesh's Bahraich district and Bihar's Samastipur district. During these visits, with the help of non-structured interviews and observational studies, the team explored the nuances of supply and demand in rural energy supply and financing. Simultaneously, preparations were underway for quantitative data collection, with the design and finalisation of questionnaires and discussion guidelines which were pilot tested in the field. The translation of all quantitative and qualitative tools into Hindi ensured that they were properly understood by all the respondents, who were then able to accurately respond to provide the required information.

Since the quantitative survey was undertaken as a digital data collection process, the development and refinement of the Computer Assisted Personal Interviewing (CAPI) programs were undertaken as and when the questionnaires were being prepared. As the plan for groundwork was set, the team created field manuals and prepared for quantitative interviews at the household level. Simultaneously, plans for respondent groups for Focus Group Discussions (FGDs) were laid out, with approval sought from relevant stakeholders.

Further steps required the team to finalise the sampling design, mobilization, selection, and training of interviewers and supervisors. As data collection commenced, the team prepared for the analysis phase, developing detailed plans for both quantitative and qualitative data. Ultimately, the culmination of these efforts resulted in the submission of draft and final reports, alongside the delivery of comprehensive datasets in SPSS/STATA format and finalized transcriptions, marking the conclusion of the project.

1.3. Limitations of the Study

Despite the best efforts by Sambodhi and ACPET teams, the study has certain limitations and the study also faced few challenges. These have been summarized in the following points:

- **Challenges in coverage of planned samples impacting randomness and disproportionate distribution of samples among the states:** Some challenges in communication and coordination with a few implementing agencies impacted the initial selection of sites for the field survey, and eventually led to disproportionate sampling across the three states selected for the study. However, with the cooperation of ACPET, most of such issues were navigated and largely resolved. As a result of these challenges, habitations/villages in many places were selected based on the convenience of receiving support from implementing agencies, thereby impacting randomness of sampling and it led to disproportionate distribution of samples. This might have increased sampling bias while estimating at the aggregate level.

- **Not standardized definition of villages**: In the samples under main grid category, the revenue/census villages were selected from the list of villages from the Census data / Government Directory. However, under mini-grid category samples, hamlets/habitations were selected from the list of villages/habitations received from the implementing agencies and these are not necessarily revenue villages. Therefore, any village level findings should be interpreted accordingly and the comparison of findings at the village level in this report might not be exactly comparable with village level findings of other surveys as in other surveys, particularly Government sponsored surveys, normally revenue/census villages are considered as village level units.

- **Inadequate sample size for village level analysis**: The village level analysis in the report is based on 120 village samples. While conducting estimation, further categorization of villages has been undertaken leading to lesser samples per category of villages. The smaller sample size of different categories of villages does not provide statistical rigour and the village level findings might be only indicative.

- **Challenges in securing interviews with DISCOMs:** Despite best efforts by the field team, qualitative interviews could not be conducted with DISCOM officials at the substation level due to administrative challenges. Therefore, supply and distribution-related insights in this report have been provided from literature review and secondary data analysis.

- **Paucity of time:** Since the study set out to cover multifaced aspects of energy transition, an in-depth understanding and reporting of the same is a time-consuming task. The core research team at Sambodhi have tried to complete the study to the best of their ability in the limited time of around four months that was available. There is scope to draw out richer insights and conduct additional analysis beyond the findings of this report.

2. Approach and Methodology

2.1. Study Design

The study adopts a mixed-methods approach, combining both quantitative and qualitative techniques for data collection and analysis, along with a literature review that focuses on financing models for renewable energy supply in rural areas. This methodological choice enables a more comprehensive exploration of the learning questions, harnessing the strengths of both approaches. By integrating the two methods, the study aims to provide a more nuanced and well-rounded understanding of the subject matter.

The research follows a cross-sectional design that involves collecting data from a diverse group of representative consumers in the rural context and a set of stakeholders involved in the supply side aspects at a single point in time. This strategy offers a snapshot view of the research subject, allowing for the identification of variations or patterns among different segments of the population. The cross-sectional approach provides valuable insights into the current state of the research area, which can be pivotal in decision-making processes.

Furthermore, the study's data collection process is characterized by its inclusivity. The study seeks input from a wide array of stakeholders, encompassing rural consumers of various types (domestic, institutional, and commercial), mini-grid and micro-grid operators, funders and implementors of mini/micro grid projects, as well as community-based organizations. This expansive data collection strategy not only enhances the depth and breadth of the research but also ensures that the perspectives of key actors within the research context are considered.

2.2. Areas of Enquiry

Sambodhi has identified key research questions in the project to be addressed through comprehensive assessment. Measurement of the indicators using the key research questions proposed will help to determine the gaps and understand the existing challenges and issues based on primary and secondary data. The research questions identified for the assessment are -

- **Research Question 1 -** What are the prevailing patterns of energy usage, supply, distribution, and utilisation of clean energy transition finance in the study areas, as well as the actual cost of providing clean energy infrastructure, including maintenance and depreciation costs?

- **Research Question 2 -** What are the primary drivers and barriers affecting energy financing, as perceived by representative consumers? What are the recent trends in budgetary allocation and contribution of MNRE and multilateral agencies in energy transition at the national level based on available data?

- **Research Question 3 -** How sufficient is the energy supply for rural consumers, and what specific challenges do they face in the current electricity supply services?

- **Research Question 4 -** To what extent are rural consumers satisfied or dissatisfied with their energy sufficiency and the existing electricity supply services?

- **Research Question 5 -** What key improvements do consumers desire in electricity services, and how do these align with their preferences and expectations?

- **Research Question 6 -** What is the willingness of consumers to pay for enhanced electricity services, and what factors influence their decision to pay for improvements? What are the current and potential economic improvements for the household, especially income-generating activities for women, that are dependent on sustained and reliable electricity supply?

- **Research Question 7 -** What are the key aspects of electricity generation, operation, maintenance, distribution, billing, and revenue generation in mini-grids and micro-grids operated by agencies and committees in rural areas? What is the role played by the village community, Panchayat, and other community-based organisations in energy transition?

- **Research Question 8 –** What are the major financing models that are prevalent in the renewable energy landscape, and the opportunities and gaps therein? What are the existing dynamics of taxation and subsidies in these models?

Delineating the areas of enquiry ensures that specific, detailed objectives of the study are crystallised, and expectations are aligned. Using the above approach as a reference, the following key questions have been carried out by delving into **primary research.** Based on the research objectives mentioned above, we have formulated the areas of enquiry and the key learning questions in the table below.

Table 1: Key learning questions

DEMAND SIDE			
SN	**Area of Enquiry**	**Learning Questions**	**Data Sources**
1	**Access and Awareness**	• What is the level of awareness among different demographic groups about energy transition financing options? • What are the perceptions about the value that clean energy brings to customers? – Reduction of atmospheric pollution/greenhouse gases? Reduction of smoke and grime in the house? Reduction of cost for electricity services? Others? • How accessible are clean energy options to various communities and regions? What challenges do they face?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • Village questionnaire • FGD
2	**Demand for Renewable Energy**	• What is the current demand for renewable energy technologies and services among households, businesses, and institutions? • How does this demand vary by region and income group? • What is the level of interest and willingness among representative consumers to adopt renewable energy sources for their energy needs?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • FGD
3	**Financial Literacy**	• How aware are providers and potential consumers regarding energy transition financing and the actual cost of clean energy supply both in terms of capital cost and monthly operational costs? • Do they understand the financial instruments such as subsidies and credit facilities under specific government schemes and policies for clean energy adoption?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • FGD • Mini/micro-grid operator questionnaire

4	**Affordability and Barriers**	• How do clean energy costs compare with that of grid-based electricity? How do electricity usage patterns vary across these sources in the case of dual connections? • What are the key barriers to clean energy adoption? How do these barriers differ across regions and communities? • What is the willingness to pay among consumers for improved quality of energy services from renewable sources as well as the main grid?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • FGD
5	**Preference for Clean Energy**	• What are the factors influencing the preference for clean energy sources over traditional fossil fuels? • How does this preference vary based on demographics, income levels and cost of services? • What is the role played by the village community, Panchayat, and other community-based organisations in energy transition?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • Village questionnaire • FGD

SUPPLY SIDE			
SN	**Area of Enquiry**	**Learning Questions**	**Data Sources**
1	**Supply of Financing**	• What are the available sources and types of financing for clean energy transition? • How accessible are these sources for agencies/committees implementing and operating mini-grids and micro-grids?	• Micro/mini-grid operator questionnaire • Implementing agencies (TRIF, PRADAN, MCT, HCL) • Literature review and secondary data analysis
2	**Investment in Clean Energy**	• What are the emerging policies on investment in clean energy? • What is the level of dependency of consumers on grid-based electricity systems? What is the scope of investments for expansion in the clean energy sector? • What are the opportunities and infrastructure constraints in grid-based energy storage solutions? • Are there specific sectors or technologies receiving more funding?	• Household questionnaire • Institutional consumer questionnaire • Commercial consumer questionnaire • Mini/micro-grid operator questionnaire • Implementing agencies (TRIF, PRADAN, MCT, HCL) • Literature review and secondary data analysis
3	**Financial Inclusion**	• To what extent is financing for energy transition reaching underserved and marginalized communities? • Are there initiatives to promote financial inclusion in clean energy projects? • To what extent are local communities, including the village community, Panchayat, and other community-based organizations, involved in financial aspects related to electricity delivery, meter reading, billing, and revenue collection?	• Village questionnaire • Mini/micro-grid operator • District-level electricity department KII • Literature review and secondary data analysis
4	**Role of Financial Institutions**	• How actively are financial institutions (NBFCs, banks, microfinance, etc.) involved in providing energy transition financing? • Are there partnerships or collaboration models with renewable energy companies?	• Mini/micro-grid operator • Implementing agencies (TRIF, PRADAN, MCT, HCL) • Literature review and secondary data analysis
5	**Innovation and Technology**	• What innovative financing mechanisms and technologies are being used to facilitate energy transition financing? • What are the prevailing financial models in the domain of energy transition? How have innovations and emerging trends affected the financing landscape, especially from the perspective of agencies operating mini-grids and micro-grids?	• Mini/micro-grid operator • Implementing agencies (TRIF, PRADAN, MCT, HCL) • Literature review and secondary data analysis

These learning questions have helped the project assess the dynamics of energy transition financing, from the perspectives of both those seeking financing for clean energy initiatives (demand-side) and those responsible for providing financing (supply-side). This approach has provided a comprehensive understanding of the energy transition finance landscape in select Indian states.

2.3. Sampling

2.3.1 Sampling Methodology

The objective of the sampling approach and methodology was to ensure adequate representativeness at the level of evaluation unit across different components of project interventions. The sampling designs of the quantitative and qualitative studies are described below.

2.3.2 Sample for Quantitative Survey

A multi-indicator analysis **based on machine learning-based clustering methods** was undertaken to segregate states into aspiring and laggard states/districts, and a representative selection of states and districts was undertaken by the ACPET team.

The selected states for the study are Uttar Pradesh, Jharkhand, and Bihar. In each state, a mix of aspiring (representing the more developed) and laggard districts were covered for the survey. The selection of districts was randomly undertaken from the two groups of aspiring and laggard districts, mapped to the presence of renewable energy mini/micro-grid projects. The districts have been chosen after a mapping exercise with the list of aspiring districts under the Aspiring Districts Programme of Niti Aayog, backed by the secondary data-based machine learning analysis which created a cluster of aspiring and developed districts within each state based on their range of development indicators linked to various SDGs. Four districts had been selected in each state, and a total of 13 districts across Uttar Pradesh, Bihar, and Jharkhand were covered. The list of selected districts is as follows:

Table 2: State-wise sampled districts categorized under aspiring and laggard

State	District	Type of district (from ACPET multi-indicator analysis)
Jharkhand	Gumla	Aspiring
	Simdega	Laggard
	Lohardaga	Laggard
	Khunti	Laggard
	Palamu	Aspiring
Bihar	Banka	Laggard
	Jamui	Laggard
	Samastipur	Aspiring
	Begusarai	Aspiring
Uttar Pradesh	Hardoi	Aspiring
	Bahraich	Laggard
	Shravasti	Aspiring
	Lakhimpur Kheri	Laggard

Selection of villages/habitations: In the samples under main grid category, the revenue/census villages were selected from the list of villages from the Census data / Government Directory. However, under mini-grid category samples, the word village does not necessarily mean revenue villages as many of these are hamlets/habitations that were selected from the list of villages/habitations received from the implementing agencies. In each district, the proposed sample specified a selection of 10 villages, however, due to logistical challenges, 7-10 villages per district were selected, with a mix of grid-based and off-grid decentralized mini/micro-grid centric solar energy-based electricity supply. The latter category also included villages with a dual source of energy supply, dependent on both the main grid and mini/micro-grid. ACPET had suggested that 50% of the total sample was to be allocated for mini/micro-grid villages in each state, however mini grid villages were unequally covered in different states due to logistical challenges. In each state, against the proposed 40 villages, 28-52 villages were covered, with a shortfall in UP that was covered by an overachievement in Jharkhand. A total of 120 villages were covered across three states. The number of the main grid and mini-grid villages covered in each state is provided in the table below.

Table 3: Distribution of main grid and mini grid villages sampled across states

State	Main Grid Villages	Mini Grid Villages	Total
Uttar Pradesh	21	7	28
Jharkhand	24	28	52

Bihar	38	2	40
Total	**83**	**37**	**120**

ACPET team facilitated the process of obtaining complete lists of renewable villages/ habitations in each selected district from the implementing agencies for sampling, after which the Sambodhi team selected villages/habitations with renewable energy projects through systematic random sampling. Main grid villages were sampled by Sambodhi from the Census in each selected district using systematic random sampling methodology. For all the sampled villages, the Sambodhi team verified from implementation agencies the presence and functional status of mini/micro-grid projects. In case the electricity supply from the renewable energy project was not functional, the same was documented, and a replacement village/habitation with a functional mini/micro-grid was selected appropriately.

Selection of households (domestic consumers): As per the proposed sample, in every sample village, a quantitative survey was to be conducted involving **20 randomly selected households,** but due to the above limitations this was revised to **16-20 randomly selected households**. This included 16 households with functional electricity connections, 2 households with disconnected electricity connections, and 2 households with no electricity connections, wherever applicable. If there was a shortage of samples in the last two categories, additional samples were drawn from households with functional electricity connections. In case a village had a dual electricity supply from the main grid as well as a solar mini grid, the sampling was considered based on the electricity connections provided by the renewable energy grid. In case the renewable energy project serves as a backup to the grid-based supply, and connections are largely provided to commercial consumers, then the majority of the domestic consumer sample was replaced by the commercial consumer sample.

In villages with renewable energy supply, if there were little to no commercial connections, then only domestic consumers were included. In such a case, an effort was made to include 2 – 3 households with household enterprises, which have some association with electricity usage. If part of the domestic consumer could not be covered due to paucity of electricity connection, then the remaining were sampled from the commercial consumers on a pro-rata basis.

Selection of institutional and commercial consumers: Furthermore, in each village, 2 institutional consumers and 2 commercial consumers were planned to be interviewed. A total of 238 institutional consumers and 305 commercial consumers were covered across three selected states against the standing 240 institutional consumer interviews and 240 commercial consumer interviews that were intended according to the proposed sample, depending on the availability of such consumers in the sampled villages. For commercial consumers, the total sample is representative of small/petty, and medium to large enterprises.

Community representative interviews (Village questionnaire): Additionally, a structured interview was conducted at the village level with Panchayat and community representatives to complete the village-level questionnaire. The village-level discussion included information on the electricity supply situation(s) in the village. A total of 120 village-level interviews were conducted.

Interviews with mini-micro grid operators: in each district, 2-3 mini-micro grid operators were planned to be selected purposefully for the study. A total of 44 mini-micro grid operators were covered across three states using a structured questionnaire. The sample mini/micro grid operators were identified before visiting the field with the help of the ACPET team. If the financing of projects and the information on operation and maintenance were undertaken with different entities, the discussion was accordingly designed. Central managerial stakeholders in the implementing agencies were able to provide information on the construction and financing of the project through a separate qualitative questionnaire administered to them during a discussion on topline findings, while information on operation and maintenance was collected at the village level with the structured tool.

Thus, with the coverage of the above types of samples, a total of 3,059 against the proposed sample of 3,030 quantitative interviews were conducted, including 2,352 household interviews, 238 institutional consumer interviews, and 305 commercial consumer interviews. Additionally, 44 mini/micro grid operators and 120 community representatives in the sampled villages were surveyed.

The following overall sample size was covered for the study:

Table 4: Quantitative sample distribution

S.N.	Type of sample	Uttar Pradesh	Bihar	Jharkhand	Total

1	Districts	4	4	5	13
2	Villages	28	40	52	120
3	Community representative interviews (Village questionnaire)	28	40	52	120
4	Household interview	463	818	1071	2,352
5	Institutional consumer interview	45	87	106	238
6	Commercial consumer interview	128	81	96	305
7	Mini/micro grid operator	-	20	24	44
	Total quantitative interviews				**3,059**

2.3.3 Sample for Qualitative Survey

While the quantitative arm of the study helps understand 'what' has happened, it is also important to understand 'why' observed outcomes have come about and what are the reasons for impact heterogeneity.

In each state, 6-7 Focus Group Discussions (FGDs) were conducted with demand-side stakeholders, which means a total of 22 FGDs were conducted across three states. The following stakeholders were covered:

- FGDs with consumers availing electricity from renewable energy sources – mini/micro grid, rooftop solar panels, PM KUSUM pumps, etc.
- FGDs with consumers whose electricity connection is not functional/is disconnected.
- FGDs with community stakeholders (including Gram Panchayat, SHGs/CBOs) involved in rural electricity operations – meter reading, billing, revenue collection, and monitoring.

The total sample numbers covered for each category are provided in the table below:

Table 5: Qualitative sample distribution

S.N.	Stakeholder category	Tool	Sample
1.	Renewable energy consumers – mini/micro-grid, rooftop solar panels, PM KUSUM pumps	FGD	11
2.	Consumers with non-functional/disconnected electricity connections	FGD	4
3.	Community stakeholders (Gram Panchayat, SHGs/CBOs/FPOs)	FGD	7
	Total		**22**

In addition to the above, two telephonic interviews were conducted with members from implementing agencies Transform Rural India (TRI) Foundation and Mlinda Charitable Trust for information about specific supply-side insights related to implementation and financial models.

2.3.4 Analysis Plan

Demand-Side Assessment: The demand-side assessment focused on understanding consumer preferences, awareness, energy utilisation, quality and reliability of electricity services, knowledge regarding energy transition financing, and the willingness to pay for service improvements involving the analysis of the collected data from the demand side. The study explored household, commercial, and institutional preferences for energy transition financing and identified key factors influencing their choices.

The study included an assessment of how well consumers grasp the financing options available to them, whether they are aware of incentives or subsidies, and whether they can make informed decisions regarding energy transition projects.

This provided a comprehensive view of the demand side aspects, allowing the study to identify areas where consumer education and awareness campaigns may be necessary and pinpoint specific preferences and expectations that need to be addressed to encourage greater uptake of clean energy among rural consumers.

Supply-Side Assessment: The supply-side assessment focused on evaluating existing financing options and mechanisms for rural renewable energy projects, as well as the actual cost of services vis-à-vis the charges, allowing for a comprehensive view of the supply side aspects. Here, the data collected from an extensive literature review as well as a structured survey administered to mini/micro-grid operators was reviewed and analyzed, as this information provided insight into the types of financing mechanisms and business models in place, their effectiveness, and their coverage across different regions. It also helped identify any gaps or limitations in the supply of financing.

This assessment involved an examination of the sources of finance for renewable energy solutions, the types of business models, the structure of financing as well as the existing gaps therein. We assessed their operations, policies, and the range of services they offer. The findings highlighted the criteria for the selection of geography and specific rural contexts for setting up renewable energy projects that are scalable. This assessment helped understand the supply side's capacity to meet the demands of energy transition projects and will give a clear picture of the strengths and weaknesses in the supply of financing for energy transition projects. This knowledge fed into the synthesis and recommendations phase, which provided insights on how to bridge the supply-side gaps effectively and ensure the sustainability of current interventions, as well as policy-level inputs for scaling up such projects. The framework to report on different financing models and the information is included in the analysis and presentation of findings.

2.4. Field Preparatory Steps

2.4.1 Formative Research

In pursuit of gaining valuable insights for the formative research on clean energy transition financing in India, our research team conducted two simultaneous field visits from the 20th to the 22nd of December 2023. The formative research conducted had clear objectives that aimed at understanding key aspects of renewable energy financing in rural India. First, an in-depth review of existing literature was conducted to grasp the various financing models and their effectiveness, challenges, and opportunities. Second, was to delve into the delivery of electricity services to different user groups, evaluating operations, billing practices, and the socio-economic impact of electricity availability. Third, requires investigating the broader energy supply infrastructure, analyzing traditional and renewable sources' operational dynamics and impact on local energy consumption. Finally, the insights from the literature were applied to real-world scenarios in specific locations in Uttar Pradesh and Bihar, gathering diverse stakeholder perspectives on energy financing.

Regarding the scope of the research, it was anchored in a comprehensive literature review that informed subsequent field visits' methodology. Districts were selected in Bihar and Uttar Pradesh based on a multi-indicator composite index developed by the ACPET Team. These districts represented different levels of development and the presence of renewable energy mini grids. Integration of these insights guided the design of effective quantitative and qualitative tools for the main survey, ensuring a holistic approach that balanced theoretical knowledge with on-ground realities.

The field visit helped in gaining insightful information about the prevailing situations in different states for instance in Bahraich District, Uttar Pradesh, the team collaborated with the Transforming Rural India Foundation (TRIF) to explore Motipur Village in the Mihinpurwa block. This visit helped to gain insights into an upcoming solar mini grid plant managed by women members of the Farmers' Producer Organization (FPO). Discussions with the village Pradhan, and the key consumers for the mini-grid scheme and the usage dynamics, including the carpenters, provided the researchers with diverse perspectives on electricity supply dynamics. The visit concluded with a debriefing session, offering a comprehensive understanding of solar mini grids and traditional electricity supply.

Shifting focus to Samastipur District, Bihar, the team partnered with Jawahar Jyoti Bal Vikas Kendra (JJBVK) and visited Akhtiyarpur Village. Interestingly, they found that solar panels were only used for the organization's office energy needs and not for the villagers in general. The exploration continued to Kashipura village, where discussions with JJBVK officials shed light on the villagers' solar energy reliance. In Darwa and Halai villages, interactions with consumers connected to the main grid and solar mini grid deepened our understanding of dual-energy consumption patterns. Further visits to Raipur Bujurg Pethia, Raipur Bajar, and Gangsara uncovered insights into solar microgrid usage and local energy dynamics.

2.4.2 Centralized Field Training

As all the selected states of the study (Uttar Pradesh, Bihar and Jharkhand) are Hindi speaking states and the survey was to be undertaken in a time bound manner, the field training for the study for all the states was conducted centrally at Lucknow as it served as a convenient location accessible to all participating state team members. The training was conducted exclusively in Hindi, the language common across all states involved in the study. This approach ensured uniformity and consistency in communication throughout the research process.

The training sessions were structured to cover both quantitative and qualitative aspects separately, emphasizing key concepts, survey protocols, questionnaire administration techniques, and adherence to established guidelines. The training curriculum also included protocols for quality checks to maintain the integrity and accuracy of the data collected. Experienced researchers from the Sambodhi core team led the training sessions, providing valuable insights and guidance to the field staff.

Participants received training on both hard copy tools and Computer-Assisted Personal Interviewing (CAPI) methods, equipping them with the necessary skills to effectively collect data using diverse mediums as well as ensuring that the questionnaires and routing patterns were clearly understood. The training sessions were attended by Field Managers and Field Executives representing all participating states. Each state was allocated three teams, totaling nine teams across the three states. Each team consisted of one supervisor responsible for overseeing operations and four interviewers tasked with conducting surveys. Additionally, a contingent of four to five buffer interviewers was trained to provide flexibility and support as needed throughout the data collection process.

The comprehensive training program spanned five days, with an additional day allocated for field practice to simulate real-world scenarios and allow enumerators to practice their skills in a controlled environment. This hands-on approach not only enhanced the proficiency of the field staff but also instilled confidence and readiness for the challenges they would encounter during actual data collection activities.

3. Literature Review

India's energy transition, characterized by a robust shift towards renewable energy, underscores the nation's commitment to sustainable and clean energy solutions and to global climate imperatives and its alignment with ambitious climate commitments, including the pledge to achieve net-zero emissions by 2070, as announced by Prime Minister Narendra Modi at the COP26 summit (Ministry of Science & Technology, 2023)[14]. With an installed non-fossil fuel capacity exceeding 179.57 GW as of November 2023, representing about 42% of its total capacity, India has emerged as a formidable player in the global renewable energy landscape (Ministry of New and Renewable Energy, 2023)[15]. This growth and transition are buoyed by an ambitious target to achieve 500 GW of non-fossil fuel-based energy by 2030, encompassing solar, wind, and green hydrogen sectors, as part of the Panchamrit action plan (Ministry of Science & Technology, 2023)[16]. This is supported by a comprehensive strategy that includes the adoption of renewable energy, e-mobility, ethanol-blended fuels, and green hydrogen, underpinned by India's updated Nationally Determined Contributions (NDCs) following the Paris Agreement, committing India to reduce the emissions intensity of its GDP by 45 percent by 2030 from 2005 levels (Ministry of Environment, Forest and Climate Change, 2022)[17].

Government initiatives such as the Renewable Purchase Obligation (RPO), which mandates a specific share of energy consumption to be derived from renewable sources, escalating to 43.33% by 2029-30, alongside strategic schemes like the Solar Park Scheme and the PM-KUSUM Scheme, have played pivotal roles in this expansion (Ministry of Power, 2022[18]; Invest India, n.d.[19]).

Despite the progress, the energy transition in India faces several research gaps, particularly in financing mechanisms and the integration of renewable energy into the existing grid. The reliance on traditional banking and non-banking financial institutions for project financing underscores the critical need for innovative financial models to support the unique demands of renewable energy projects. Furthermore, there is a need for research into scalable solutions for energy storage and grid integration to manage the intermittent nature of renewable sources and ensure a stable and reliable energy supply. The financial allocations and strategic policy initiatives, such as the Union Budget 2023's

[14] Ministry of Science & Technology (2023). *India is committed to achieve the Net Zero emissions target by 2070 as announced by PM Modi, says Dr. Jitendra Singh*. Retrieved from https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1961797

[15] Ministry of New and Renewable Energy (2023). *Non-fossil fuel sources account for nearly 44 per cent of India's total installed electricity generation capacity.* Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1983201

[16] Ministry of Science & Technology (2023). *India is committed to achieve the Net Zero emissions target by 2070 as announced by PM Modi, says Dr. Jitendra Singh*. Retrieved from https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1961797

[17] Ministry of Environment, Forest and Climate Change (2022). *Cabinet approves India's Updated Nationally Determined Contribution to be communicated to the United Nations Framework Convention on Climate Change.* Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1847813

[18] Ministry of Power (2023). *Renewable Purchase Obligation and Energy Storage Obligation Trajectory till 2029-30.* Retrieved from https://powermin.gov.in/sites/default/files/webform/notices/Renewable_Purchase_Obligation_and_Energy_Storage_Obligation_Trajectory_till_2029_30.pdf

[19] Invest India (n.d.). *Renewable Energy in India - Indian Power Industry Investment.* Retrieved from https://www.investindia.gov.in/sector/renewable-energy

earmarking of INR 35,000 crores for energy transition (Ministry of New and Renewable Energy, 2023)[20] and the National Green Hydrogen Mission (Ministry of New and Renewable Energy & Ministry of Environment, Forest and Climate Change, 2022)[21], underscore the government's efforts towards this shift. However, addressing these research gaps requires a multi-disciplinary approach, encompassing technological innovations, financial modelling, and policy frameworks, to foster a robust, sustainable, and diversified energy ecosystem.

In synthesizing a comprehensive understanding of India's energy transition, it becomes evident that bridging these research gaps is essential for the nation to meet its ambitious renewable energy targets and cement its position as a leader in the global shift towards sustainable energy solutions.

3.1. Major Components of the Energy Transition Financing Ecosystem

The financing ecosystem for India's energy transition is multifaceted, reflecting the complexity and scale of the shift towards renewable energy sources. Central to this ecosystem are three primary financing models: Government Lending, Private Finance Initiatives (PFI), and Public-Private Partnerships (PPP). Each model plays a crucial role in the development and expansion of the renewable energy sector, reflecting a strategic approach to meet the ambitious targets set forth by the government.

Government Lending is a key component, where direct financing from government bodies is provided to renewable energy projects. A prime example of this is the Clean Energy Finance Investment Program by the Asian Development Bank (ADB) and the Government of India, aiming to support renewable energy projects including wind, biomass, hydropower, and solar through the Indian Renewable Energy Development Agency (IREDA). This program leverages private capital to increase lending for at least 10 renewable energy projects and includes training for government officials on project finance (Asian Development Bank, 2014)[22].

Private Finance Initiatives (PFI) involve private sector investment in public projects. Here, private investors finance, construct, and manage projects, generating profits through leasing or power sales agreements. The Rooftop Solar programme under the Ministry of New and Renewable Energy (MNRE), which installed about 741 MW capacity from January to November 2023, serves as an example. This initiative demonstrates how private and government collaboration can significantly contribute to the energy transition, with an additional approximately 2.77 GW capacity installed in all sectors with or without Central Financial Assistance during the same period (Ministry of New and Renewable Energy, 2024)[23].

Public-Private Partnerships (PPP) merge the efficiency of the private sector with public oversight. These partnerships co-invest in renewable energy projects, sharing risks and rewards. The success of the Initial Public Offer (IPO) of IREDA in November 2023, which was subscribed a strong 38.80 times, illustrates the effectiveness of PPP in attracting investor confidence and raising capital for renewable energy projects (Ministry of New and Renewable Energy, 2024)[24].

Another notable mention is the **Reserve Bank of India's (RBI)** revision of its guidelines in August 2019, categorizing the renewable energy sector as a priority lending sector. This categorization underscores the strategic importance of renewable energy and ensures that projects in this sector receive timely and sufficient credit availability, further bolstering the transition towards sustainable energy solutions (Green Finance Platform, 2019)[25].

These components of the energy transition financing ecosystem, underpinned by governmental, private, and collaborative financing models, are essential for India's progress toward its renewable energy goals. They reflect a comprehensive strategy to leverage diverse financing sources and models, ensuring the growth and sustainability of the renewable energy sector in the face of evolving technological, economic, and environmental challenges.

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[20] Ministry of New and Renewable Energy (2023). *PROMOTION OF CLEAN ENERGY - Major steps taken by the Government to accelerate the Indian economy's transition to one powered by green energy – Union Power & NRE Minister*. Retrieved from https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1907698

[21] Ministry of New and Renewable Energy & Ministry of Environment, Forest and Climate Change (2022). *India geared for Energy Transition and Climate Action Union Budget 2022-23 provides a roadmap for clean energy and climate mitigation – a development priority for the next 25 years.* Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/feb/doc202222519401.pdf

[22] Asian Development Bank (2014). *Clean Energy Finance Investment Program* (India) [Project Report]. Retrieved from https://www.adb.org/projects/46268-001/main

[23] Ministry of New and Renewable Energy (2024). *Year End Review 2023 of Ministry of New & Renewable Energy*. Retrieved from https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1992732

[24] Ibid.

[25] Green Finance Platform (2019). *Reserve Bank of India Guidelines on Lending to Priority Sectors, Including Renewable Energy*. Retrieved from https://www.greenfinanceplatform.org/policies-and-regulations/reserve-bank-india-guidelines-lending-priority-sectors-including-renewable

3.2. Insights from Formative Research

The journey towards a sustainable and equitable energy transition in rural India is characterized by a blend of advancements, challenges, and untapped potential. Our formative research, as described in the previous chapters, was conducted in the diverse contexts of Uttar Pradesh and Bihar and sheds light on the intricate landscape of energy financing and consumption patterns in these areas.

- **Energy Supply Dynamics: A Dual Reliance**
  In rural landscapes, such as those observed in Bahraich, Uttar Pradesh, and Samastipur, Bihar, the reliance on a mix of grid and mini-grid electricity supply highlights a critical phase in the energy transition journey. This duality, characterized by the integration of traditional grid supply with renewable energy sources, notably solar power, illustrates the adaptive strategies communities employ to mitigate the unreliability of grid electricity. The seasonal fluctuations in power supply, exacerbated during the summer months due to increased demand, underline the essential role that renewable energy, particularly solar power, plays as a supplementary source, ensuring stability and reliability in electricity access.

- **Financing Renewable Energy: A Variegated Landscape**
  As mentioned in the previous section, the financing of renewable energy in rural India showcases a spectrum of models, from government lending and PFIs to PPPs, each catering to different facets of the renewable energy ecosystem. Government initiatives such as the PLI Scheme and the Viability Gap Funding (VGF) for BESS projects exemplify the multifaceted approach to stimulating the renewable energy sector. Furthermore, the success of IREDA's public subscription highlights the burgeoning confidence of investors in India's renewable energy prospects, underscoring the potential for scalable growth and sustainability within the sector.

- **Community Engagement and Empowerment**
  The transition to renewable energy is deeply intertwined with community engagement and empowerment, as observed in the formative research findings. The aspirations for improved quality of life through access to advanced electrical appliances and sustainable energy solutions reveal a community ready for transition but hampered by a lack of awareness and support infrastructure. The proactive engagement of local communities in discussions and planning for renewable energy projects, as seen in the involvement of women-led FPOs in managing solar mini-grid projects, marks a significant step towards inclusive and sustainable energy transition strategies.

- **Addressing Challenges: Infrastructure and Economic Viability**
  While the push towards renewable energy in rural India is evident, several challenges persist, notably the need for a robust infrastructure to support the deployment of renewable energy solutions and the economic viability concerns associated with the high initial costs of solar installations. The experiences from field visits underscore the necessity of addressing these challenges through a combination of policy support, community engagement, and innovative financing solutions that reduce the economic burden on rural households and enterprises.

The formative research conducted in Uttar Pradesh and Bihar provides critical insights into India's rural energy transition, highlighting the complex yet promising path towards achieving sustainable and equitable energy access. The interplay of innovative financing, community engagement, and policy support emerges as a crucial driver in navigating the challenges and leveraging the opportunities inherent in this transition. As India continues its journey towards a sustainable energy future, the lessons learned from these rural landscapes will be invaluable in shaping effective strategies for energy transition not only within the country but also in other similar contexts globally.

3.3. Stakeholder Consultation on Gaps in Energy Transition Financing Landscape

A stakeholder consultation was organised by ACPET in collaboration with Sambodhi on 15th March 2024, with implementing agencies and partner organizations such as Mlinda Charitable Trust (MCT), Transform Rural India Foundation (TRIF), HCL Foundation and PRADAN, who are working in the domain of energy transition in rural India. Insightful discussions were conducted on the prevalent gaps in the preparedness of states to facilitate and finance energy transition initiatives in rural settings.

The discussion was centered around themes such as the impact of energy transition initiatives on the lives and livelihoods of rural communities, regional diversifications in the landscape, differences in energy requirement across consumer categories, the extent to which these requirements are being met as well as the gaps and challenges in the same, the degree of satisfaction of consumers and their willingness to pay for improved services. The findings section of the report sheds light on these aspects in further detail. The report also explores differences in outcomes in geographies that are solely dependent on electricity supply from the main grid, geographies that are solely reliant on electricity supply from solar mini grids, and geographies that have a hybrid system of electricity supply from both main and mini grids. The differences in the quality of electricity services received by households in terms of age and capacity of mini grids is also highlighted in following sections.

Several supply side aspects such as business and finance models were also discussed in depth. A profiling of the same has been provided in the report, highlighting their revenue inflows, funding structures, load profiles and capacity utilization. The discussion highlighted the following ways to address financing gaps –

- Identification of context-specific load drivers – such as manufacturing units, institutional buyers like Anganwadi Centres, health and wellness centres, etc. – which are integrated into the agricultural and social enterprise value chains in the local economy
- Integration of job creation and the digital economy with commercial and institutional load centres in rural settings
- Provision of grant-based capital expenditure and minimal interest-based support for operating expenditure
- Replication of blended financing models so that the break-even point can be reached earlier
- Technology-specific optimum module expansion for the creation of new load centres

Some of the immediate action points were outlined as follows:

- Energy transition financing in different load centres by balancing seasonality and anchor load profiling
- Ensuring mitigation of power outages within 2-3 hours, reduction of power thefts along with protection of inverters
- Investments specific to business models, catalytic financing of operating expenditure complemented with the creation of replicators with anchor load profiling and assessment in different location contexts
- Utilisation of the benefits of carbon trading for subsidy provisioning in energy transition financing

The principles of accessibility, availability, reliability, quality, and affordability (AARQA framework[26]) has guided the reporting of findings as well as outlining a set of recommendations that may inform the long-term vision and strategy of India for an equitable, viable and sustainable energy transition pathway.

Subsequently, a discussion was conducted on 1st May 2024 with key stakeholders to deliberate upon the key findings of the study. A crucial insight that emerged is that mini grid supply is addressing the gaps that arise out of the unreliability of main grip supply. However, the willingness to pay for service improvements is contingent on affordability constraints, which in turn depends on consumption expenditure and income of households. One way to make mini grid operations viable is identifying anchor loads, which primarily include commercial enterprises, diesel generators, markets, institutions such as Anganwadi Centres, Panchayat offices, schools, etc. The key drivers for renewable energy demand include improving access to energy to meet basic needs, the lack of reliable options, and reduction in costs. Consumers have demonstrated a preference for the cheapest and most reliable alternative when it comes to electricity service providers, highlighting the centrality of cost-effectiveness in decision-making.

While CSR funding is crucial in initiatives geared towards ‘greening the grid’, the exit space needs to be clearly defined in the roadmap towards sustainability of these initiatives. Village-level energy committee models running renewable energy initiatives have been successful in many geographies such as Chhattisgarh and West Bengal. This approach encourages greater involvement of beneficiaries in the operations of energy supply through the community transference of ownership and accountability, which has had a positive impact on outcomes. The discussion was concluded with the understanding that the medium and long-term impact of energy transition initiatives depends on a robust policy ecosystem and favorable market dynamics, both of which are context-specific in nature. This highlights the importance of flexibility and evolution that go beyond a one-size-fits-all approach to energy transition solutions.

[26] https://web.iitd.ac.in/~pmvs/courses/rdl722/RuralEnergy_India.pdf

3.4. Financing and Revenue Models

Table 6: Matrix presenting the different types of financing models, their descriptions, challenges, opportunities, and their relevance in the Indian Renewable Energy Sector

Financing Model	Description	Challenges	Opportunities	Relevance in the Indian Renewable Energy Sector
Revenue-Based	• Involves capital investment from investors in exchange for a percentage of ongoing gross revenues. The repayment is linked directly to the revenue, with investors receiving a regular share until a predetermined amount, typically a multiple of the principal investment, is paid back. • This particularly appeals to startups and small enterprises in the renewable energy sector.	• Unpredictability of revenue streams. • Can be exacerbated by changes in government policies related to tariffs and subsidies, technology costs, and market demand, making it less attractive to investors looking for stable returns[27]. • The risk of fluctuating revenue streams may not be suitable for early-stage or highly innovative projects due to their unpredictable revenues.	• Could be suitable for established renewable energy projects with consistent revenue streams. • While not widely adopted in India, it could find applications in established renewable energy projects with more predictable revenue streams, such as operational solar farms or wind projects with long-term power purchase agreements (PPAs). • Attractive for established companies with stable revenues. • Allows companies to maintain control while accessing capital. • Represents a novel and flexible financing option, particularly suited for the renewable energy sector. • Offers a non-dilutive, revenue-linked repayment structure that aligns investor and business interests.	• Not prominently featured due to the variable nature of revenue in energy projects, influenced by factors such as policy changes and market demand[28]. • Typically suits businesses with predictable revenue streams, which renewable energy projects, especially new or experimental ones, might lack. • Relatively new and evolving concept. • Direct data about the model for solar energy projects in India is limited. • Growing adoption signifies a shift towards more innovative financing methods in the Indian market[29].

27 https://www.mondaq.com/india/renewables/1339514/renewable-energy-sector-in-india-recent-developments
28 https://www.mondaq.com/india/renewables/1339514/renewable-energy-sector-in-india-recent-developments
29 https://www.investindia.gov.in/team-india-blogs/revenue-based-financing-101

Financing Model	Description	Challenges	Opportunities	Relevance in the Indian Renewable Energy Sector
Philanthropic	• Typically involves funding from non-profit organizations or charitable foundations, focusing on sustainable and socially impactful projects rather than financial returns. • Involves various forms of support, including grants, loans, and funding from philanthropic organizations and international financial institutions. • Aims at supporting initiatives that may not offer immediate financial returns but have a significant impact on community development and environmental sustainability.	• Limited availability and sustainability of funds compared to the requirements of large-scale renewable energy projects. • It may not always align with market-driven approaches. • Challenges with aligning the goals of philanthropic organizations with those of energy projects.	• Supports projects with high social or environmental impact that might not be commercially viable. • Encourages innovation in areas that may be overlooked by traditional investors. • These funds are usually aimed at research, pilot projects, or supporting communities to transition to renewable energy.	• The World Bank has been actively involved in supporting renewable energy projects in India. For instance, agreements were signed for a $150 million loan, a $28 million Clean Technology Fund (CTF) loan, and a $22 million CTF grant to increase India's power generation capacity through renewable energy sources. This financial support underscores the Indian government's commitment to achieving cleaner energy sources[30]. • The World Bank also approved $165 million in additional financing to support India's residential sector in adopting rooftop solar systems, making solar energy more affordable. This initiative is part of the broader effort to expand renewable energy sources across the country[31].

[30] https://www.worldbank.org/en/news/press-release/2022/12/16/world-bank-signs-project-to-scale-up-innovative-renewable-energy-technologies-in-india
[31] https://www.worldbank.org/en/news/press-release/2022/06/28/world-bank-provides-165-million-to-support-renewable-energy-in-india-s-residential-sector

Financing Model	Description	Challenges	Opportunities	Relevance in the Indian Renewable Energy Sector
Equity-Based	• Involves investors directly investing by buying a stake in a renewable energy project or company. • Investors are seeking to capitalize on the growing demand for clean energy while also contributing to sustainable development. • These investments are helping startups in the renewable energy sector, particularly in solar and wind, to scale up their operations, innovate, and contribute significantly to India's renewable energy goals.	• Potential dilution of ownership for original stakeholders. Investors may demand a significant say in business operations. • Challenges related to regulatory complexities, land acquisition, and grid integration. • Alignment of long-term objectives between investors and project owners[32].	• Can provide substantial capital for growth. Attracts a wide range of investors, including venture capitalists and angel investors. • Large-scale capital influx, risk-sharing, and potential for significant capacity growth.	• Greenko Energy Holdings, an India-based renewable energy company, raised a significant amount of equity from two other entities: Cambourne Investment Pte Limited, a sovereign wealth enterprise (SWE) of Singapore's GIC Private Limited, and a SWE of the Abu Dhabi Investment Authority (ADIA). In one of the funding rounds, Greenko raised $230 million in equity from these investors. ADIA contributed $150 million, and GIC invested $80 million in this round[33]. • Greenko Energy Holdings raised an additional $329 million from GIC and ADIA. This funding was part of a larger primary equity fundraising effort of $824 million, which included a previously announced $495 million that Greenko received from GIC and ADIA. These funds were intended to support Greenko's business plan for two years, financing the capital expenditure of renewable energy projects and exploring acquisitions[34]. • The Indian government introduced Infrastructure Investment Trusts (InvITs) as an innovative financing mechanism for renewable energy projects[35]. These InvITs allow investors to invest in renewable energy assets, providing them with regular income. These trusts are appealing due to their structure, which mandates the distribution of 90% of net distributable cash flows to investors, and limits on leverage and under-construction asset exposure[36]. • Hyderabad-based Fourth Partner Energy, which provides rooftop solar energy solutions, raised $125 million from investors to strengthen its presence across South and Southeast Asia[37]. • CleanMax Solar, focusing on rooftop solar and open access solar for commercial and industrial segments, raised Rs 275 crore from a Macquarie-managed UK Climate Investment[38]. • India ranks ninth globally for climate tech investment, with the country's climate tech firms receiving $1 billion in venture capital funding between 2016 and 2021. This influx of capital is not just limited to solar energy but extends across various segments of the renewable energy sector, including wind energy[39]. • The Mahindra Group, a prominent Indian conglomerate, entered into a strategic partnership with Canada's Ontario Teachers' Pension Plan Board (OTPPB) involving the acquisition of a 30% equity stake in Mahindra Susten Private Limited, Mahindra Group's renewable energy business[40].

[32] https://www.mondaq.com/india/renewables/1339514/renewable-energy-sector-in-india-recent-developments
[33] https://www.swfinstitute.org/news/43880/greenko-energy-holdings-raises-equity-from-gic-and-adia
[34] https://www.vccircle.com/greenko-energy-raises-329-mn-more-from-gic-adia
[35] https://ieefa.org/resources/ieefa-india-infrastructure-investment-trusts-unlock-value-renewable-energy-assets
[36] https://www.etmoney.com/learn/personal-finance/all-you-need-to-know-about-infrastructure-investment-trusts-invits/
[37] https://yourstory.com/2022/03/5-solar-energy-startups-reduce-carbon-foot-climate-change
[38] https://yourstory.com/2022/03/5-solar-energy-startups-reduce-carbon-foot-climate-change
[39] https://www.investindia.gov.in/team-india-blogs/future-climate-tech-building-indias-green-unicorns
[40] https://www.forbesindia.com/article/take-one-big-story-of-the-day/mahindra-groups-susten-deal-spotlights-indias-renewable-energy-opportunity/79951/1

Financing Model	Description	Challenges	Opportunities	Relevance in the Indian Renewable Energy Sector
Public	• Involves government initiatives, subsidies, and investments in renewable energy projects.	• Subject to political changes and policies. • Can be slow-moving and bureaucratic. • The focus is often on large-scale, grid-connected projects, potentially overlooking smaller, decentralized initiatives[41].	• Can provide significant and stable funding and support, especially for large-scale projects. • Often comes with policy support that can aid long-term sustainability. • Alignment with national energy and climate goals.	• The Reserve Bank of India includes bank loans for renewable energy projects under Priority Sector Lending, with a loan limit of up to ₹30 crore for companies and ₹10 lakh for individual households[42]. • The Green Energy Corridor project aims to facilitate renewable power evacuation and reshape the grid for future requirements, with significant government investment in transmission lines and substations[43]. • The World Bank approved $1.5 billion in financing to support India's low-carbon transition, which includes renewable energy projects[44]. • The Indian government, through its Union Budget 2023, allocated Rs 35,000 crore for priority investment towards energy transition and net-zero objectives, underlining the significant public investment in this sector[45]. • The Ministry of New and Renewable Energy (MNRE) is involved in various programs and initiatives to promote renewable energy, including solar[46]. • The budget for India's National Green Hydrogen Mission, for example, includes a significant allocation for facilitating the transition to a low-carbon intensity and green economy[47].

Comparative analysis of the various models:

- **Risk Profile:** Public finance and philanthropic models typically carry lower financial risks compared to equity and revenue-based models, which are more exposed to market fluctuations.
- **Scale and Impact:** Public finance models are suited for larger-scale projects due to government backing, whereas philanthropic financing is often more focused on smaller, high-impact projects.
- **Control and Ownership:** Equity-based financing can dilute control, whereas revenue-based financing allows companies to maintain more control.
- **Sustainability:** Philanthropic and public finance models are often more aligned with long-term sustainability and social goals.

Philanthropy plays a crucial role in the renewable energy sector, especially where market forces and government interventions are not sufficient. Philanthropic organizations can afford higher risk investments and provide the necessary early-stage funding for climate solutions to scale up, which is essential for broad adoption and cost reduction, as evidenced by the successful expansion of solar and wind power (Cox et al., 2021)[48].

41 https://mnre.gov.in/g-20-india-2023/
42 https://pib.gov.in/PressReleasePage.aspx?PRID=1897041
43 https://pib.gov.in/PressReleasePage.aspx?PRID=1885147
44 https://www.worldbank.org/en/news/press-release/2023/06/29/world-bank-approves-1-5-billion-in-financing-to-support-india-s-low-carbon-transition
45 https://www.indiatoday.in/business/budget-2023/story/budget-2023-nirmala-sitharaman-environment-green-energy-net-zero-climate-change-2329020-2023-02-01
46 https://mnre.gov.in/g-20-india-2023/
47 https://www.indiatoday.in/business/budget-2023/story/budget-2023-nirmala-sitharaman-environment-green-energy-net-zero-climate-change-2329020-2023-02-01
48 Cox, S., Hellstern, T., Henderson, K., Nowski, T., O'Flanagan, M., Pinner, D., Ray, T., & Sabow, A. (2021). It's time for philanthropy to step up the fight against climate change | McKinsey's Sustainability Practice and Philanthropy. *McKinsey Sustainability*. Retrieved from https://www.mckinsey.com/capabilities/sustainability/our-insights/its-time-for-philanthropy-to-step-up-the-fight-against-climate-change

4. Results and Discussion

4.1. Village Profile[49]

Distribution by district type (Laggard and Aspiring): The respondents are categorized into two types of districts: aspiring and laggard. Among the respondents, 50.8% are from aspiring districts, while 49.2% are from laggard districts. The distribution between aspiring and laggard districts is relatively balanced, with a slight majority of respondents from aspiring districts, and this is as per the project design.

Total population served by different electricity grid types: The average population served in the villages/habitations serviced by the main grid is 1245, while that for villages/habitations serviced only by the solar mini grid is 295. The average population of villages/habitations served by both the main grid and the solar mini grid is 1681. Thus, solar mini grids have mostly been implemented in small villages/habitations.

The main grid serves the highest mean total population, followed by the population served by both the main grid and solar mini grid, with the solar mini grid serving the lowest mean total population.

Average number of households in the village: The average number of households in the main grid villages is 219, while the average number of households in the mini grid villages/hamlets is 55.

Average number of connections (Main Grid): The average number of domestic consumers connected to the main grid in the surveyed villages is approximately 212 while the average number of commercial consumers connected to the main grid is only 15, indicating fewer commercial establishments in the area.

The higher number of domestic connections compared to commercial and institutional connections underscores the importance of electricity for residential purposes in the sampled villages. The presence of villages without main grid electricity connections in 33 out of 120 villages (27.5%) highlights an area for potential improvement in access to electricity services, which could contribute to improved living standards and socio-economic development.

Average number of households supplied by Solar Mini Grids: The mean number of households supplied by solar mini grids is approximately 44. This indicates that solar mini grids play a significant role in providing electricity access to communities, especially in areas where connecting to the main grid may be challenging or uneconomical.

Availability of all-weather motorable roads: Approximately 80.70% of villages with main grid electricity have an all-weather motorable road leading to them. Only 31.30% of villages with solar mini grid electricity have an all-weather motorable road leading to them, supporting the fact that these villages and hamlets are more isolated and not easily accessible.

Economic activities by electricity grid type:

- **Main Grid Villages:** On average, households in the villages connected to the main grid have a higher engagement in agriculture and allied activities, with an average number of 193 households engaged in agriculture. Similarly, the average number of households engaged in small-scale/cottage industries and salaried employment is relatively lower at 4 and 38, respectively. This is because the geographies in which the survey was conducted were rural areas predominantly dependent on agricultural livelihoods.
- **Solar Mini Grid Villages:** Households in the villages with solar mini grid connections exhibit lower engagement in agriculture and allied activities, with an average number of 51 households engaged in agriculture. Similarly, the average number of households engaged in the small-scale/cottage industries and salaried employment are also lower at 1 and 3, respectively. This is also because the solar mini grid sites were predominantly smaller habitations with fewer households as compared to main grid villages, therefore the total number of households that were surveyed under this category is also lower than the households connected to the main grid.
- **Villages with both Main Grid and Solar Mini Grid:** Villages with access to both main grid and solar mini grid electricity display a broader spectrum of economic activities, indicating potentially better economic development

[49] **Total number of villages = 120**
Aspiring Districts = 61 (Main Grid = 43; Solar Mini Grid = 4; Both Main and Solar Mini Grids = 14)
Laggard = 59 (Main Grid = 40; Solar Mini Grid = 12; Both Main and Solar Mini Grids = 7)

prospects and diversification of livelihood options. One reason behind the same may be attributed to the availability of a more reliable and undisrupted flow of electricity services that facilitate commercial enterprises.

Status of Village Electrification:

All villages in the sample meet the criteria of 100% electrification as per government definition. As described by the Ministry of Power (2004)[50], a village would be declared as electrified if the basic infrastructure such as distribution transformer and distribution lines are provided in the inhabited locality as well as the Dalit Basti hamlet where it exists; electricity is provided to public places like schools, Panchayat Office, Health Centers, Dispensaries, Community Centres etc.; and the number of households electrified should be at least 10% of the total number of households in the village.

In some villages, village representatives reported that a few households did not have electricity supply at the time of the survey. It is pertinent to mention that while asking the question to village level representatives/ knowledgeable persons, the word 'some households' does not clearly mention the exact number of households not having electricity connection during the time of visit and therefore, it does not reflect the extent of non-connection of electricity supply.

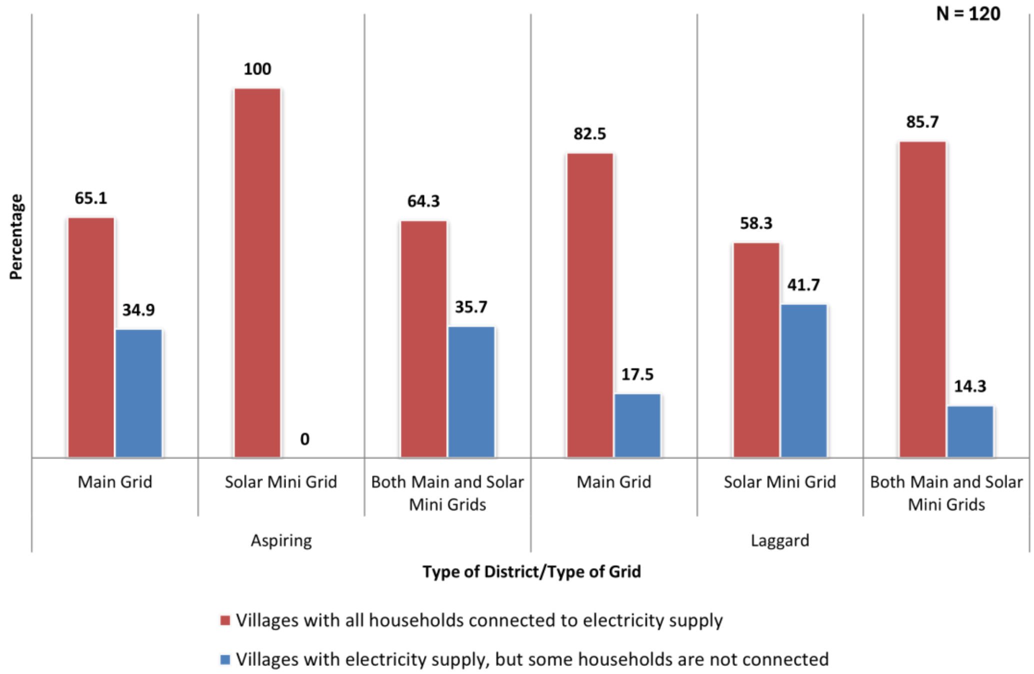


Figure 3: Percentage of villages/ hamlets with electrification of the households by district types

Main Grid Villages: For the villages in aspiring districts that are connected to the main grid, about 65% of villages reported that all households are successfully connected to electricity, while about 35% of the villages reported that while there is electrification in the village, some households remain without electricity. For the villages connected to the main grid in the laggard districts, 82.5% of villages reported that all households are successfully electrified while 17.5% of villages reported that some households remain without electricity. This indicates significant progress in extending the main grid infrastructure in socio-economically backward geographies. However, some households still do not have electricity connections in spite of the village being electrified, which may be intuitively attributed to gaps in implementation of government schemes, inequities in distribution of electricity services, and inadequate infrastructure.

Solar Mini Grid Villages: Of all the villages that are connected to mini grids, 68% have households that are electrified through the mini grid. The remaining 32% of these villages, all of which are located in Bihar, do not have any households connected to the mini grid because the mini grids in these villages are primarily designed to cater to irrigation needs.
All of the villages in aspiring districts that are connected to mini grids reported that all households are successfully electrified. In contrast, in the laggard districts, about 58% of the villages connected to mini grids reported that all the households were successfully electrified while about 41% of the villages said that some households remain disconnected from electricity. This may be because laggard districts are comparatively backward to aspiring districts in terms of infrastructural development and socio-economic progress.

[50] Ministry of Power (2004). *Definition of Electrified Village.* Retrieved from https://www.ddugjy.gov.in/page/definition_electrified_village

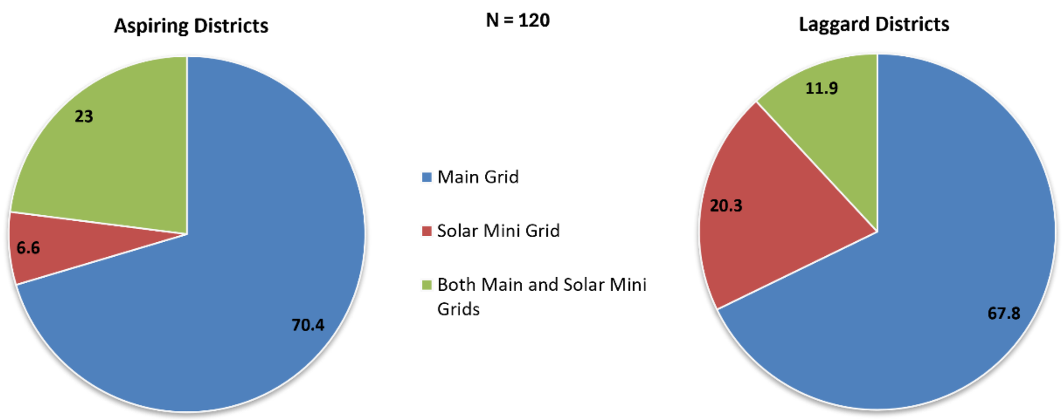
Villages with both Main Grid and Solar Mini Grid: For all the villages in the aspiring districts that are connected to both the main grid and solar mini grids, about 64% reported that all households are successfully connected to electricity while about 36% of the villages reported that some households remain disconnected from electricity. For similar villages in the laggard districts, about 86% of the villages reported that all households are connected to electricity while about 14% of villages reported that some households remain without electricity. Since more mini grid sites in the sample are located in laggard districts, a smaller proportion of households are currently disconnected in these villages as compared to aspiring districts, thereby highlighting the impact of mini grids on improving last mile connectivity in socio-economically backward areas where main grid connections are also availed.

Disconnected consumers face challenges in working after sunset, in conducting agricultural and irrigation activities, as well as in education. This underscores the importance of targeted interventions to address access gaps and ensure equitable access to electricity for all households within a village.

> "There were some documentation issues related to land ownership, due to which we did not get electricity connection." – Disconnected consumer, Banka, Bihar
>
> "We were unable to pay the monthly bills and they kept piling up, until it reached Rs. 14000 and they cut the main line." – Disconnected consumer, Lohardaga, Jharkhand

Source of Electricity:

Figure 4: Percentage of different electricity grid types available in villages by district type



Aspiring Districts:

- About 70% of the sample villages in aspiring districts receive electricity from the main grid provided by DISCOMs.
- The survey was able to cover only a small proportion (about 6%) of villages dependent solely on solar mini grids in the overall sample of villages in the aspiring districts due to ground-level challenges.
- Almost a quarter of the sample villages in the aspiring districts (23%) have both main and solar mini grids installed. While this percentage is relatively low compared to villages with only main grid electricity supply, it still reflects a growing trend towards decentralized energy generation and consumption, contributing to overall energy resilience and sustainability.

Laggard Districts:

- A little over two thirds (about 68%) of the villages in laggard districts also receive electricity from the main grid provided by DISCOMs.
- The proportion of villages which rely on solar mini grids or solar plants for electricity supply in laggard districts is about 20%. This underscores the significance of decentralized energy solutions in bridging the electricity access gap in districts where the main grid infrastructure may be inadequate or non-existent.
- The proportion of villages in laggard districts which have both types of grids installed is close to 12% which is a small but significant number.

Overall Insights:

The data indicates the adoption of solar energy solutions alongside the main grid infrastructure to augment the electricity supply situation in aspiring districts, whereas, in the laggard districts, the solar mini grids are more of a solution in places where the main grid infrastructure is not able to reach. In qualitative discussions with disconnected consumers, most of the respondents said that they were interested in trying to use renewable energy options.

Despite differences in electrification status between villages in aspiring and laggard districts, both categories of districts show a significant reliance on solar energy as a last-mile solution, highlighting its role as a key enabler of energy access and resilience in remote districts. Notably, the presence of rooftop solar panels in both aspiring and laggard districts suggests a growing awareness and uptake of decentralized energy generation options. With adequate financing, these initiatives can contribute to energy self-sufficiency and sustainability at the local level.

Primary Source of Electricity in Villages:

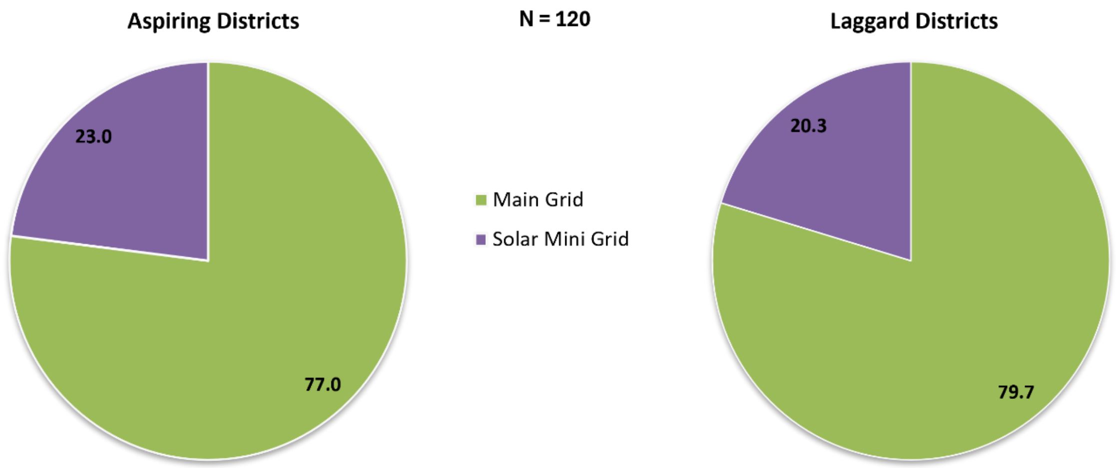


Figure 5: Percentage of villages with main grid or solar mini grid as the primary source of electricity by district type

Main Grid as Primary Source:

- In aspiring districts, 77% of villages primarily rely on the main grid for electricity.
- In laggard districts, a slightly higher percentage (79.7%) depends on the main grid as their primary power source.
- Overall, approximately 78.3% of villages, irrespective of their classification, rely on the main grid as their primary source of power. This finding has been corroborated in qualitative interviews with community stakeholders as well. This is primarily because most consumers still rely on electricity supply from the state electricity boards.

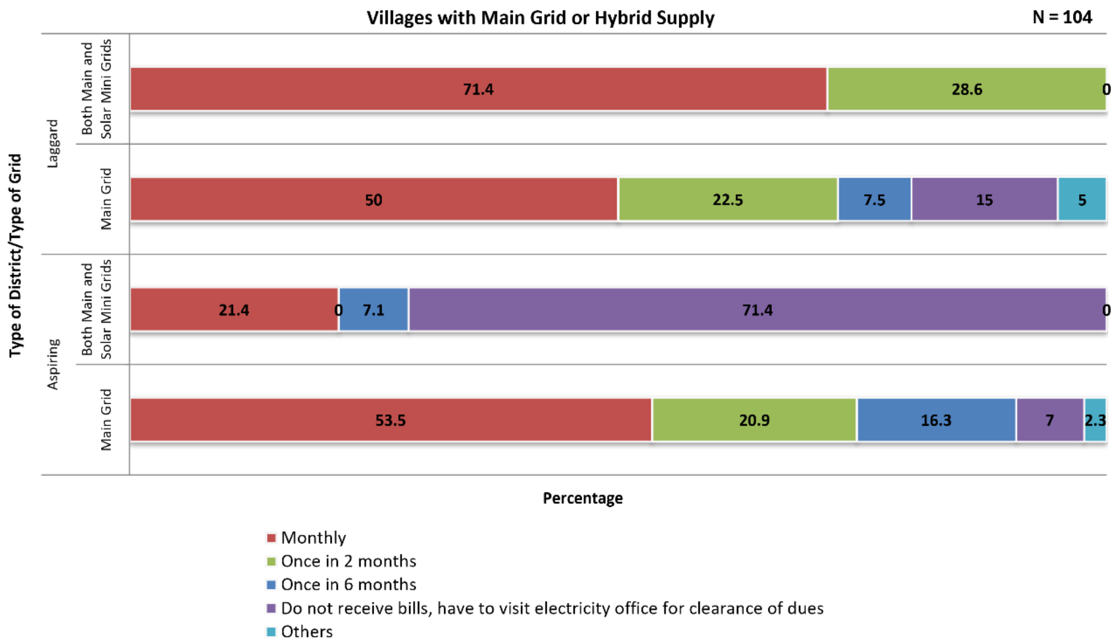
Solar Mini Grid as Primary Source:

- In aspiring districts, 23% of villages rely on solar mini grids as their primary power source.
- In laggard districts, this percentage slightly decreases to 20.3%.
- Across both aspiring and laggard districts, around 21.7% of villages rely on solar mini grids as their primary source of power. Due to solar mini grids functioning efficiently in rural geographies as elaborated in following sections, more consumers are coming forward to take up solar electricity connections from the mini grids. Due to the reliability and stability of supply, many consumers have started to depend on mini grids as their primary source of power.

Another notable insight comes from villages that have both main grid and solar mini grid as sources of electricity supply. In the aspiring districts, 71.4% of such villages have solar mini grid as their primary source of supply while in the laggard districts, all such villages rely primarily on the main grid for their supply needs. This suggests that in the aspiring districts, for the villages where the main grid supply is provided but is not effective, consumers prefer the solar mini grid as the primary source of supply.

These insights suggest that while the main grid remains the dominant source of electricity in both aspiring and laggard districts, there is a significant reliance on solar mini grids, indicating efforts towards diversifying energy sources, especially in remote or underdeveloped regions.

Frequency of Billing:



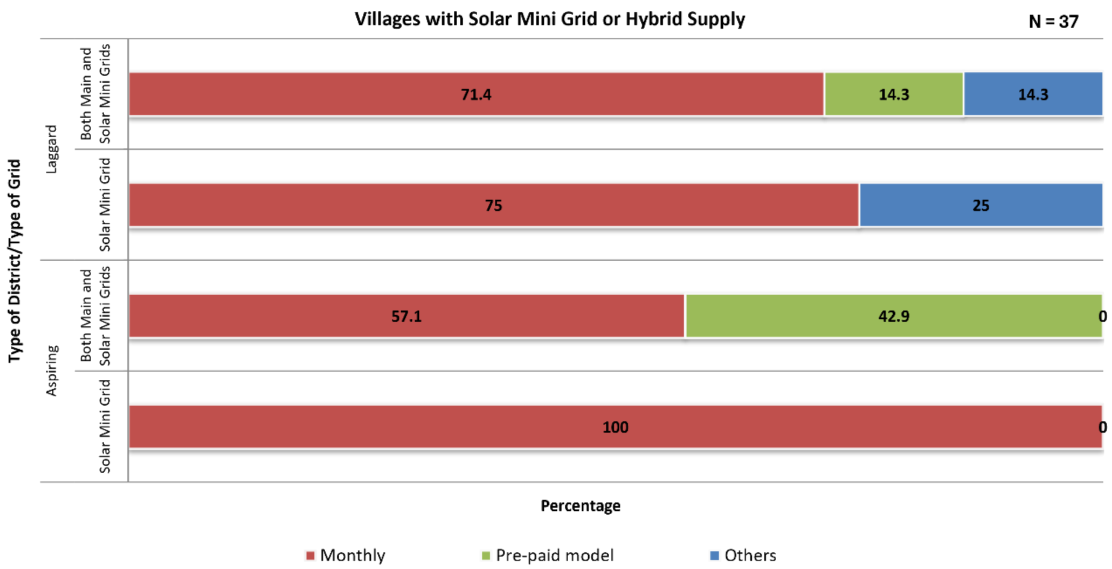


Figure 6: Percentage distribution of billing frequencies by grid and district types

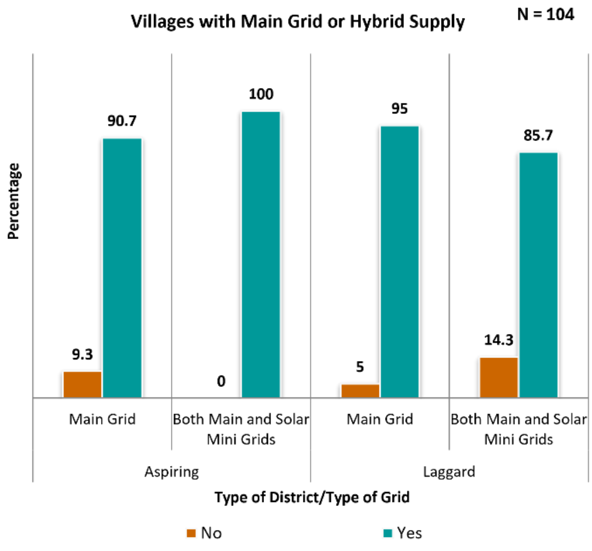
Main Grid Villages: In aspiring districts, 53.5% of villages receive monthly bills for electricity from the main grid, indicating a regular billing cycle. The situation is similar in the laggard districts, with 50% of villages reported receiving monthly bills for electricity from the main grid. The similar pattern can be attributed to the reliable main grid infrastructure, and distribution channels. In aspiring districts, a smaller percentage of 20.9% receive bills once every 2 months, while 16.30% are billed once every 6 months. Similarly, in laggard districts, 22% of the villages receive bills every 2 months, while 7% are billed every 6 months. Only 7% of villages in aspiring districts and 15% in laggard districts do not receive bills.

Solar Mini Grid Villages: All the solar mini grid connections in surveyed villages are metered. This ensures accurate measurement and billing of electricity consumption, promoting transparency and accountability in the usage of electricity services.

In villages in the aspiring districts with only mini grid connections, all of the respondents receive monthly bills, indicating monthly billing is the only regular billing cycle for electricity consumption. In the laggard districts, 75% of the villages reported receiving monthly bills while 25% reported a different frequency of billing.

These insights highlight variations in billing practices across different types of electricity sources and underscore the need for improved billing infrastructure and practices, particularly in districts where billing irregularities exist.

Existence of Overdue Bills:



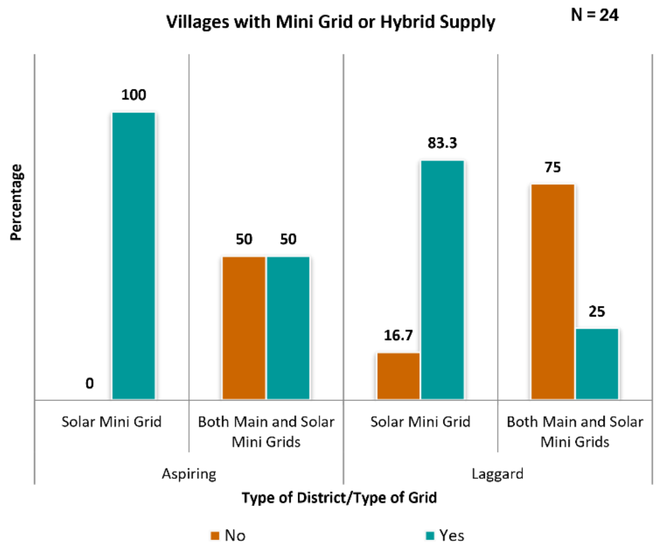


Figure 7: Percentage of villages that reported the existence of overdue bills by grid and district types

Main Grid Electricity Supply: Across both aspiring and laggard districts, the majority of villages have reported that villagers have overdue electricity bills for the main grid electricity supply. Only a small percentage of villages in aspiring districts (9.3%) and laggard districts (5%), have reported that the villagers do not have overdue bills for the main grid electricity supply.

These findings indicate a prevalent issue of overdue bills for main grid electricity supply in both aspiring and laggard districts. Through qualitative interviews with community stakeholders, it was found that the predominant reason behind this was that most households receive bills infrequently. This irregularity disrupts their knowledge regarding the accrued amount and leads to the accumulation of dues.

> "We do not get bills on a monthly basis, there is no regularity. We have to go to the electricity supply office and check what our dues are. Sometimes the amount reaches somewhere around Rs. 5000 to Rs. 10000, which we cannot pay at once. Thus, the fines keep adding up and it becomes difficult to settle dues." – Community stakeholder, Shravasti, Uttar Pradesh

Addressing this issue could involve implementing measures to improve billing and payment processes, enhancing financial discipline among villagers, and ensuring better access to electricity billing services. Paying bills on time will allow the State Electricity Boards to improve the electricity services.

Solar Mini Grid Electricity Supply: In the aspiring districts, all of the villages have reported that villagers have overdue bills whereas in the laggard districts, the majority of villages (83.3%) have reported villagers as having overdue bills. A high percentage of villages with overdue bills suggest potential challenges in timely bill payments for solar mini grid electricity supply.

Electricity Supply Disconnection Due to Non-payment of Bills:

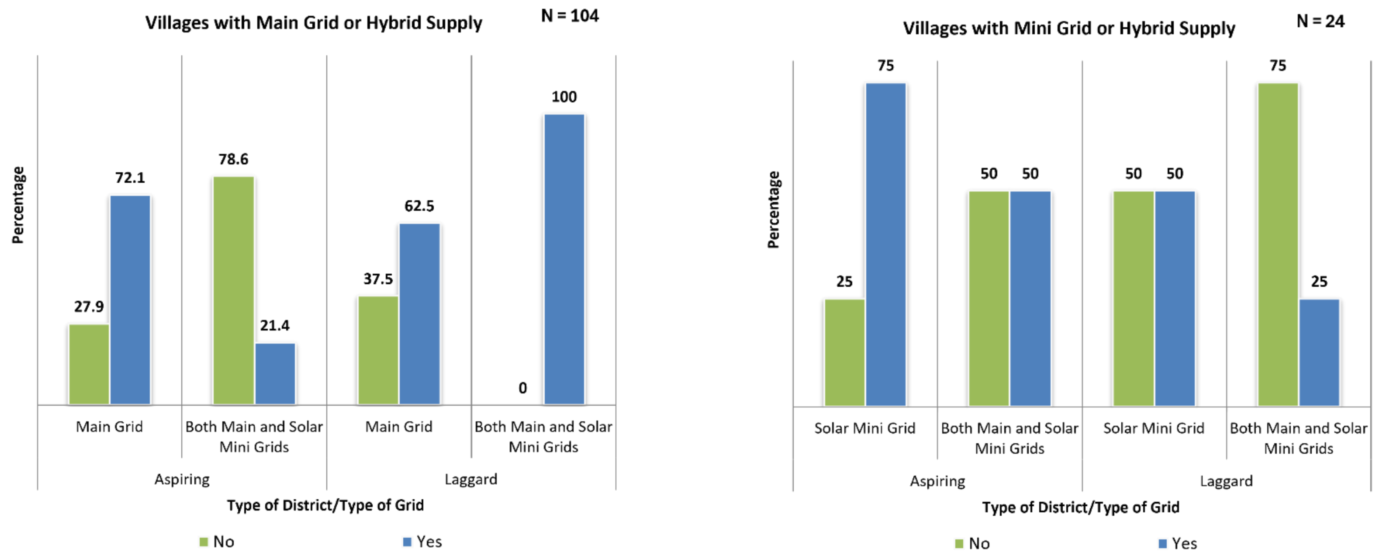


Figure 8: Percentage of villages that reported disconnection of electricity supply due to non-payment of bills by grid and district types

Main Grid: In aspiring districts, about 72% of the respondents reported that the electricity supply is disconnected due to non-payment of bills, while about 28% stated otherwise. In laggard districts, a relatively lower percentage (62.5%) reported electricity supply disconnection due to non-payment of bills, with a higher percentage (37.5%) of the respondents indicating no disconnection was undertaken. The slight variation in service disconnection can be attributed to the time variant factors like geographic location, level of development, and accessibility (the disconnection notices/teams may take some extra time to reach, and identify the households).
Overall, across both aspiring and laggard districts, the majority (67.5%) reported electricity supply disconnection due to non-payment of bills, while the rest stated otherwise.

Solar Mini Grid: Three out of four respondents in the aspiring districts reported that the electricity supply is disconnected when dues are not paid, with half of the respondents in the laggard districts reporting the same.
Overall, across both aspiring and laggard districts, just over half the respondents (about 56%) reported electricity supply disconnection due to non-payment of bills, while the rest stated otherwise.

These findings highlight a significant issue of electricity supply disconnection due to non-payment of bills, particularly more pronounced in aspiring districts. Addressing this issue may involve implementing measures to improve billing processes, provide financial assistance or education, and ensure fair access to electricity services for all residents.

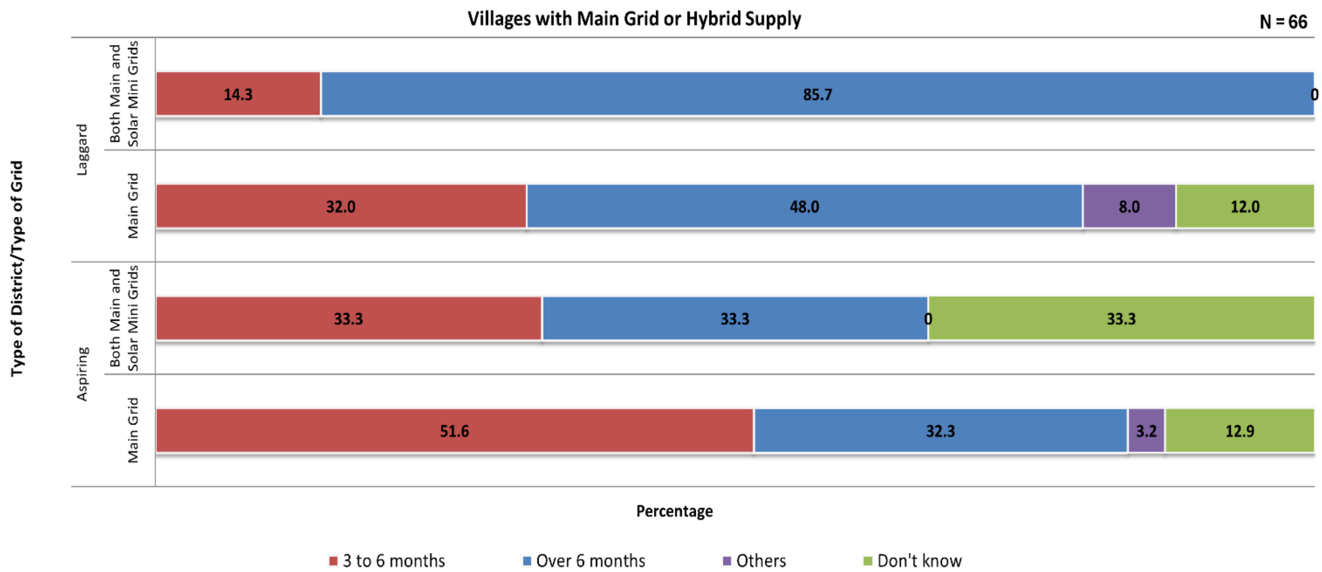


Figure 9: Percentage of non-payment duration post which supply is disconnected by district type

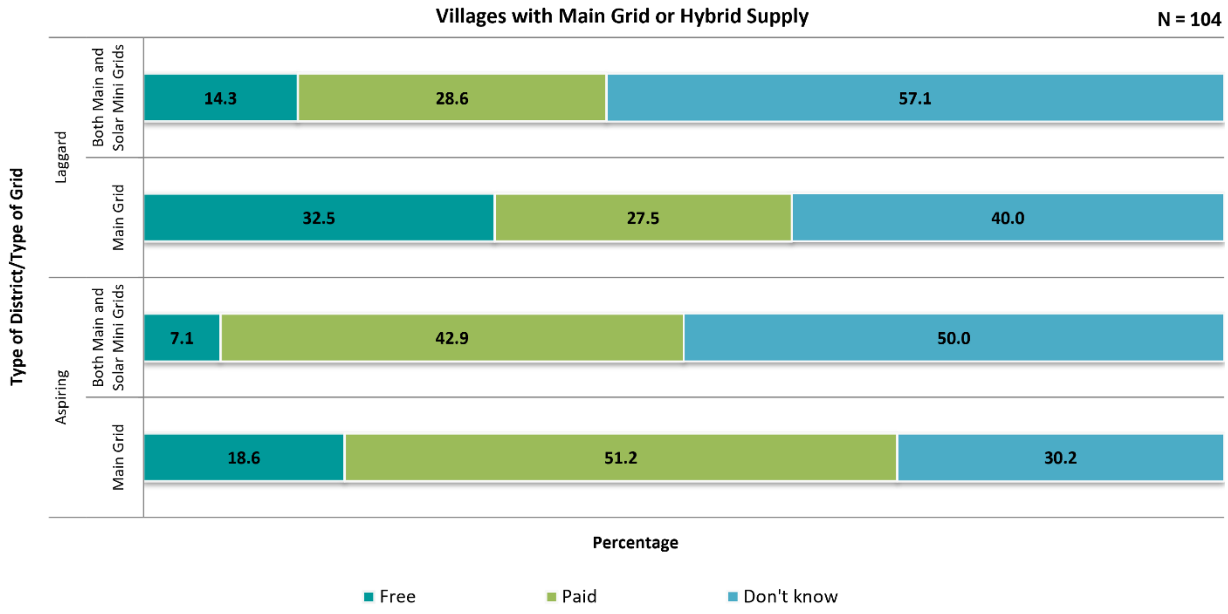
The duration of non-payment before disconnection of electricity services is much lower in aspiring districts (3 - 6 months as reported by half of the villages) as compared with villages in the laggard districts (over 6 months as reported by 48% of the villages).

These insights suggest variations in the duration of non-payment before electricity supply disconnection between aspiring and laggard districts – suggesting that the norms are not standardized across geographies, with laggard districts experiencing disconnection after longer periods of non-payment, which was also corroborated in qualitative interviews with disconnected consumers. Addressing this issue may involve exploring the reasons behind delayed disconnections, implementing measures to improve payment systems or providing financial assistance to prevent disconnections.

"We need three things from the government – waive off the current dues, reduce the connection cost, and leverage electricity platforms for children's education." – Disconnected consumer, Lohardaga, Jharkhand

Solar Mini Grid: All respondents who experienced supply disconnection due to non-payment reported that it occurred within 3 to 6 months of non-payment.

Provision of Electricity to Institutions:



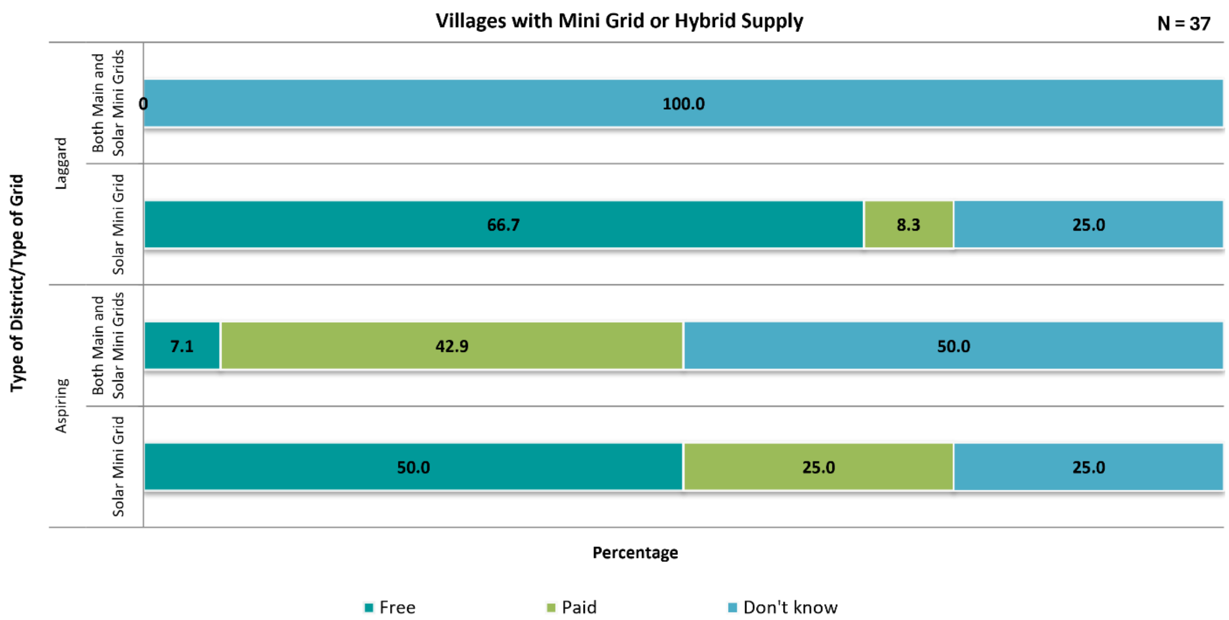


Figure 10: Percentage of institutions required to pay for electricity supply by grid and district types

Main Grid: In aspiring districts, almost half the villages (51.2%) reported that institutions such as schools, Anganwadi centres, panchayat offices, etc. have to pay for the electricity supplied, while a smaller portion (18.6%) stated that these services are provided for free. In laggard districts, a larger percentage (32.5%) reported free electricity services provided to these institutions as compared to aspiring districts.

However, a higher percentage (40%) of villages in laggard districts expressed uncertainty about whether institutions are offered free or paid electricity services, compared to 30.2% in aspiring districts. This could be an indication of centralized billing to the departments.

Solar Mini Grid: In aspiring districts, half of the villages reported that institutions such as schools, Anganwadi centres, panchayat offices, etc. are supplied electricity free of charge, while a quarter of the villages each said that the supply is either paid for or that they are unaware about the payment requirements. In laggard districts, two-thirds of the villages reported free electricity services provided to these institutions while only less than 10% of the villages reported that institutions pay for electricity supply.

These insights highlight the need for clarity and transparency in the provision of electricity services and the billing aspects to institutions in both aspiring and laggard districts. Efforts to improve awareness and communication regarding the availability of government schemes and the provision of cheaper cost of electricity services to essential institutions could enhance accessibility and address any potential disparities between aspiring and laggard districts.

Village Level Reporting of Challenges Faced by Households with Main Grid Electricity Supply:

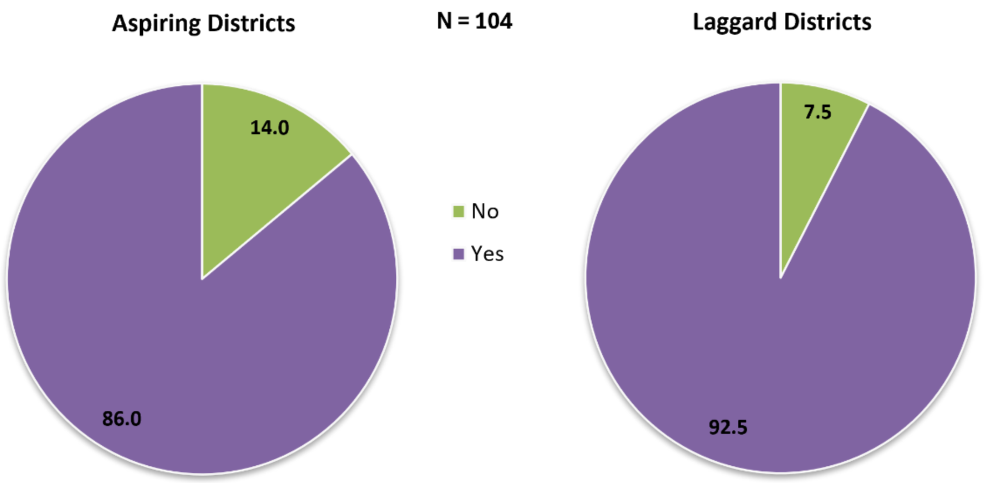


Figure 11: Percentage of main grid villages reporting the existence of challenges due to insufficient electricity supply by district type

In aspiring districts, the majority of villages (86%) face challenges with the supply from the main grid. In laggard districts, a slightly higher percentage (92.5%) of villages reported facing challenges with the supply from the main grid. A similar trend is observed in villages with both main grid and solar mini grid supply, with the majority of villages in both aspiring (92.9%) and laggard (85.7%) districts facing challenges with the main grid supply. This is one possible reason for consumers embracing the electricity supply from solar mini grids in these areas to improve the electricity situation.

Overall, a significant proportion of villages across all categories perceive challenges with the current main grid system, indicating a widespread issue that needs to be addressed. Through qualitative interviews, it emerged that households face challenges such as electricity poles falling and wires getting torn during thunderstorms in the monsoon season. Outages and disruptions due to technical faults take longer to fix during summers and monsoons.

These insights underscore the importance of identifying and addressing the challenges faced by the villages and the inhabitants with the current electricity grid systems, particularly in remote and underserved areas. Efforts to improve grid reliability, accessibility, and affordability are essential to enhance the overall quality of life and promote socio-economic development in these regions.

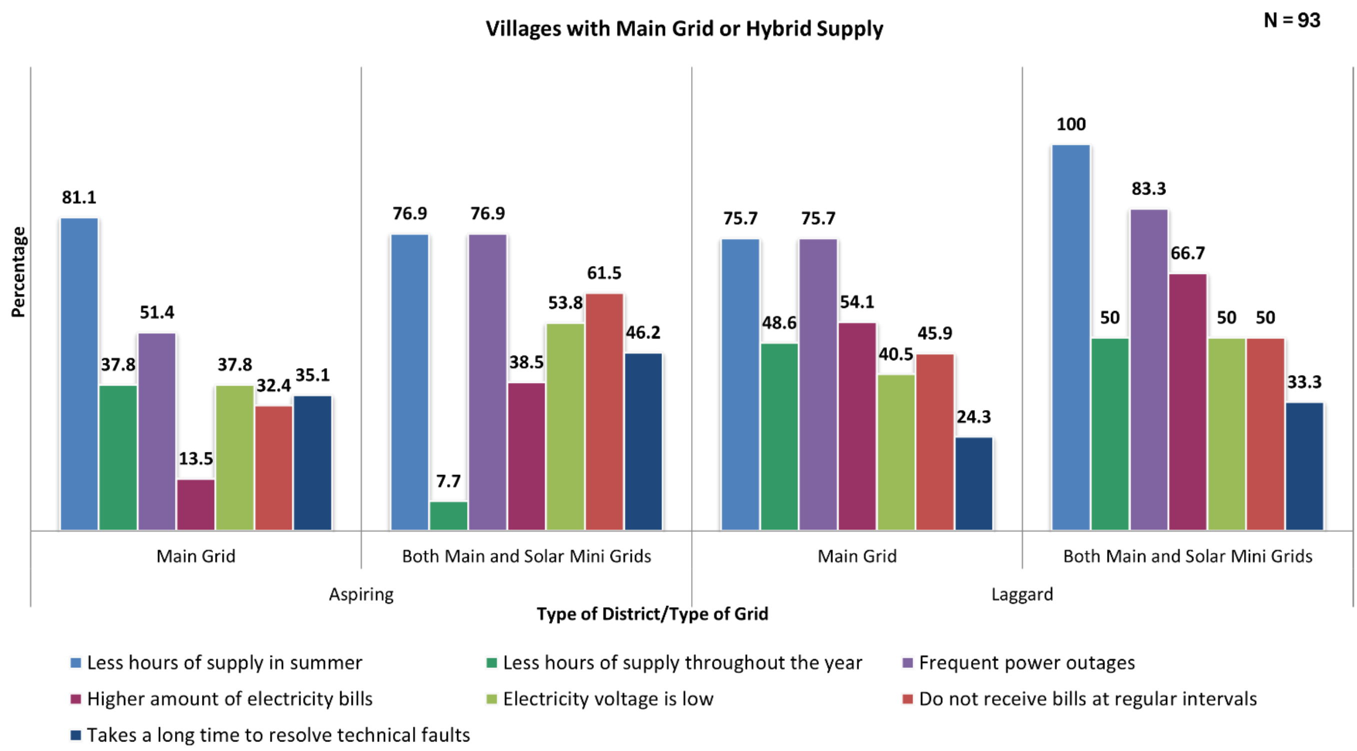


Figure 12: Percentage of villages connected to the main grid that reported different types of challenges faced due to insufficient electricity supply by district type

On further probing the reasons for the challenges faced by the households in the villages, the following were highlighted:

- In aspiring districts, the most common challenges reported by villages include fewer hours of supply in summer (81%), frequent power outages (51.4%), and low electricity voltage (37.8%). However, the problems with the low hours of supply are more prevalent during the summers as compared to throughout the year (37.8%).
- In laggard districts, most villages reported fewer hours of supply in summer (75.7%) and frequent power outages (75.7%). The proportion of villages reporting low electricity voltage (40.5%) was lesser than the villages in the aspiring districts. Additionally, almost half the villages in laggard districts mentioned challenges related to fewer hours of supply throughout the year (48.6%), higher electricity bills (54.1%), and not receiving bills at regular intervals (45.9%).

Notably, challenges such as fewer hours of supply in summer, frequent power outages, and low electricity voltage are common across both aspiring and laggard districts, indicating systemic issues in grid electricity supply during the summer months. However, laggard districts face additional challenges such as irregular billing, higher bills, and longer resolution times for technical faults, suggesting a more complex electricity supply situation in these regions.

"Since the load is higher during summer time, more frequent loadshedding happens. There is often no supply at night, and only 2-3 hours of supply during the day." – Community stakeholder, Samastipur, Bihar

These insights highlight the specific challenges highlighted by the villages in aspiring and laggard districts regarding main grid electricity supply. Addressing these challenges requires targeted interventions to improve service reliability, billing practices, and technical support, tailored to the unique needs of each area. One of the potential reasons for this challenge is import dependence (coal and gasoline price and supply fluctuates, and power generation companies must adjust production accordingly), and lack of or high cost of substitutes. With more renewable energy, we can reduce import dependence, and reduce supply related issues like outrages, irregular supply, voltage. Newer investment models, innovative financing in the sector, policy and regulatory consistency in the sector can encourage investors, markets, and other stakeholders to participate and support the clean energy transition.

Improvement in Main Grid Electricity Supply Quality:

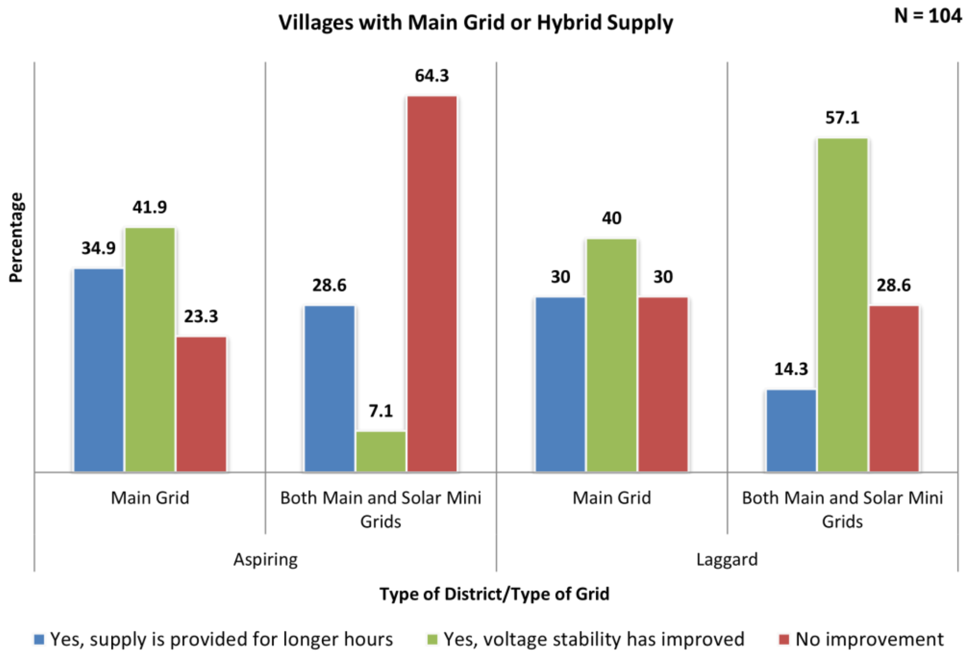


Figure 13: Percentage of villages connected to the main grid reporting improvement in the quality of supply by grid and district types

The village representatives were asked about the kind of improvements experienced in the grid-based electricity supply. In aspiring districts, a third of the villages experienced supply for longer hours (34.9%), while about 42% of the villages stated that there was an improvement in voltage stability. Interestingly, a notable portion of villages in aspiring districts (23.3%) mentioned that there was no improvement in either supply hours or voltage stability, indicating that quality issues remained unaddressed in some areas due to factors such as infrastructural constraints, inadequate load capacity and adverse weather conditions.

In laggard districts, a comparatively similar proportion of villages reported an improvement in supply duration (30%), and a similar proportion reported an improvement in voltage stability (40%). Notably, a considerable percentage stated that there had been no improvement in supply quality (30%), suggesting persistent challenges in these regions due to inadequate infrastructure or load capacity, or weather-related issues particularly during summers and monsoons.

"The presence of solar mini grid has improved the duration of supply, we now get 9-10 hours of supply in a day, when earlier it used to be for 1-2 hours only." – Community stakeholder, Lohardaga, Jharkhand

"New transformers and electricity poles have been installed in the village. We don't even realise when power cuts happen these days because of the solar electricity back up." – Community stakeholder, Gumla, Jharkhand

"Improvement in the quality of electricity has brought about many positive changes – household chores have become easier, children can study for longer hours, women feel safer stepping outdoors in the evening, farmer incomes and irrigation facilities have improved, and shops can stay open for longer hours." – Community stakeholder, Lakhimpur Kheri, Uttar Pradesh

No respondents in either aspiring or laggard districts reported a deterioration in the quality of electricity supply, indicating a stable or improving trend in supply quality overall. While improvements have been noted in some respects such as supply duration and voltage stability, challenges remain, particularly in laggard districts, highlighting the need for continued efforts to enhance the reliability and stability of electricity supply in these regions.

Hours of Electricity Supplied:

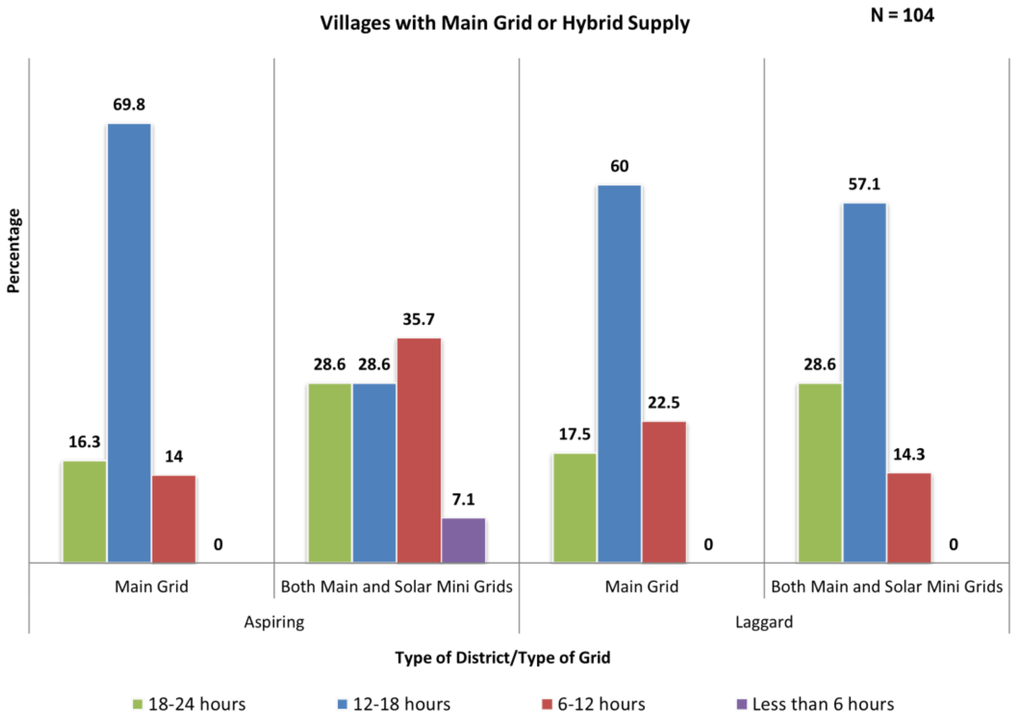


Figure 14: Percentage of villages connected to the main grid reporting hours of supply by grid and district types

Main Grid:

- **Aspiring Districts:** The majority of respondents in aspiring districts who rely solely on the main grid reported receiving electricity for 12-18 hours per day (69.8%). Almost a sixth of the villages (16.3%) reported receiving electricity for 18-24 hours. A few villages reported lower durations of electricity provision, with only a small percentage (14.0%) receiving electricity for 6-12 hours per day, but none reported receiving less than 6 hours of electricity. This indicates a relatively good situation in terms of electricity supply.
- **Laggard Districts:** The majority of villages in laggard districts reported receiving electricity for 12-18 hours per day (60.0%), however this proportion is considerably lower than that of villages in the aspiring districts. A notable proportion (17.5%) reported receiving electricity for 18-24 hours. The percentage of villages receiving electricity for 6-12 hours per day (22.5%) was slightly higher compared to villages in aspiring districts, suggesting variability in service reliability within laggard districts. No villages in laggard districts reported receiving less than 6 hours of electricity per day, indicating that even in regions with significant challenges, there is a baseline level of service provision.
- **Overall:** The data suggests that while there may be variations in the duration of electricity provision within both aspiring and laggard districts, the majority of respondents in both categories receive electricity for at least 12 hours per day, indicating a basic level of service provision across the surveyed regions.

Solar Mini Grid: The average hours of service provided per day by solar mini grids during the summer and winter seasons is approximately 21 hours. This indicates that solar mini grids can provide a substantial amount of electricity service during the summer months, which is crucial for meeting the energy needs of households, businesses, and institutions. Therefore, there is immense potential for energy transition financing to be channelized in this direction, in order to supplement the duration of main grid electricity in order to meet the energy requirements of households, commercial enterprises and institutions in rural India.

Frequency of Power Outages for Main Grid Connections:

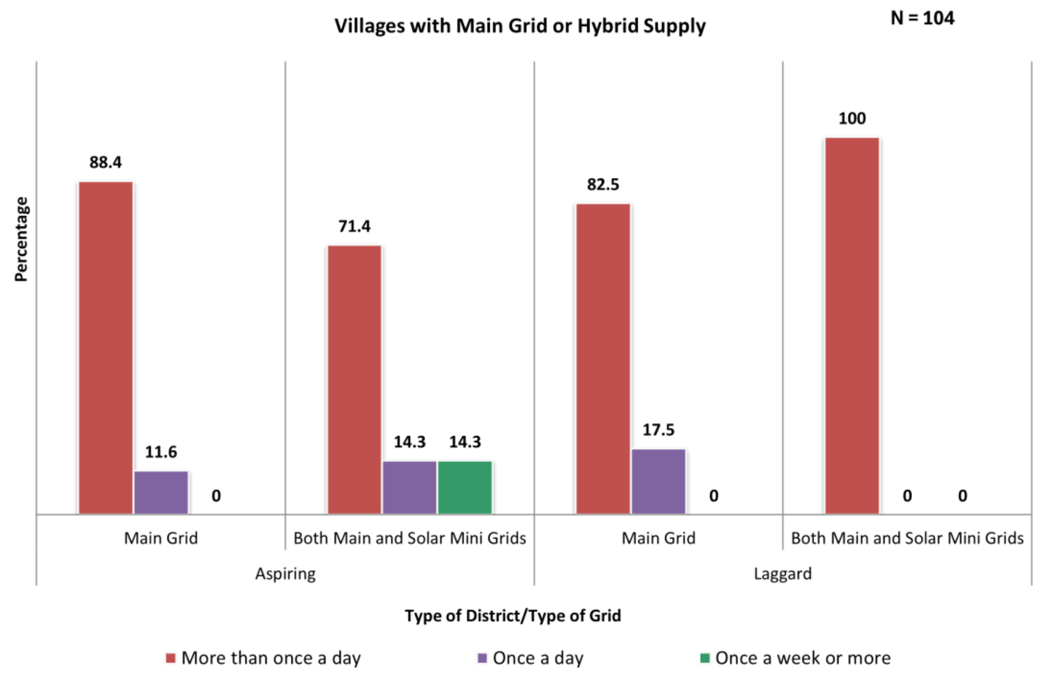


Figure 15: Percentage of villages connected to the main grid reporting on the frequency of power outages by grid and district types

Aspiring Districts: A majority (88.4%) of villages in aspiring districts reliant solely on the main grid reported experiencing power outages more than once a day. This indicates a high frequency of power disruptions, which could significantly impact daily activities and quality of life. A smaller proportion of villages (11.6%) reported experiencing power outages once a day, suggesting that even those who do not face multiple disruptions may still experience regular interruptions to electricity supply.

Laggard Districts: Similar to aspiring districts, a significant majority of villages (82.5%) in laggard districts reported experiencing power outages more than once a day. This indicates a common challenge across both aspiring and laggard districts regarding the aspect of power disruptions. A smaller percentage of villages (17.5%) reported experiencing power outages once a day, which is slightly higher than the frequency reported in aspiring districts indicating a slightly better situation in the laggard districts.

Overall: The data highlights a widespread issue of frequent main grid power outages in both aspiring and laggard districts, with the majority of respondents in both categories reporting that they experience disruptions more than once a day, due to multiple factors such as insufficient load capacity and infrastructural inadequacies which lead to frequent load-shedding, adverse weather conditions such as rain and thunderstorm particularly during monsoons that lead to torn wires, faulty transformers, etc. This indicates a critical need for improvements in the reliability and stability of electricity supply, particularly from the main grid, to enhance the quality of life and support economic activities in these districts.

Reasons for Better Consumer Perception of Mini Grid Electricity Supply:

Villages that are connected to both the main grid and a solar mini grid were asked which grid electricity supply they preferred. In the aspiring districts, the majority of villages (85.7%) prefer solar mini grids over the main grid (14.3%). This case is the complete opposite for laggard districts where villages prefer the main grid (85.7%) over the solar mini grids (14.3%).

In the hybrid villages where the main grid electricity is preferred, all respondents indicated that a cheaper monthly bill and no restriction on running motor load were the reasons for preferring main grid electricity in the aspiring districts. For the same category in the laggard districts, the reasons for preferring the main grid electricity were divided among a cheaper monthly bill (50%), government backing (50%), and no restrictions on motor load (75%).

In the hybrid villages where solar mini grid supply is preferred, the main reasons in the aspiring districts are more hours of electricity supply per day (83.3%) and better service with less disruption (58.3%). For the same category of villages in the laggard districts, the preference for solar mini grid was mostly due to more hours of electricity supply per day (76.9%), with other factors being less cumbersome official procedures (30.8%) and better service with less disruption (53.8%).

However overall, it appears that the consumer preference leans towards a combination of both main grid and solar mini grid supply, as that meets their energy requirements optimally. This presents a strong case for directing energy transition financing towards deploying mini grid solutions in order to improve the reliability and sufficiency of electricity supply in rural areas.

In qualitative discussions with community stakeholders, it emerged that the general perception is that solar energy will be more cost-effective in the long run, especially if subsidized for rural domestic consumers. Simplifying the process of obtaining a connection could further enhance consumer satisfaction and promote grid electricity uptake. Consumers are also aware of the fact that solar energy is good for the environment, and therefore aligned to SDG 13 – climate action. The affordability and cost-effectiveness of energy from mini grids also highlights their contribution to SDG 7 – affordable and clean energy.

> "Introduction of solar panels will save money, which we can then invest in farming and shops. It will also lead to better outcomes for the environment and guarantee us more reliable supply." – Community stakeholder, Jamui, Bihar

Summary:

- Villages with access to both main grid and solar mini grid electricity display a broader spectrum of economic activities, indicating potentially better economic development prospects and diversification of livelihood options.
- Despite high overall electrification rates, disparities exist within villages, where some households still lack electricity supply despite the village being categorized as 100% electrified. The presence of mini grids, especially in underserved regions where the main grid supply is not easily accessible, has improved rural electrification outcomes.
- While the main grid remains the dominant source of electricity, both aspiring and laggard districts show a significant reliance on solar energy as a last-mile solution, highlighting its role as a key enabler of energy access and resilience in remote geographies and indicating diversification of energy sources.
- Although the majority of respondents reported a monthly billing system for both main grid and mini grid connections, a significant issue of electricity supply disconnection due to non-payment of bills persists across all categories, particularly more pronounced in aspiring districts. Addressing this issue may involve implementing measures to improve billing processes, provide financial assistance or education, and ensure fair access to electricity services for all residents.
- Most consumers reported facing several challenges with the main grid electricity supply, such as fewer hours of supply in summer, frequent power outages, and low electricity voltage, indicating systemic issues in grid electricity supply during the summer months. Laggard districts face additional challenges such as irregular billing, higher bills, and longer resolution times for technical faults.
- The data suggests that the majority of respondents receive electricity for at least 12 hours per day from the main grid, indicating a basic level of service provision across the surveyed regions. Most respondents also reported experiencing power outages more than once a day. In contrast, the average hours of service provided per day by solar mini grids during the summer and winter seasons is approximately 21 hours, which makes it more reliable than the main grid.
- While improvements have been noted in some respects such as supply duration and voltage stability, challenges remain, particularly in laggard districts, highlighting the need for continued efforts to enhance the reliability and stability of electricity supply in these regions.
- Overall, consumer preference leans towards a combination of both main grid and solar mini grid supply. The general perception is that solar energy will be more desirable in the long run, as it is environment-friendly and cost-effective, especially if subsidized for rural domestic consumers.

4.2. Consumer Perspectives on Rural Energy Services

Through interviews with different categories of consumers such as households, commercial enterprises, and institutions, the study captured insightful perspectives on the demand, supply quality, challenges in supply, the usage pattern and enablement livelihoods and living standards for energy among rural consumers. A wide range of aspects pertaining to electricity supply from both main grid and solar mini grid were covered by the study, including regularity of supply, voltage fluctuations, frequent outages and disruptions in supply, adequacy of supply, load capacity, etc. Issues of metering, billing, and payments were also explored.

The majority of respondents with main grid electricity connections reported that while they receive electricity supply daily, challenges related to low voltage and frequent outages persist. Respondents with mini grid connections reported that the supply is more reliable as compared to main grid, although the load capacity is sometimes inadequate for the usage of heavy appliances, especially for commercial consumers. A higher degree of satisfaction was also recorded among mini grid consumers. Most of the main grid and mini grid connections have attached meters, and billing and payments occur on a monthly basis. More main grid consumers have overdue bill payments for over a month as compared to mini grids.

4.2.1 Domestic Consumers[51]

Caste/Tribe Distribution by Electricity Grid Type:

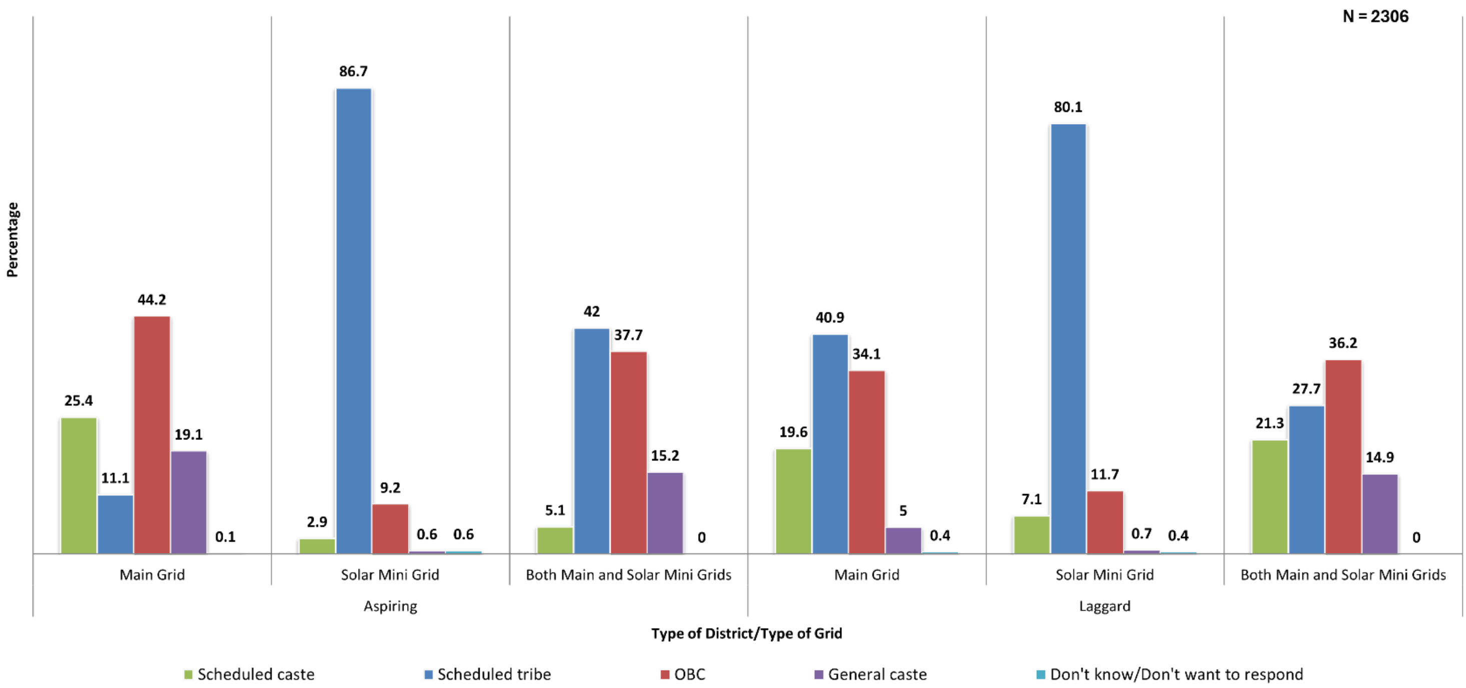


Figure 16: Percentages showing the distribution of the caste of the head of the household by grid and district types

Aspiring Districts

- **Scheduled Caste (SC):** In aspiring districts, 25.4% of households connected to the main grid belong to scheduled castes, while only 2.9% and 5.1% of households connected to solar mini grid and both main and solar mini grid, respectively, belong to this category.
- **Scheduled Tribe (ST):** A significant portion of households in aspiring districts with solar mini grid connections (86.7%) belong to scheduled tribes, compared to 11.1% and 42% for main grid and both main and solar mini grid, respectively.
- **Other Backward Class (OBC) and General Caste:** OBC households are relatively evenly distributed across all electricity grid types in both aspiring and laggard districts. General caste households show similar trends, with lower

[51] **Total number of domestic respondents = 2306**
Aspiring Districts = 1152 (Main Grid = 841; Solar Mini Grid = 173; Both Main and Solar Mini Grids = 138)
Laggard = 1154 (Main Grid = 826; Solar Mini Grid = 281; Both Main and Solar Mini Grids = 47)

representation in solar mini grid-connected households compared to main grid-connected households in both district types.

Laggard Districts

- **Scheduled Caste (SC):** In laggard districts, 19.60% of households connected to the main grid are from scheduled castes, compared to 7.10% and 21.30% for solar mini grid and both main and solar mini grid, respectively.
- **Scheduled Tribe (ST):** In laggard districts, a higher percentage of households connected to solar mini grid (80.10%) are from scheduled tribes, compared to 40.90% for main grid and 27.70% for both main and solar mini grid.

These findings suggest households belonging to the marginalized section face some inequalities in accessing main grid, and electricity from the main grid. The household belonging to the STs, and SCs do have limited access to main grids as compared to other social categories. These insights suggest variations in the distribution of caste and tribe among households based on the type of electricity grid they are connected to, highlighting potential disparities in access to electricity services among different social groups in rural areas. Mini grids in both laggard and aspiring districts have mostly been installed in isolated villages, in which the dominant social group is the scheduled caste category. This aspect of representation of marginalised communities in the beneficiary groups who have access to mini grid energy ties back to SDGs 1 and 10, which aim for a reduction in poverty and inequality.

Demographic Profile:

The average age of respondents in aspiring and laggard districts is 43 years and 42 years, respectively. A substantial percentage of women were interviewed in households, with 41% female respondents in aspiring districts and 46% female respondents in laggard districts.

Religious Profile:

Aspiring Districts:

- **Hinduism:** The majority of households connected to the main grid (87.9%) follow Hinduism, while a smaller proportion of households connected to solar mini grid (19.7%) and both main and solar mini grid (47.1%) are Hindu.
- **Islam:** A notable percentage of households connected to both main grid and mini grid (11.6%) are followers of Islam, while households connected to only main grid have lower representation (8.6%).
- **Christianity:** Christian households are predominantly connected to solar mini grid (12.1%) compared to those connected to both main grid and mini grid (0.7%).

Laggard Districts:

- **Hinduism:** Similar to aspiring districts, Hindu households dominate all grid types, with consumers having both main grid and mini grid connections having the highest representation (80.9%), followed by main grid (63.7%) and solar mini grid (13.5%).
- **Islam:** Islam followers constitute a smaller percentage in households connected to the main grid (4.2%), solar mini grid (3.6%), and both main and solar mini grid (6.4%).
- **Christianity:** In laggard districts, a significant portion of Christian households are connected to solar mini grid (29.5%), followed by main grid (8.8%) and both main and solar mini grid (2.1%).

Comparison by Grid Type:

- **Main Grid:** Hinduism is the dominant religion among households connected to the main grid in both aspiring and laggard districts.
- **Solar Mini Grid:** Sarna, a tribal religion, has a significant presence among households connected to solar mini grids in both aspiring (68.2%) and laggard (53.4%) districts in Jharkhand. This highlights the distinct social composition of mini grid villages in Jharkhand.
- **Both Main and Solar Mini Grids:** Hinduism has the highest representation in both district types, followed by Sarna in aspiring districts and Christianity in laggard districts.

These findings are in line with the overall distribution of religious communities in the country and states.

Household Profile:

The average number of members in the households across the grid type is 5.

Table 7: Percentages of types of primary occupation of households by grid type

Type of Occupation	Main Grid	Solar Mini Grid	Both Main and Solar Mini Grids	Total
Agriculture/cultivation on own/ leased-in/shared land	42.4	50.7	26	**42.7**
Animal husbandry	1.5	2.0	0	**1.5**
Fishing	0.1	0.7	0	**0.2**
Agriculture labour	14.8	19.8	16.2	**15.9**
Non-agriculture unskilled labour	12.8	8.8	16.2	**12.3**
Non-agricultural skilled labour	6.7	3.1	6.0	**5.9**
MGNREGS labour	1.2	0.2	0.5	**1.0**
Enterprise/business /shops	1.7	1.1	9.2	**2.2**
Salaried government job	0.5	0.7	1.1	**0.6**
Salaried private job	5.8	2.4	7.6	**5.3**
Not working but seeking and is available for work	0.1	0.2	0.5	**0.2**
Unable to work due to ill- health/disability currently	1.2	0.7	4.3	**1.3**
Not employed and not seeking work	11.1	9.7	12.4	**10.9**

Main Grid: The primary occupation among households connected to the main grid is agriculture/cultivation, constituting 42.4% of the households. Other significant occupations include agriculture labour (14.8%), unskilled non-agriculture labour (12.8%), and skilled non-agriculture labour (6.7%)

Solar Mini Grid: Higher proportion of households living in solar mini grid villages depend on agriculture (50.7%) and labour-based occupations (19.8% on agricultural labour and 8.8% on non-agricultural labour) as compared to households in the villages with only main grid connection.

Both Main and Solar Mini Grid: For households connected to both main and solar mini grids, there is a significant shift in occupational distribution. Agriculture/cultivation, is the occupation of only 25.9% households, suggesting a more diversified economy. Enterprise/business/shops see a substantial increase in representation among households with both main and solar mini grid connections, rising to 9.2% compared to 1.7% and 1.1% for main grid and solar mini grid households, respectively. Additionally, a higher percentage of households in this category report being unable to work due to ill-health/disability currently (4.3%) compared to main grid (1.2%) and solar mini grid (0.7%) households.

Education Profile of Chief Wage Earner (CWE) by Type of Grid:

Main Grid: Among households connected to the main grid, the majority of CWEs have below 10th or completed 10th grade education, constituting 52% of the total. Those who have completed their 12th grade education represent 8.8% of CWEs, while 4.4% are graduates and 1.3% have completed postgraduate studies. A notable percentage (31.1%) of CWEs have not completed any grade or have not passed any class, indicating a significant portion with limited formal education.

Solar Mini Grid: Similar to main grid households, the highest educational attainment among CWEs in households with solar mini grid connections is below 10th or passing the 10th grade, with 53% achieving this level of education. The percentage of CWEs who have completed the 12th grade is slightly higher in solar mini grid households compared to main grid households, at 9.4%. The proportion of graduates (2.9%) and postgraduates (0.9%) is lower among solar mini grid households compared to main grid households.

Both Main and Solar Mini Grid: CWEs in households connected to both main and solar mini grids show a higher educational attainment compared to those in households with only one type of grid connection. The percentage of CWEs who have passed the 12th grade is notably higher in households with both main and solar mini grid connections, at 15%. Additionally, the proportion of graduates (5.9%) is higher in these households compared to those with only a main grid or solar mini grid connection.

Overall Insights: Educational attainment among CWEs varies by electricity grid type, with households connected to both main and solar mini grids showing the highest levels of education. The 10th grade or below is the most common level of education achieved across all grid types, followed by the 12th grade. Solar mini grid households generally have educational attainment levels similar to or slightly higher than main grid households, but lower than households with both main and solar mini grid connections.

Total Annual Income by Electricity Grid Type and District Type:

Aspiring Districts: Among households in aspiring districts, the total annual income is highest for those connected to both main and solar mini grids, with an average income of Rs 128,709. Households reliant solely on the main grid have a slightly lower average annual income at Rs 108,445, while those with solar mini grid connections have the lowest at Rs 89,893.

Laggard Districts: In laggard districts, households with both main and solar mini grid connections again have the highest average annual income at Rs 149,732. Those connected only to the main grid have an average annual income of Rs 108,087, while households with solar mini grid connections have a slightly higher average income at Rs 109,689.

Households with both main and solar mini grid connections tend to have the highest average annual income in both aspiring and laggard districts, indicating potentially better economic conditions or access to resources in these households. The fact that these villages had a renewable energy solution over and above the electricity supply from the main grid, and the fact that they do not have a high proportion of vulnerable population groups, points to a socio-economically stronger community, with a higher proportion in trade or enterprises, who could be leveraged for provisioning better electricity services.

Solar mini grid connections are associated with lower average annual incomes compared to main grid connections, regardless of district type. This might suggest differences in economic opportunities or affordability between households with different types of electricity access.

Energy consumption patterns:

Across all categories of district type and grid type, firewood has emerged as the most commonly used household cooking fuel. LPG, cattle dung cakes, and crop residues are also used widely. For the category of consumers with both main grid and mini grid connections, 5% consumers in aspiring districts and 9% consumers in laggard districts recorded usage of electric cook stoves and induction stoves.

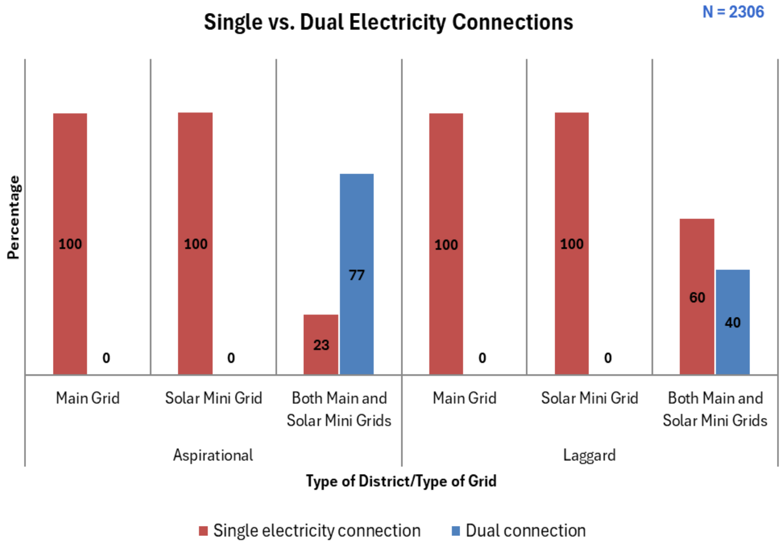


Figure 17: Percentage of households with single versus dual electricity connection by grid and district types

Across all types of districts and grids, all households reported that they have functional electricity connections at present. This is aligned with the national objective of universal village electrification. The proportion of households having dual electricity connection from both main grid and mini grid is higher in aspiring districts as compared to laggard districts.

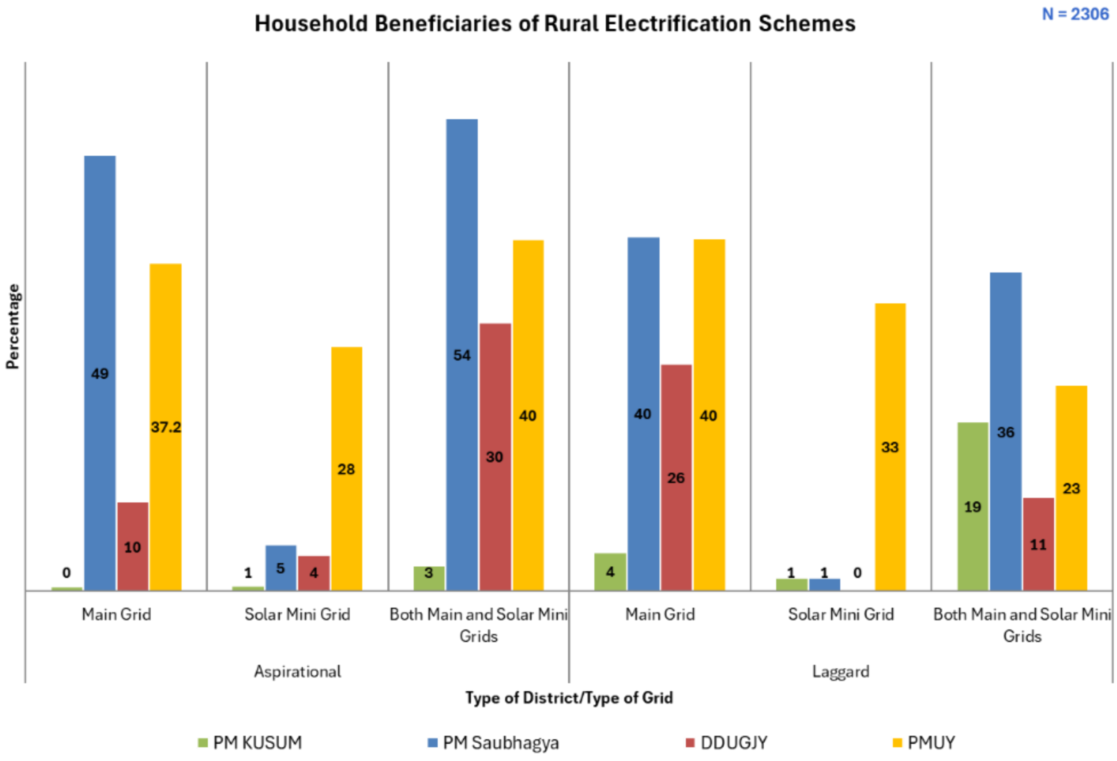


Figure 18: Percentage of households benefitting from government schemes by grid and district types

In aspiring districts, a higher proportion of respondents are beneficiaries of the PM Saubhagya scheme. Across all categories, PMUY beneficiaries are also prominent, followed by DDUGJY beneficiaries. PM KUSUM has the lowest proportion of scheme beneficiaries across all categories.

Lights, ceiling fans, table fans, pedestal fans, mobile phones, mixer-grinder, refrigerators, televisions, clothes irons and water pumps are commonly owned electrical appliances at the household level. None of the respondents own air conditioners, microwave ovens or drinking water filters. Across all types of districts and grids, a majority of households have toilets. However, the majority of them reported that the toilets do not have electric light connections. The highest proportion of households with electric light connections in toilets receives electricity services from both the main grid and solar mini grid.

> "We have lights and fans, but if better quality of electricity supply is provided, we would like to purchase motors, television sets, fridge, chakki machine, even laptops if we can afford." – Domestic consumer, Simdega, Jharkhand

In aspiring districts, only main grid consumers reported that their peak electricity usage hours are in the afternoon, between 12:00 noon to 4:00 PM. For only mini grid consumers and those with both main grid and mini grid connections, electricity usage is the highest in the evening, between 4:00 PM to 8:00 PM. In laggard districts, only main grid and only mini grid consumers reported peak usage in the evening, while those with both main grid and mini grid connections reported higher load requirement in the afternoon. These timings correspond to the main working hours during the day, during which the highest amount of electricity is utilized by households for daily chores, business activities, operating lights especially after sunset, etc.

Frequency of electricity supply – Comparison between main grid and solar mini grid:

Aspiring Districts: In aspiring districts, the majority of households across all types of electricity grid connections receive electricity supply on a daily basis. For households connected to the main grid, 89.5% report daily electricity supply, while for solar mini grid connections, this figure is even higher at 99.4%. Among households with both main and solar mini grid connections, 70.3% report daily supply.

Laggard Districts: Similarly, in laggard districts, the majority of households receive electricity supply daily, although the percentages are slightly lower compared to aspiring districts. For households connected to the main grid, 86.8% report daily electricity supply, while for solar mini grid connections, this figure is higher at 95.9%. Among households with both main and solar mini grid connections, 87% report daily supply.

Most consumers receive daily electricity supply across both aspiring and laggard districts, indicating a relatively evolved electricity supply situation. Solar mini grid connections show slightly higher percentages of daily supply compared to main grid connections, suggesting the reliability and effectiveness of solar energy solutions in providing continuous electricity access.

Across all categories, the majority of consumers have reported that electricity services from the main grid are available on a daily basis. A higher proportion of only main grid consumers in both aspiring and laggard districts receive electricity supply daily from the main grid. For mini grids as well, a substantially high proportion of consumers across all categories have reported that electricity services are available on a daily basis. A higher proportion of households in the hybrid electricity villages of aspiring districts (30%) as compared with households of hybrid electricity villages in laggard districts (13%) report not receiving daily electricity.

Reliability of Electricity Supply:

Reliability was defined as electricity services being available at a particular time on supply days for a certain duration (expected number of hours).

Aspiring Districts: In aspiring districts, around 52% of respondents (main grid) report that electricity supply is reliable on the days of supply, indicating a slightly positive perception of reliability. However, a significant proportion, approximately 48%, report that the electricity supply is not reliable on the days it is supposed to be provided.

Laggard Districts: In laggard districts, a slightly lower percentage (49.8%) of respondents (main grid) perceive electricity supply as reliable on the days of supply. Conversely, a slightly higher percentage (50.2%) report that the electricity supply is not reliable on the days it is supposed to be provided.

There is a relatively balanced perception of electricity supply reliability between aspiring and laggard districts, with slight differences in the proportions of respondents perceiving reliability. The similar perception can be attributed to the centralized network of DISCOMs, and uniformity in the supply of electricity across the districts of the states (number of hours of electricity to be provided can be similar due to economic and political reasons). Laggard districts have a comparable electricity supply situation to aspiring districts.

Around half of the respondents across all categories reported ongoing challenges in ensuring consistent and reliable electricity supply, regardless of the district's development status. Further investigation into the factors affecting reliability, such as infrastructure quality, maintenance practices, and service interruptions, could provide deeper insights into addressing these challenges.

On average, households connected with main grid reported receiving electricity on all 7 days preceding the survey. Similarly, households connected with the mini grid reported receiving electricity on all 7 days preceding the survey.

The main grid supply was reported to be adequate by almost two thirds of the domestic consumers in villages where only main grid electricity is available in aspiring districts, while this proportion is a little less in the laggard districts. A slightly higher percentage of consumers in aspiring districts using electricity from both main and mini grid reported that main grid electricity supply is not reliable. As maybe expected, only a third of the domestic consumers reported adequacy of main grid supply in villages where both main and mini grid is available, and this is possibly the reason why the solar grid was implemented in these villages/habitations. A substantial majority of mini grid consumers across all categories have reported that they receive round the clock provision of electricity supply, and that voltage fluctuations from the mini grid supply are infrequent in nature.

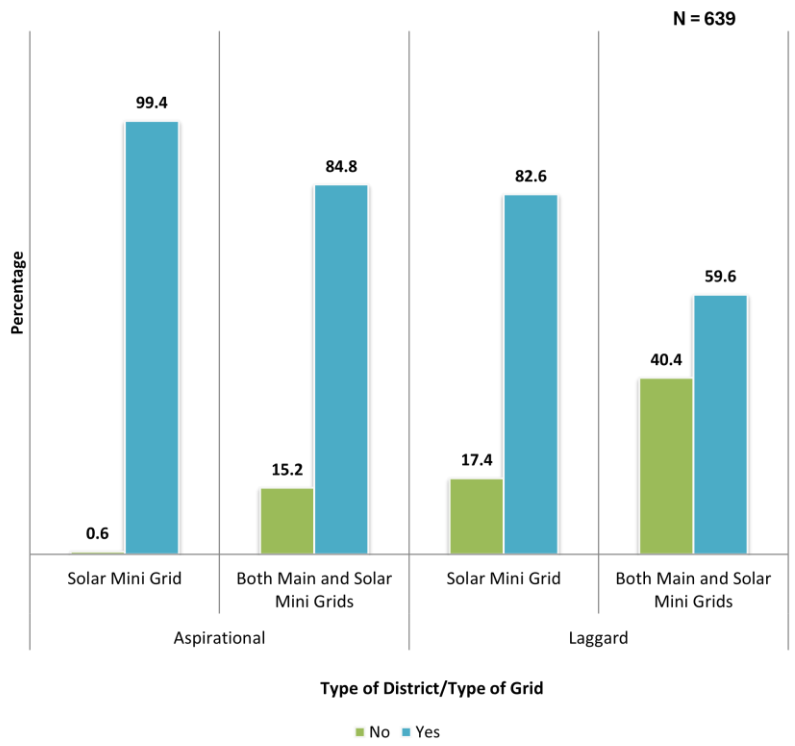


Figure 19: Percentage of households round the clock electricity supply by grid and district type

While the majority of mini grid consumers across all categories (86%) reported that they receive round the clock electricity supply on a daily basis from the mini grid, frequent outages and disruptions were reported for the main grid supply. In aspiring districts, electricity outages from the main grid were reported to be more frequent in the rainy season. The majority of main grid consumers reported that electricity outages from the main grid are infrequent, while the majority of those receiving electricity from both main grid and mini grid reported outages happen daily. In laggard districts, the frequency of electricity outages from the main grid were reported to be high throughout the year by only main grid consumers, and higher in summer season by consumers using electricity from both main grid and mini grid. The majority of main grid consumers reported daily outages, while most of those receiving electricity from both main and mini grid reported infrequent outages. Across all categories, most of the consumers reported that electricity outages usually last for a duration of 1-4 hours. The reason behind higher power outages in summer may be attributed to higher load and adverse weather conditions such as rain and thunderstorm which may cause damage to power distribution infrastructure such as transmission wires, transformers, poles, etc.

Overall, 2.8% respondents in aspiring districts and 2.5% respondents in laggard districts own inverters. 3.2% respondents in aspiring districts and 2.3% respondents in laggard districts reported the use of inverters as coping mechanisms during power outages and disruptions in supply. The slightly higher figures for aspiring districts can be explained by the fact that they fare better than laggard districts in terms of socioeconomic indicators which determine the purchasing power of households. Overall, a greater proportion of only main grid consumers (2.9%) reported the use of inverters as compared to consumers with both main grid and mini grid connections (1.6%), thereby pointing towards the need for extra expenditure on battery solutions such as inverters as back up for main grid supply, which can be mitigated by adopting solar mini grids as a potential alternative source of supply.

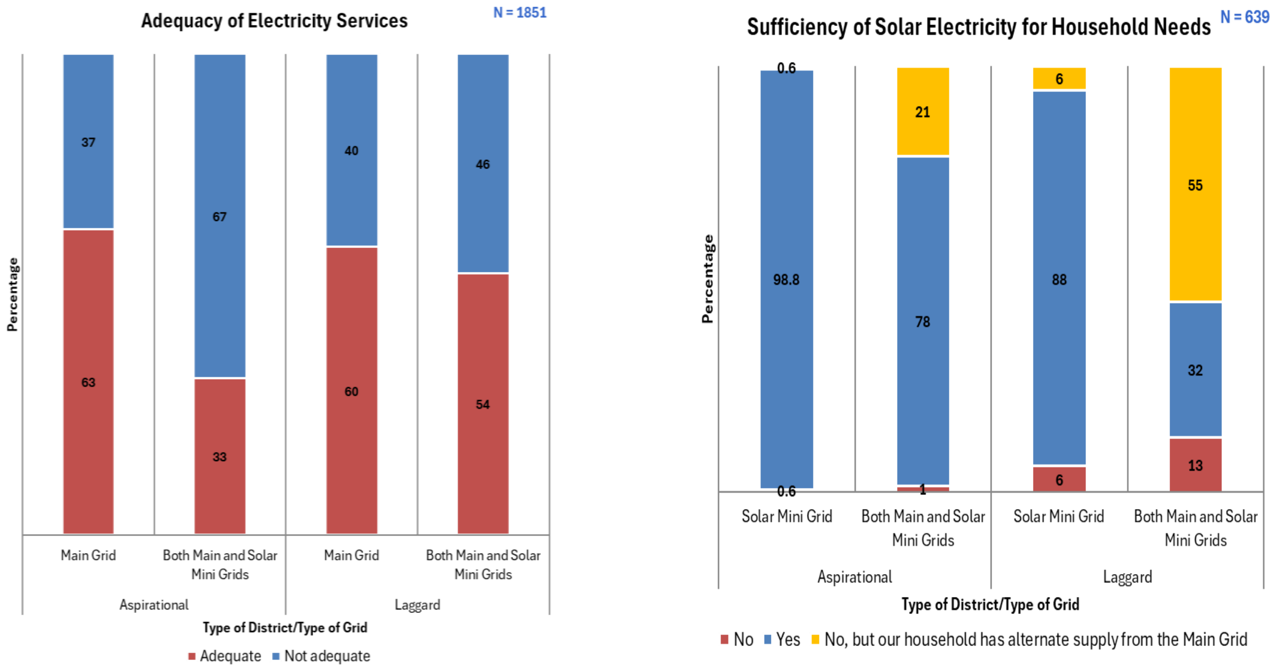


Figure 20: Percentage of households reporting the adequacy of electricity supply by grid and district types (Main Grid - left, Solar Mini Grid - right)

The majority of only main grid consumers in both aspiring and laggard districts, as well as consumers with both main grid and mini grid connections in laggard districts, have reported that the main grid electricity supply is adequate. Around 67% of consumers with both main grid and mini grid connections in aspiring districts have reported that the main grid electricity supply is not adequate. Across all categories, most of the consumers have said that mini grid electricity supply is sufficient to meet the daily requirements of households either by itself, or in combination with a main grid connection.

Mini Grid: In Aspiring Districts, 98.8% of respondents using solar mini grid reported sufficient supply for households needs. In laggard districts, 88% of respondents using solar mini grid reported sufficient supply for households needs.

Billing and payments:

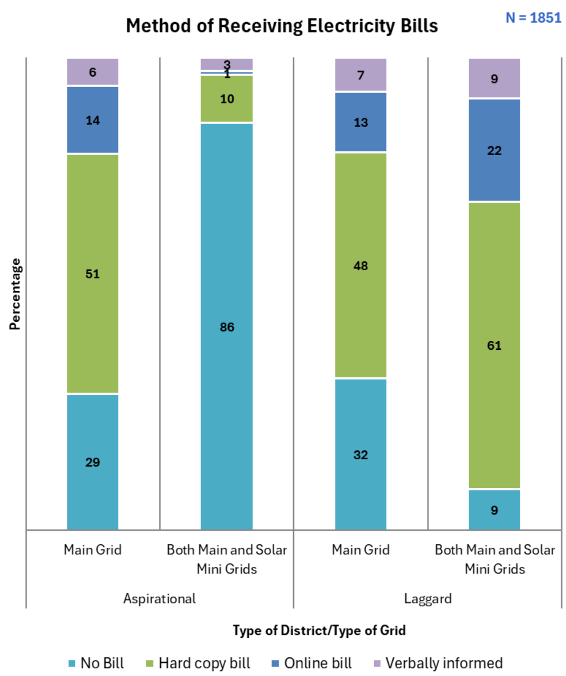


Figure 21: Percentage of different billing methods available to consumers of the main grid by district type

A substantially high proportion of consumers with only main grid connections (29%) and both main grid and mini grid connections (86%) in aspiring districts reported that they do not receive electricity bills for their main grid connection. Across all other categories, the majority of consumers receive hard copies of electricity bills for their main grid connection on a monthly basis. Smaller proportions of consumers reported receiving online bills or being verbally informed regarding their main grid electricity bills. A substantial proportion of consumers (26.5%) across all categories also reported that the frequency at which they receive bills for their main grid connection is not fixed.

The majority of only mini grid consumers in both aspiring and laggard districts have postpaid electricity meters attached to their mini grid connection and receive bills at the end of the usage period. The majority of consumers with both main grid and mini grid connections have prepaid electricity meters attached to their mini grid connection and have to recharge at the beginning of the usage period as per requirement.

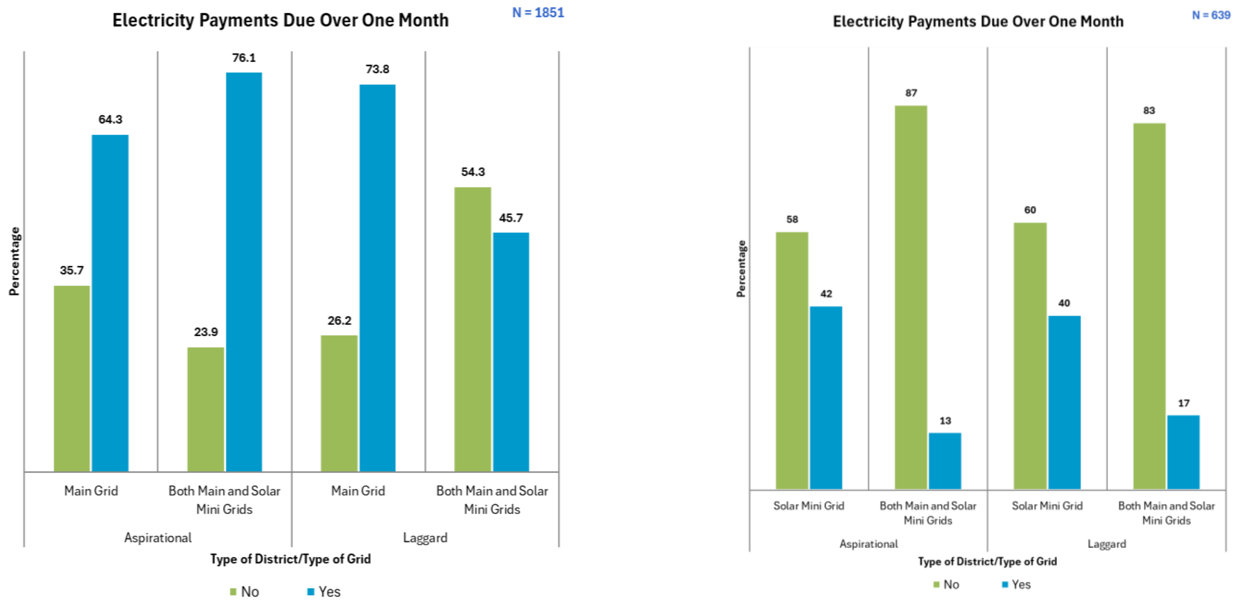
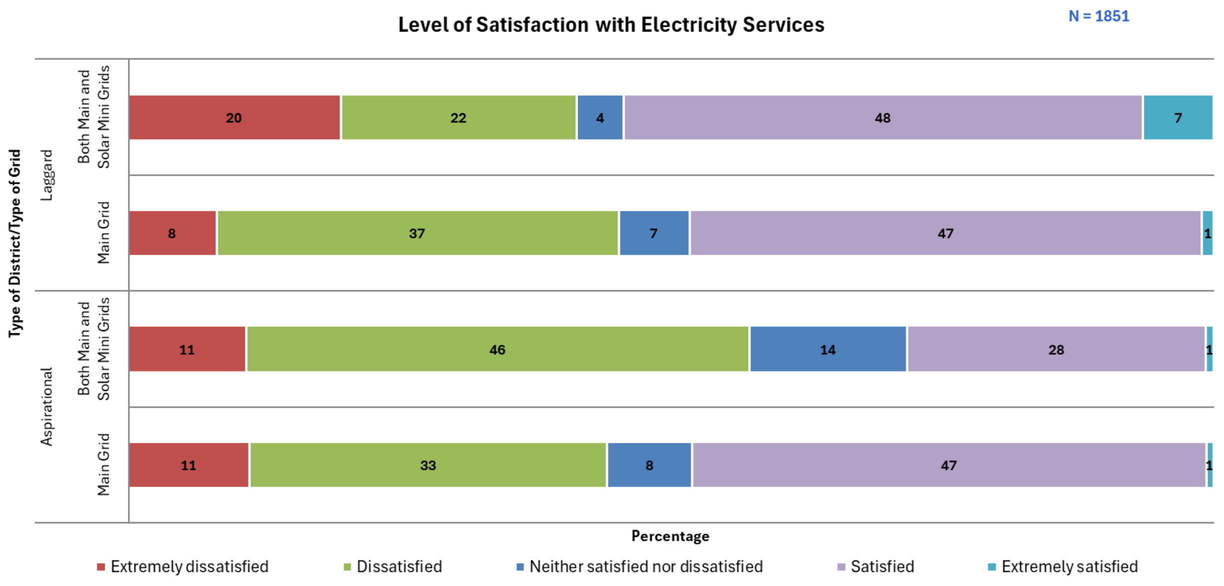


Figure 22: Percentage of households reporting the existence of bills due for over a month by grid and district types (Main Grid – left, Solar Mini Grid – right)

Overdue payments are for main grid supply in both aspiring and laggard districts is found for almost one in every five domestic consumers. The proportion is lower in villages which have both main and mini-grid supply. The reverse is true for villages with mini-grid only, where almost two out of every five consumers report no dues for over a month. However, the remaining report dues for over a month. However, in mini-grid villages, which also have main grid supply, more than four out of every five domestic consumers have dues for over a month.

Level of satisfaction with electricity services:



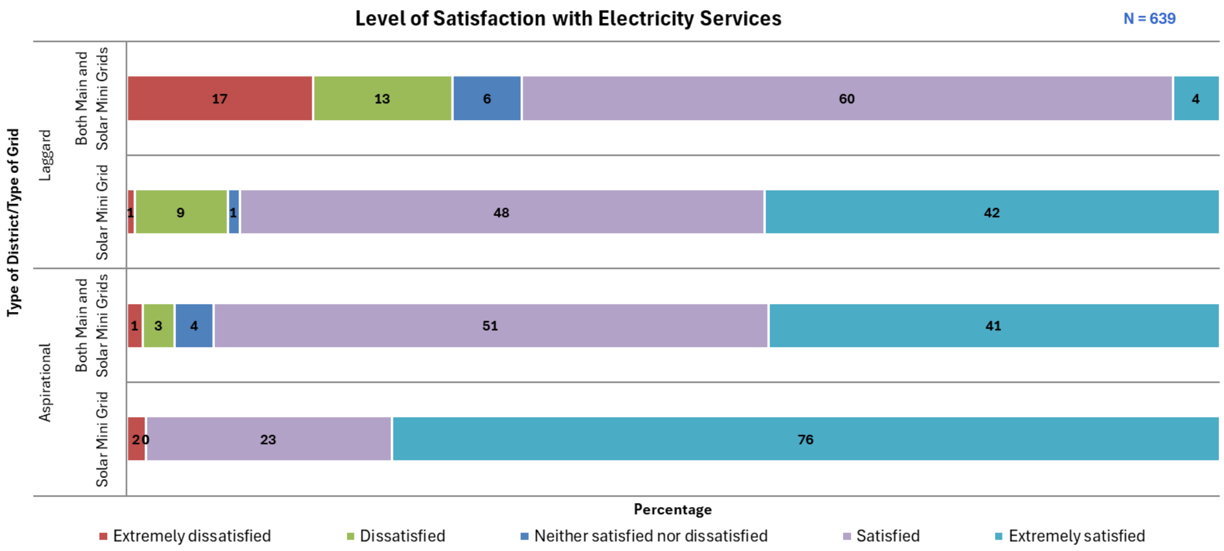


Figure 23: Percentage of households rating the quality of electricity supply by grid and district types (Main Grid – top, Solar Mini Grid – bottom)

In aspiring districts, the highest proportion of only main grid consumers (47%) have reported that they are satisfied with the quality of main grid electricity services. The highest proportion of consumers with both main grid and mini grid connections (46%) have reported dissatisfaction with main grid electricity services. This indicates that when there is an alternative source of electricity for comparison, a higher proportion of consumers reported dissatisfaction with main grid supply. The majority of only mini grid consumers (76%) have reported that they are extremely satisfied with the quality of mini grid electricity services. The majority of consumers with both main grid and mini grid connections (51%) have reported satisfaction with mini grid electricity services.

In laggard districts, the highest proportion of only main grid (47%) and both main grid and mini grid consumers (48%) have reported satisfaction with main grid electricity services. A relatively smaller proportion of consumers (only main grid – 8%; both main grid and mini grid – 20%) reported extreme dissatisfaction, and an even smaller proportion (only main grid – 1%; both main grid and mini grid – 7%) reported extreme satisfaction. The majority of respondents (only mini grid – 90%, both main grid and mini grid – 64%) reported that they are either satisfied or extremely satisfied with mini grid electricity services.

"Main grid supply faces frequent disruptions due to faulty poles and wires. Solar mini grid is more reliable due to its 24-hour power supply, cost-effectiveness, and prompt resolution of voltage fluctuations and other issues during adverse weather conditions. The only disruptions in mini grid supply happen during cloudy weather and periods of low sunlight." – Domestic consumer, Simdega, Jharkhand

"With longer hours of stable electricity from the mini grid, children can study without disturbance. Farm incomes have also improved as electric motors can now be used efficiently for irrigation." – Domestic consumer, Gumla, Jharkhand

Usage of electricity in agriculture:

Main Grid: In aspiring districts, 72.2% of households undertake cultivation on their own land. while 25.4% do not engage in cultivation on their own or leased-in land. Only a small proportion (2.4%) cultivate on leased-in or rented land. In laggard districts, 90.4% of households are cultivating on their own land, 8.1% are not engaging in cultivation on their own or leased-in land, and 1.5% are cultivating on leased-in or rented land.

Solar Mini Grid: In aspiring districts, almost all (96%) of households cultivate on their own land, while only 3.5% do not engage in cultivation on their own or leased-in land. The percentage of households cultivating on leased-in or rented land is minimal (0.6%). In laggard districts, a similar pattern is observed, with 95% of households cultivating on their own land, 4.6% not engaging in cultivation on their own or leased-in land, and 0.4% cultivating on leased-in or rented land.

Both Main and Solar Mini: In aspiring districts, 91.3% of households cultivate on their own land, 8.7% do not engage in cultivation on their own or leased-in land, and none cultivate on leased-in or rented land. In laggard districts, 70.2% of households cultivate on their own land, 27.7% do not engage in cultivation on their own or leased-in land, and 2.1% cultivate on leased-in or rented land.

This pattern indicates that a higher proportion of households in rural areas are dependent on agriculture for their livelihoods and rely on cultivating their own land as a primary source of income. This may be attributed to several factors such as slower economic development and limited job opportunities, limited access to leased or rented land due to higher demand, land tenure issues or lack of availability, risk aversion as leasing or renting land is relatively uncertain and financially risky, as well as effective government support through subsidies, agricultural extension services or infrastructure development.

Across all categories, almost all respondents (98%) irrigate their own land. Borewell or tubewell (46.4%) and natural water sources such as ponds, rivers and streams (37.4%) are the most common sources of irrigation.

Source of Electricity for lifting of water using pump sets:

Main Grid: In aspiring districts, the majority (74.6%) of households that use pump sets to lift water from the water source operate them on diesel, followed by households who use electricity from the main grid (13.2%). A small percentage (5%) do not use pump sets and motors. In laggard districts, a different trend is observed, with 71.2% of households using solar pump sets, 21.7% of households operating pump sets on diesel, 5.3% using electricity from the main grid, and 2.7% not using pump sets and motors.

Solar Mini Grid: In aspiring districts, a considerable proportion (39.3%) of households using pump sets operate them on solar electricity, while 39.3% operate on diesel. Only a small percentage (21.4%) do not use pump sets and motors. In laggard districts, almost half (47.9%) of households operating pump sets on diesel, while 22.9% operate them on solar electricity. A small percentage (14.6%) do not use pump sets and motors.

This is due to the availability of cross subsidy on diesel, and the price differentials. Agriculture is highly subsidized when it comes to sources and usage of power.

Both Main and Solar Mini: In aspiring districts, 35.7% of households using pump sets operate them on solar electricity, followed by 23.8% on diesel. A smaller percentage (16.7%) uses electricity from the main grid, and 16.7% do not use pump sets and motors. In laggard districts, a significant majority (42.4%) of households operating pump sets on diesel, while 57.6% operate them on solar electricity. Only 3% use electricity from the main grid, and none do not use pump sets and motors.

> “Using main grid connection for irrigation is inconvenient because we have to draw long wires from the house to the field, and supply is irregular during summer and monsoon seasons. Solar pumps are useful as they save irrigation time, operate smoothly for four years without issues, and repairs also happen relatively quickly depending on the availability of spare parts.” – Farmer, Banka, Bihar

Additional Analysis for Domestic Consumers Connected to the Solar Mini Grids (by age and capacity of mini grid)

Installation of Solar Mini Grid:

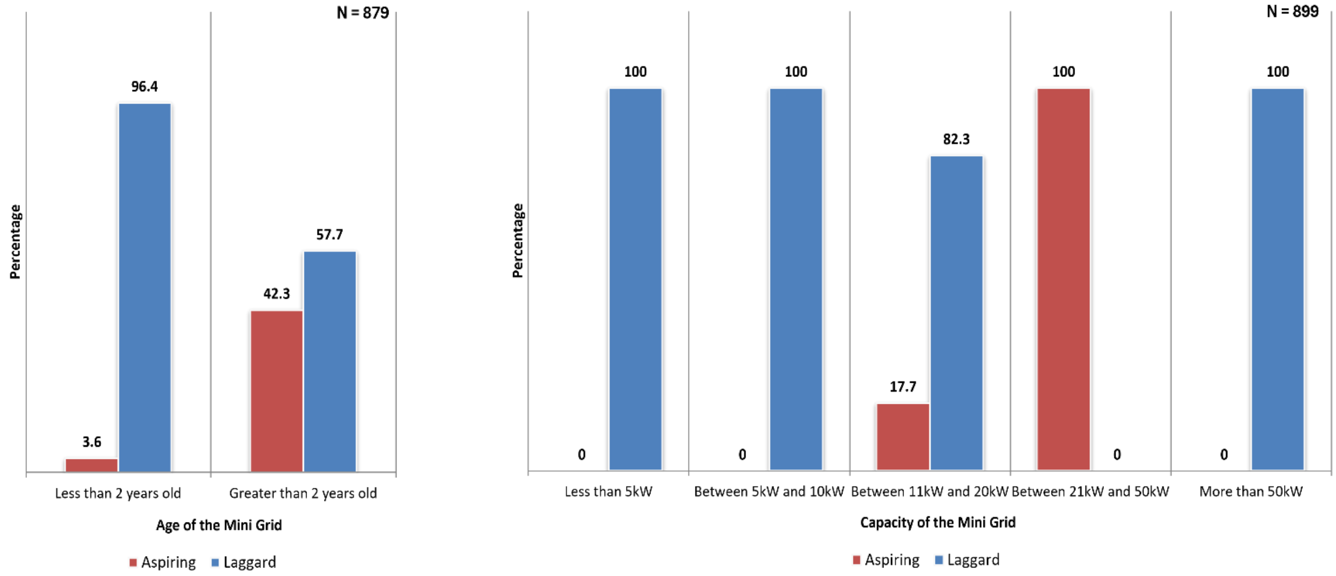


Figure 24: Percentage of households in aspiring and laggard districts by grid age and capacity of solar mini grid

The findings reveal significant differences in the installation of solar mini grids between Aspirational and Laggard districts. In Aspirational districts, only 3.6% of mini grids are less than 2 years old, while a substantial 42.3% are older than 2 years. Conversely, in Laggard districts, the majority (96.4%) of mini grids are less than 2 years old, with 57.7% being older than 2 years.

These findings suggest that there are considerable variations in the pace of installation of solar mini grid between the two types of districts. Laggard districts seem to have undergone more recent investments in mini grid infrastructure, with a higher proportion of newer mini grids. In contrast, Aspirational districts show a significant presence of older mini grids.

All mini grids in the sample with capacity up to 10 kW and those with capacity over 50 kW are located in laggard districts. For mini grids with capacity between 11 kW to 20 kW, 82.3% of them are located in laggard districts, while 17.7% are located in aspirational districts. All mini grids with capacity ranging between 21 kW to 50 kW are located in aspirational districts. This variation in mini grid capacity in aspirational and laggard districts indicates that the size is determined by load requirement at the village level.

Reliability of Electricity Supply:

Across both age categories of mini grids (less than 2 years ~ 97% respondents, greater than 2 years ~ 96% respondents), the majority of households reported receiving electricity daily from the mini grid. This consistency suggests that the age of the mini grid does not significantly impact the frequency of electricity supply, with high percentages indicating daily access to power regardless of the mini grid's age.

Irrespective of grid capacity (5 kW to 10 kW ~ 90.3%, 11 kW to 20 kW ~ 99.1%, 21 kW to 50 kW ~ 98.2%, more than 50 kW ~ 100%), the majority of households reported receiving electricity daily from the mini grid. The proportion of households who reported receiving daily electricity is comparatively lower for the 5 kW to 10 kW category.

Round the Clock Supply of Electricity:

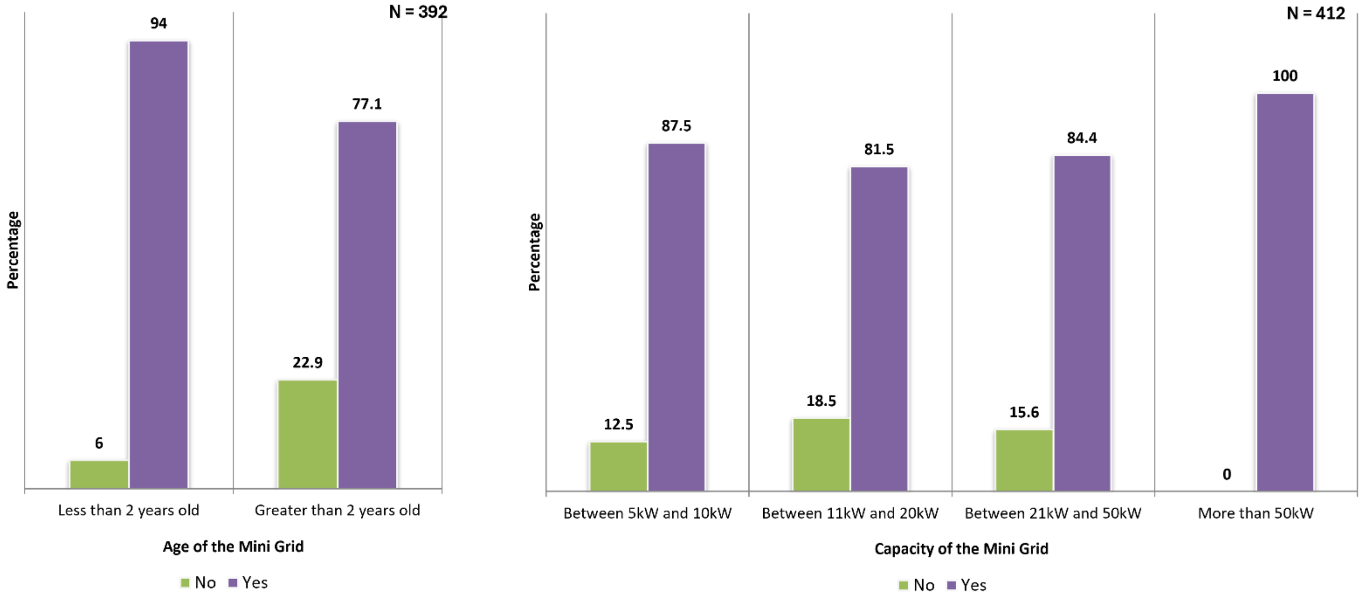


Figure 25: Percentage of households reporting round-the-clock availability of electricity supply by age and capacity of solar mini grid

Across both age categories of mini grids (less than 2 years and greater than 2 years), the majority of respondents indicate receiving electricity round the clock from the mini grid. However, the finding suggests that the age of the mini grid has a significant impact on the frequency of electricity supply. A higher percentage (94.0%) of the respondents report receiving electricity round the clock when the mini grid is less than 2 years old compared to when it is older than 2 years (77.1%). This points towards the challenge arising from technological obsolescence of older infrastructure which affects the reliability of electricity supply. Appropriate financing programmes hold potential for their mitigation.

Across all categories of grid capacity (5 kW to 10 kW ~ 87.5%, 11 kW to 20 kW ~ 81.5%, 21 kW to 50 kW ~ 84.4%, more than 50 kW ~ 100%), the majority of respondents reported receiving round the clock supply from the mini grid, with mini grids over 50 kW capacity showing the best performance in this parameter.

Fluctuation in Voltage:

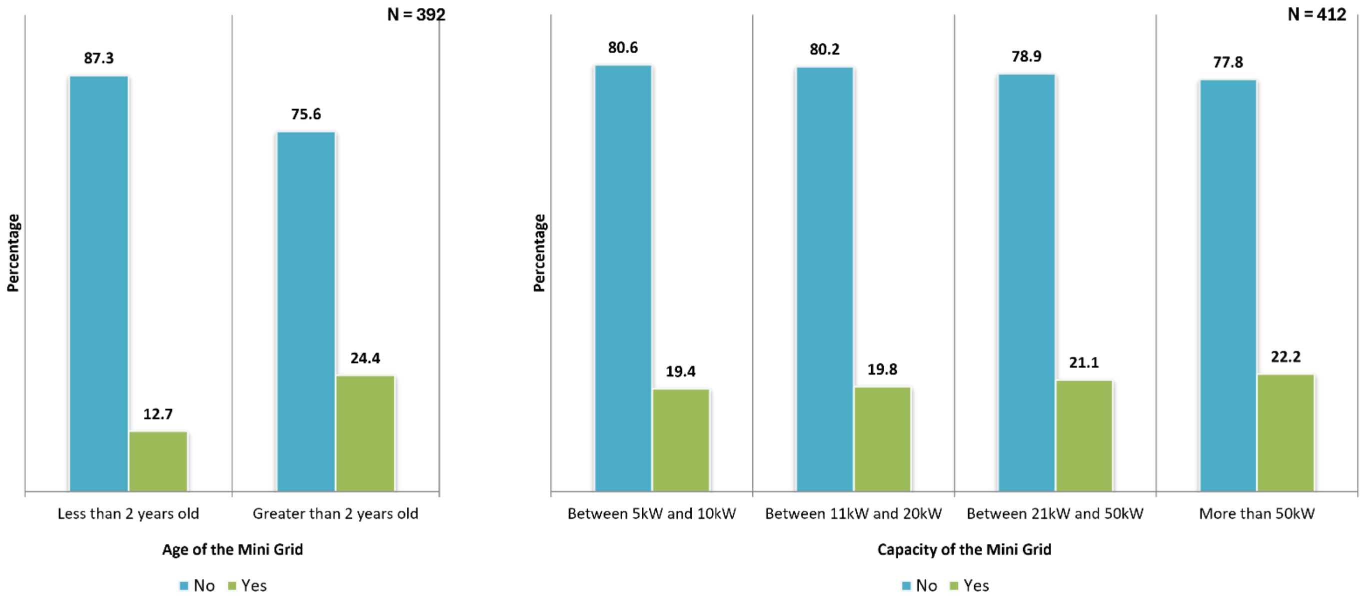


Figure 26: Percentage of households reporting voltage fluctuations by age and capacity of solar mini grid

Across both the categories of mini grids (less than 2 years old and greater than 2 years old), 2/3rd of the respondents indicates not having problems with voltage fluctuations. However, the findings suggest that the age of the mini grid has an impact on the occurrence of voltage fluctuations. A higher proportion (87.3%) of respondents report not having problems with voltage fluctuations when the mini grid is less than 2 years old, compared to when it is older than 2 years (75.6%). The higher proportion of respondents not experiencing voltage fluctuations when the mini grid is less than 2 years old suggests that newer infrastructure is more effective in maintaining stable voltage levels. This highlights the importance of investing in modern grid infrastructure to mitigate issues related to voltage fluctuations.

Across all categories of grid capacity, almost 80% of respondents do not face voltage fluctuations in mini grid supply. Although very little variation is noted across these categories (5 kW to 10 kW ~ 80.6%, 11 kW to 20 kW ~ 80.2%, 21 kW to 50 kW ~ 78.9%, more than 50 kW ~ 77.8%), the trend indicates that lesser voltage fluctuations were reported for mini grids with lower capacity.

Operating High Wattage Equipment:

The majority of respondents (2/3rd) across both age and capacity categories of mini grids (less than 2 years and greater than 2 years) do not operate high wattage equipment. However, there are slight differences in usage patterns.

When the mini grid is less than 2 years old, 68.7% of respondents do not operate high wattage equipment, compared to 61.2% when the mini grid is older than 2 years. Despite the majority not operating high wattage equipment, a notable proportion of respondents operate such equipment when required (< 2 years – 28.4%, < 2 years – 30.1%). This pattern remains consistent regardless of the age of the mini grid. However, there is a shift towards less flexible usage patterns, such as operating during daylight hours or only during specified hours, among respondents with older mini grids.

With regard to grid capacity, the highest proportion of respondents in 11 kW to 20 kW mini grids (79.7%) and 21 kW to 50 kW mini grids (49.5%) do not operate higher wattage equipment on mini grid supply. However, the highest proportion of respondents in 5 kW to 10 kW mini grids (47.2%) and all respondents in mini grids above 50 kW use higher wattage equipment as required.

In summary, non-linear patterns of usage of higher wattage equipment have emerged, which may vary based on the age and capacity of the mini grid, with potential implications for energy consumption and efficiency.

Type of meter

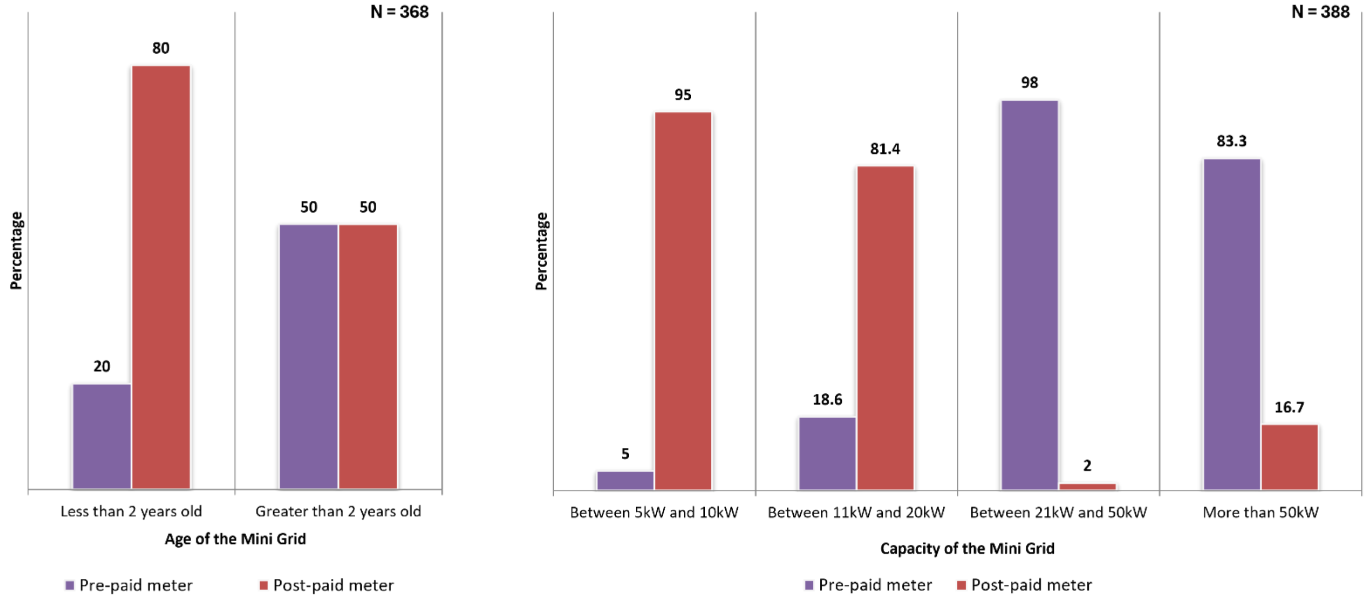


Figure 27: Percentage of households reporting prepaid versus postpaid meter by age and capacity of solar mini grid

Across age and capacity categories, most of the respondents have meters attached to their mini grid connections. While most of the newer mini grids (less than 2 years) have postpaid meters (80%), half of the older mini grids (greater than 2 years) have prepaid meters.

A large degree of variation exists in the type of meter by grid capacity. The majority of smaller capacity mini grids (5 kW to 10 kW mini grids ~ 95%, 11 kW to 20 kW ~ 81.4%) have postpaid meters, while the majority of larger capacity mini grids (21 kW to 50 kW ~ 98%, more than 50 kW ~ 83.3%) have prepaid meters.

Average Electricity Consumption:

The average number of electricity units consumed by households appears to be similar across the age of the mini grids. On average, households connected to mini grids of less than 2 years old consume 21 units of electricity, while households connected to mini grids older than 2 years consume 17 units. Across the categories of mini grid capacity, the average number of units consumed by households for 5 kW to 10 kW mini grids is 17 units, and for 11 kW to 20 kW mini grids is 16 units, while it is 150 units for 21 kW to 50 kW mini grids.

Findings suggest that the age of the mini grid has little influence on electricity consumption patterns, with households connected to newer mini grids consuming equal electricity on average compared to those connected to older mini grids. There is little variation in household consumption by capacity of mini grids within the range of 5 kW to 20 kW, however the consumption registers a sharp increase in terms of units consumed for mini grids with a larger capacity.

There seems to be no correlation between the age of the grid, and electricity consumption. Ceteris paribus Consumption is correlated with household income, pricing, and utility,

Last Monthly Recharge/Bill Amount:

The average last billing amount or monthly recharge amount appears to vary based on the age of the mini grid. On average, customers connected to mini grids of less than 2 years old have an average billing amount of INR 108, whereas customers connected to mini grids older than 2 years have a higher average billing amount of INR 228. The findings suggest that the age of the mini grid may influence billing amounts, with customers connected to newer mini grids having lower average billing amounts compared to those connected to older mini grids.

The average last billing amount or monthly recharge amount is in the same range for 5 kW to 10 kW mini grids (INR 146) and 11 kW to 20 kW mini grids (INR 133), slightly higher for more than 50 kW mini grids (INR 167), and much higher for 21 kW to 50 kW mini grids (INR 311). The higher bill or recharge amount for the last category corresponds to the higher unit consumption recorded for the same.

Billing Information:

The mode of bill provision to households varies depending on the age of the mini grid. There are notable differences in the proportions of different billing methods between mini grids less than 2 years old and those older than 2 years. For instance, households connected to mini grids of less than 2 years old primarily receive bills through modes such as having the bill amount written down in the Urja Passbook (75.4%) or being verbally informed (15.7%). In contrast, households connected to mini grids older than 2 years primarily receive verbal information about their bills (46.9%) or receive hard copy bills (3.1%).

For smaller capacity mini grids, majority of respondents reported that their bill amount is written down in the Urja Passbook (5 kW to 10 kW ~ 81.9%, 11 kW to 20 kW ~ 62.2%), followed by a much smaller proportion who are verbally informed (5 kW to 10 kW ~ 9.7%, 11 kW to 20 kW ~ 15.8%). For 21 kW to 50 kW mini grids, 89% of the respondents are verbally informed regarding their bill amount, while for mini grids over 50 kW, 66.7% of the respondents receive hard copies of the bills.

Frequency of Bill Payment:

Respondents connected to mini grids of less than 2 years old predominantly pay their electricity bills monthly (89.6%), while respondents connected to mini grids older than 2 years show a more balanced distribution, with a slight majority paying monthly (53.5%).

Across all categories of grid capacity, the majority of respondents pay bills on a monthly basis. The highest proportion is reported for 5 kW to 10 kW mini grids (83.3%), followed by more than 50 kW mini grids (77.8%), 11 kW to 20 kW mini grids (65.3%), and finally 21 kW to 50 kW mini grids (60.6%).

Outstanding bills:

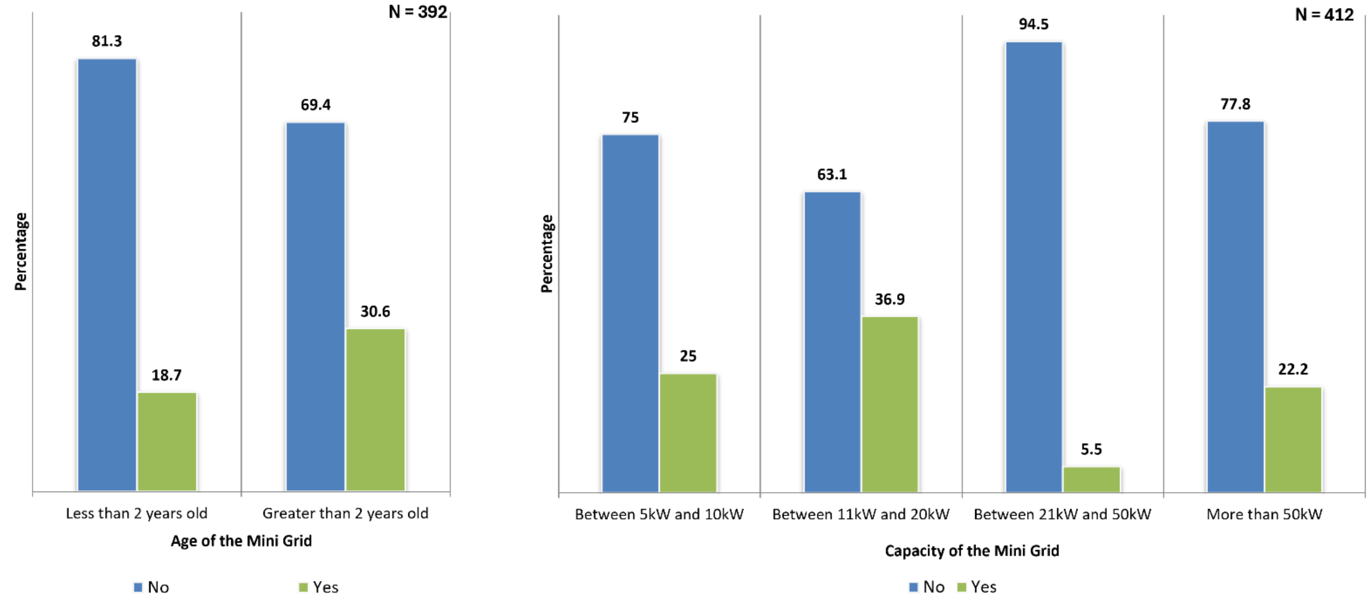


Figure 28: Percentage of households with bills due for over one month by age and capacity of solar mini grid

Households connected to mini grids of less than 2 years old have an outstanding bill for more than 1 month (18.7%). In contrast, households connected to mini grids older than 2 years have an outstanding bill for more than 1 month (30.6%).

The highest proportion of households with overdue electricity bills for more than a month has been reported for 11 kW to 20 kW mini grids (36.9%), while the lowest proportion for the same has been reported for 21 kW to 50 kW mini grids (5.5%).

Adequacy of solar electricity:

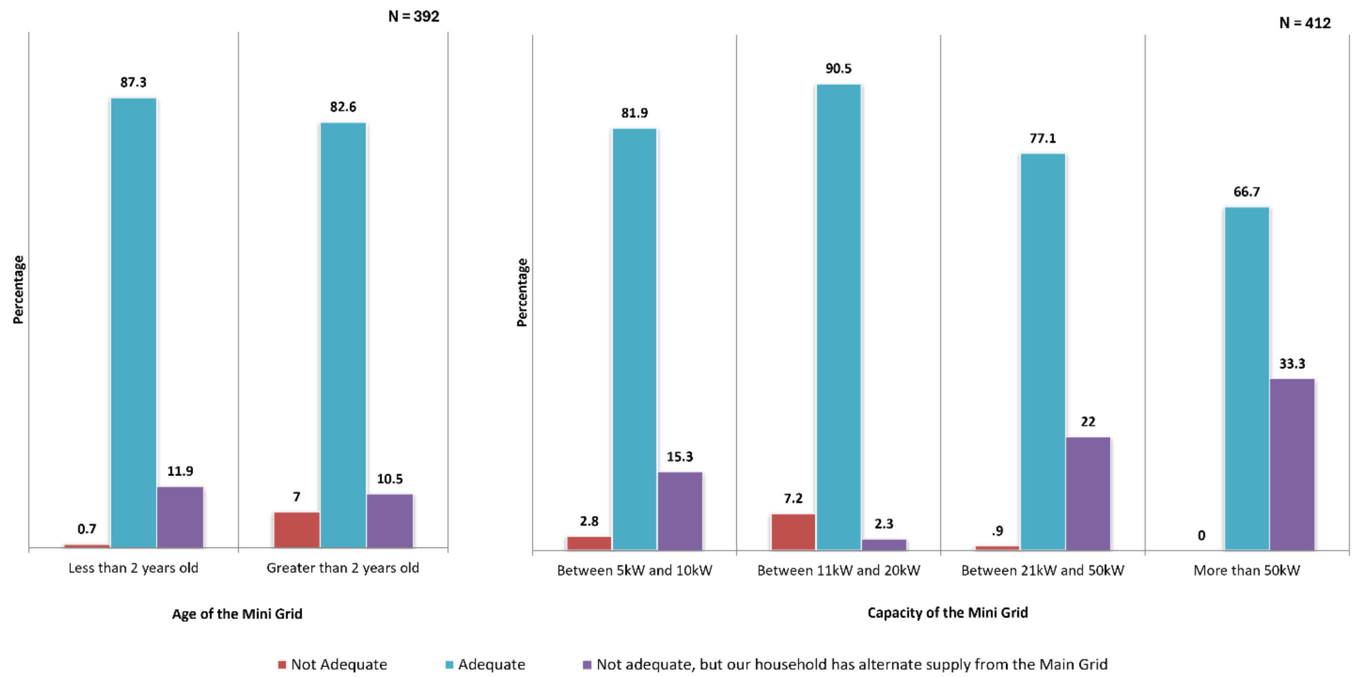


Figure 29: Percentage of households reporting about the adequacy of electricity supply by age and capacity of solar mini grid

Households connected to mini grids of less than 2 years old reported that the solar electricity is adequate for their household needs (87.3%). A slightly lower figure is observed for households connected to mini grids older than 2 years (82.6%). This indicates that supply from newer mini grids is performing better from a consumer perspective, which can be attributed to advancement in technology and infrastructure, as well as efficiency in operations and distribution.

A higher proportion of households connected to smaller capacity mini grids have reported that the solar electricity is adequate for their household needs (5 kW to 10 kW ~ 81.9%, 11 kW to 20 kW ~ 90.5%), as compared to larger capacity mini grids (21 kW to 50 kW ~ 77.1%, more than 50 kW ~ 66.7%).

Level of satisfaction:

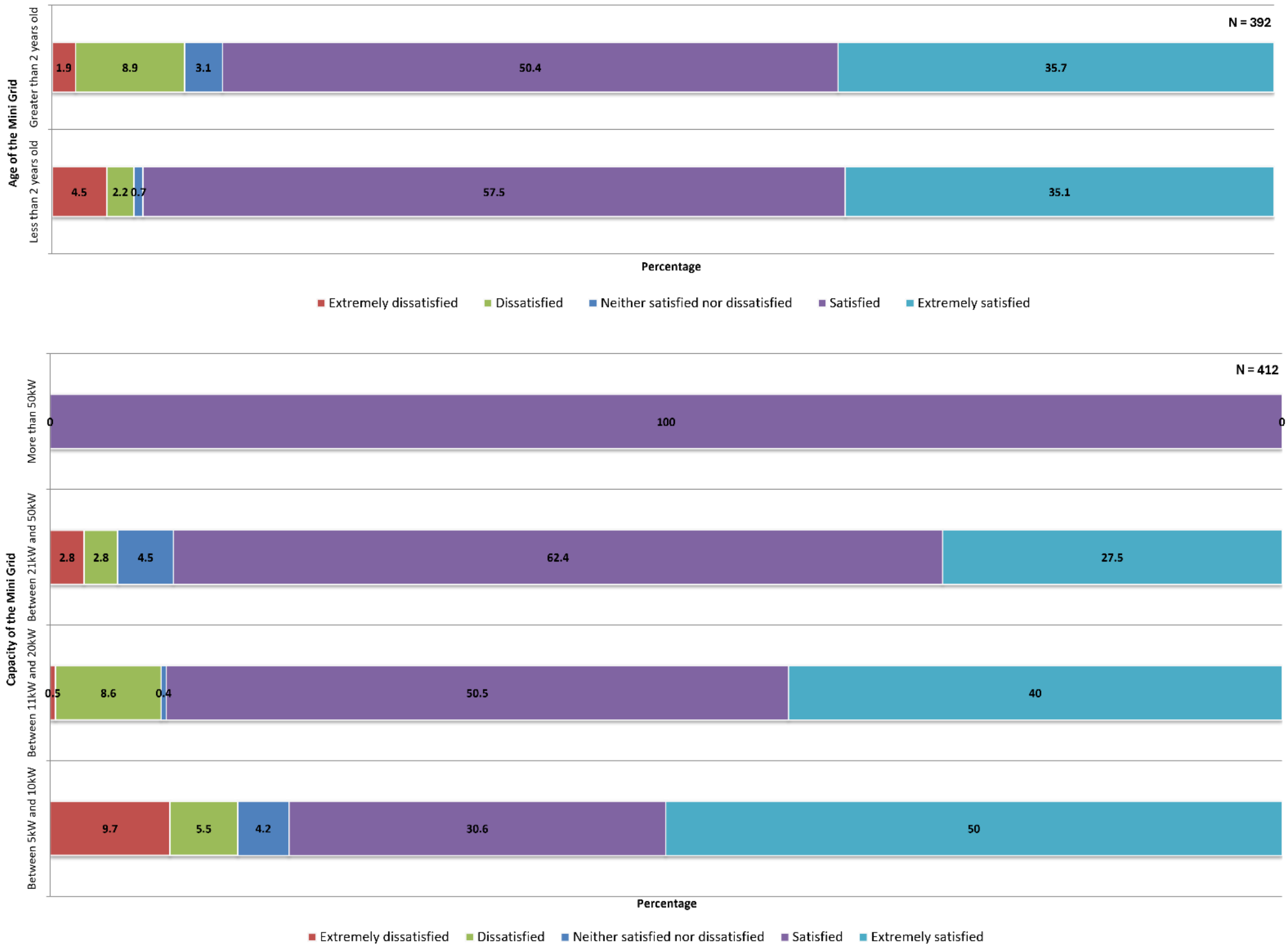


Figure 30: Percentage of households rating the quality of electricity supply by age and capacity of solar mini grid

The majority of households connected to mini grids of less than 2 years old reported that they are either satisfied or extremely satisfied with the quality of electricity that they receive from the solar mini grid (92.6%). In comparison, a lesser proportion of households connected to mini grids older than 2 years reported being either satisfied or extremely satisfied (86.1%). This can be attributed to newer mini grids providing more adequate supply, as elaborated earlier.

Across all categories of mini grid capacity, the majority of households have reported that they are either satisfied or extremely satisfied with the quality of electricity that they receive from the mini grid (5 kW to 10 kW ~ 80.6%, 11 kW to 20 kW ~ 90.6%, 21 kW to 50 kW ~ 89.9%, more than 50 kW ~ 100%). The proportion of satisfied or extremely satisfied consumers is slightly less for mini grids with smaller capacity of 5 kW to 10 kW. This pattern points towards a positive correlation between consumer satisfaction and load capacity of the mini grid.

Willingness to pay:

In both the categories of age of mini grid, the majority of households (< 2 years – 67.9%, > 2 years – 62.4%) are not willing to pay any additional amount for further improvement in the load capacity, majorly due to lack of resources and faith in the possibility of tangible improvement. On further probing, most of the respondents in both categories (< 2 years – 88.4%, > 2 years – 79.4%) said they were willing to pay 5% higher than their current bill for increase in load capacity of mini grid supply, by making some adjustments in their household expenditure budget.

The highest proportion (55.6%) of respondents for more than 50 kW mini grids reported that they are willing to pay an additional amount for both fixed cost and per unit cost for improvement in load capacity. For all other categories of mini grid capacity, however, the majority of consumers are not willing to pay any additional amount for improved electricity services (5 kW to 10 kW ~ 40.3%, 11 kW to 20 kW ~ 71.6%, 21 kW to 50 kW ~ 65.1%), primarily due to lack of resources and faith in the possibility of tangible improvement. On further probing, most of the respondents across all categories of grid capacity (5 kW to 10 kW ~ 79.1%, 11 kW to 20 kW ~ 87.3%, 21 kW to 50 kW ~ 73.7%, more than 50 kW ~ 71.4%) said they were willing to pay 5% higher than their current bill for increase in load capacity of mini grid supply, although this proportion was the highest for the 11 kW to 20 kW category of mini grids.

Summary:

- Mini grids in both laggard and aspiring districts have mostly been installed in isolated villages, with socio-economically marginalized communities as the primary beneficiaries. Households with both main and solar mini grid connections tend to have the highest average annual income, indicating potentially better economic conditions or access to resources in these households.
- A higher proportion of domestic consumers reported that they get daily round the clock supply of electricity from the mini grid, as compared to main grid. Voltage fluctuations were also reported to be lower for mini grid supply.
- Most of the domestic consumers with hybrid (main grid and mini grid) connections have reported that the main grid supply is not adequate to meet their household's energy needs, while the majority of consumers with only main grid connections have reported it to be adequate. This points towards a need for a comparable alternative for consumers to determine the quality of energy services they are receiving. Across all categories, most of the consumers have said that mini grid electricity supply is sufficient to meet the daily requirements of households either by itself, or in combination with a main grid connection.
- Higher prevalence of overdue bills is a problem for main grid supply, while most of the consumers do not have any pending bill payments for their mini grid connections.
- The satisfaction level of consumers is higher for mini grid connections as compared to main grid connections.
- Mini grid connections and solar pumps have brought massive benefits to farmers in terms of reduction of time and cost of irrigation, ease of repair and maintenance, etc.

4.2.2 Commercial Consumers[52]

Small businesses attached to households:

About 40% of households in Aspiring districts, and 54% in laggard districts have small businesses attached to their domestic electricity connection. In aspiring districts, prominent small business activities include grocery stores, bakery products, sale of forest-based products, fruit and vegetable shops agricultural product processing machines, milk outlet, etc. In laggard districts, along with these, handicrafts, poultry and milk-based products are also present.

Majority of respondents in aspiring districts reported that their business has remained the same in terms of size after electricity connection since electricity is not fundamental to their operations, while majority of mini grid consumers in laggard districts have reported that the business has expanded after electricity connection which is in alignment with SDG 8 – inclusive and sustainable economic growth as a direct result of mini grids. Across all categories, the majority of respondents have electricity connection in the area in which the business operates. Most consumers in aspiring districts have a requirement for electrical appliances in the production process. Half of only mini grid consumers in laggard districts also reported the same. In all other categories, the majority of consumers reported that they do not have any requirement for electrical appliances in the production process. The most commonly used appliances in enterprises in mini grid villages include electricity operated rice dehullers, electricity operated mills for grindings wheat, rice, soyabean, lentils, etc., and electricity operated grinding machines for spices.

[52] **Total number of commercial respondents = 263**
Aspiring Districts = 137 (Main Grid = 64; Solar Mini Grid = 65; Both Main and Solar Mini Grids = 8)
Laggard = 126 (Main Grid = 78; Solar Mini Grid = 48; Both Main and Solar Mini Grids = 0)

Challenges Faced by Commercial Respondents:

Not Reliable in Terms of Time/Duration: Among establishments reliant solely on the main grid, (76% - Aspiring districts; 75% - laggard districts) reported facing challenges with the reliability of electricity supply in terms of time or duration. For establishments utilizing both the main grid and solar mini grids, this challenge was reported by 38% of respondents (Aspiring districts). This indicates that while reliance solely on the main grid poses a significant risk of unreliable electricity supply, incorporating solar mini grids can mitigate this challenge to some extent.

Not Adequate in Terms of Capacity/Load: In establishments solely dependent on the main grid, (Aspiring - 22%; laggard-16 %) reported challenges related to inadequate capacity or load, indicating issues with meeting the demands of electrical appliances. Among establishments using both the main grid and solar mini grids, this challenge was reported by 13% of respondents (Aspiring districts).

High Electricity Bills – Not Value for Money: About 14% of establishments in aspiring districts, and 24% in laggard districts relying solely on the main grid reported facing challenges with high electricity bills, indicating dissatisfaction with the perceived value for money.

Frequent Breakdown of Electrical Assets and Costs of Repair: Around 25% of establishments in aspiring districts, and 22% in laggard districts dependent solely on the main grid reported challenges associated with frequent breakdowns of electrical assets and the associated costs of repair.

Frequent Power Outages/Disruptions due to Weather Factors: Among establishments dependent solely on the main grid (aspiring – 49%; laggard – 36%), reported facing challenges with frequent power outages or disruptions due to weather factors. For establishments (aspiring districts) using both the main grid and solar mini grids, this challenge was reported by 38% of respondents.

Energy consumption patterns of commercial enterprises:

The majority of separate commercial enterprises interviewed were grocery stores (61%), followed by tea and snacks stalls (10%). The remaining includes rice dehullers, cosmetic shops, wheat mills, and electrical shops etc. Across all categories, over 95% of such enterprises have functional electricity connections.

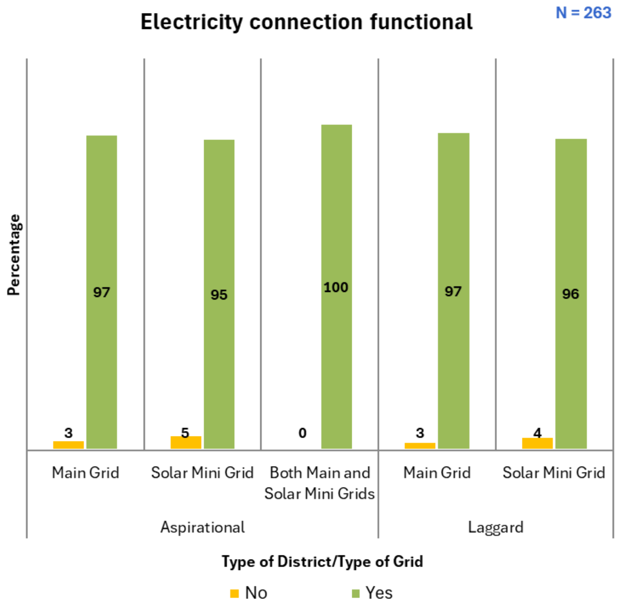


Figure 31: Percentage of commercial consumers with a functional electricity connection by grid and district types

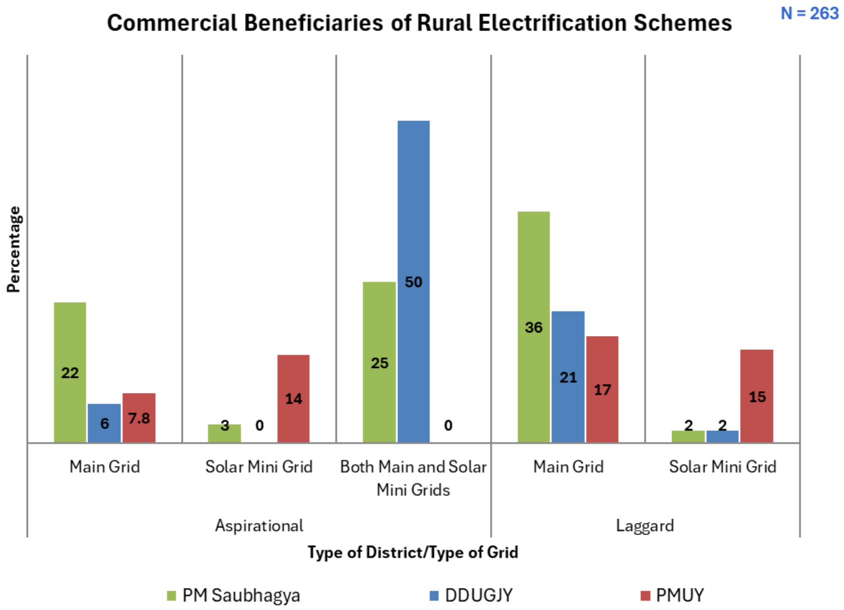


Figure 32: Percentage of commercial consumers benefitting from government schemes by grid and district types

In aspiring districts, a higher proportion of only main grid consumers are PM SAUBHAGYA beneficiaries, higher proportion of only mini grid consumers are PMUY beneficiaries, and higher proportion of consumers with both main grid and mini grid connections are DDUGJY beneficiaries. In laggard districts, PM SAUBHAGYA is dominant among only main grid consumers, and PMUY is dominant among only mini grid consumers. **In the villages covered in laggard districts with both main grid and mini grid connections, no commercial consumers could be interviewed due to lack of availability.**

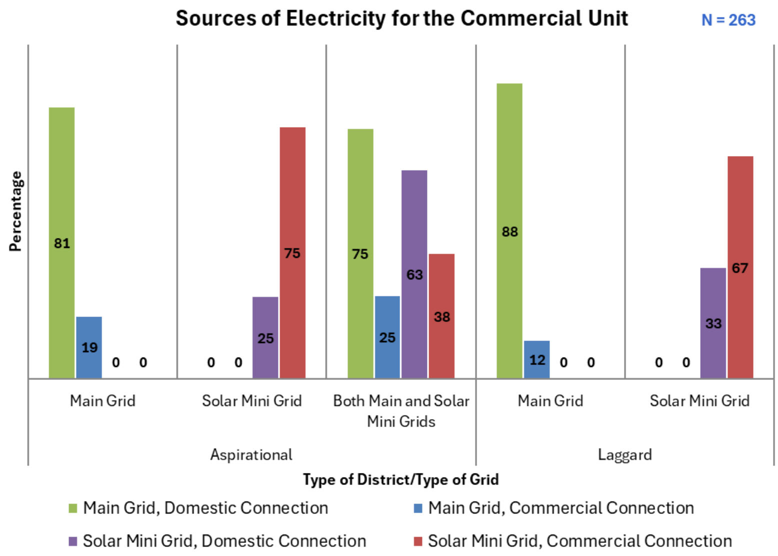


Figure 33: Percentage of commercial consumers connected to different types of connections by grid and district types

Across all districts, in villages with both main grid and mini grid connections in aspiring districts, the majority of commercial consumers have main grid domestic connection, followed by mini grid domestic connection. The majority of consumers with both main grid and mini grid connection reported that the main grid is the primary source of electricity for their commercial establishment.

Across all categories, the peak load requirement is from April to June. Electricity-operated rice dehuller, mill for grinding wheat, rice, soyabean, lentils, etc., oil mill, packaging machine, refrigerator, electric heater, cutters, and drilling machines are the commonly owned electrical assets by commercial consumers. The proportion of respondents owning these appliances are higher among those with connections from both main grid and mini grid as well as those with only mini grid connections.

Quality of electricity services – Comparison between main grid and solar mini grid:

Approximately, 50% respondents in villages served exclusively by the main grid in aspiring districts have reported the main grid electricity supply to be reliable. Conversely, all other categories have reported the main grid supply as unreliable. On average, commercial consumers in aspiring districts receive approximately 12 hours of daily supply from the main grid, exceeding the 10 hours of supply received by their counterparts in laggard districts. The corresponding figures are higher for mini-grid supply – 18.5 hours of supply in aspiring districts and 19 hours in laggard districts, respectively. Across all categories, the majority of commercial consumers have found the main grid electricity voltage to be adequate for their business activities.

Across all categories, the majority of commercial consumers receive round the clock electricity supply from the mini grid, and experience infrequent voltage fluctuation.

In both aspiring and laggard districts, the majority of commercial consumers from villages with only main grid supply experience daily electricity outages. The majority of consumers with both main grid and mini grid connections in aspiring districts was the only category who reported that business activities are undertaken as planned, as they experience electricity outages infrequently as they have a power back-up in the form of a mini grid connection. Across other categories, no schedule of work can be followed due to the unpredictable nature of the electricity supply.

> "Mini grid connections are better for shops like ours because technical faults get fixed by our local operator quickly. In case of bigger issues, the company sends a mechanic from outside within 3-4 days." – Commercial consumer, Jamui, Bihar

Billing and payments:

Almost all electricity connections used by commercial enterprises are metered. In aspiring districts, the majority of consumers receive monthly bills for main grid connection. In laggard districts, the majority of the consumers reported that the frequency of receiving main grid electricity bills is not fixed. In aspiring districts, the majority of the mini grid consumers have prepaid meters attached to their mini grid connection. In laggard districts, the majority of the consumers have postpaid meters attached to their mini grid connection.

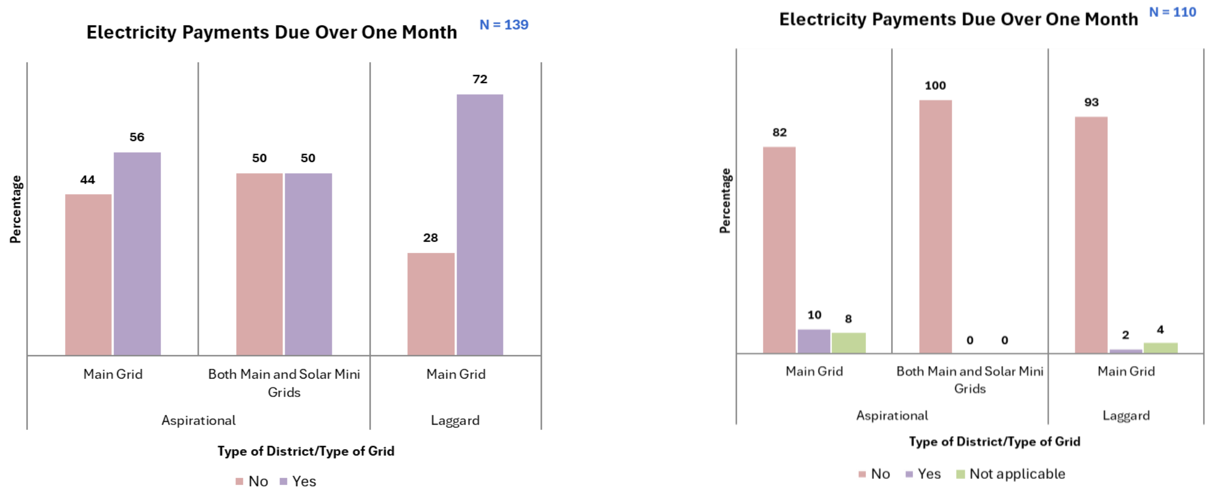
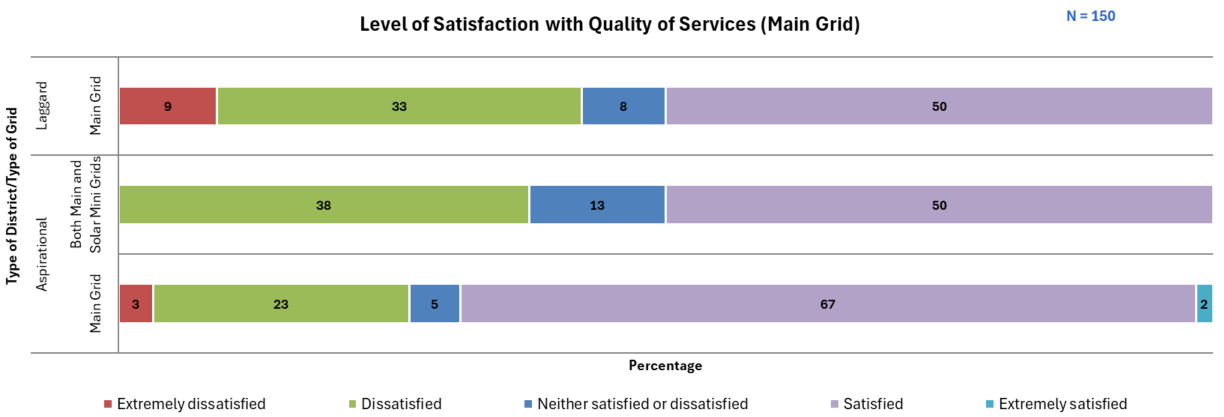


Figure 34: Percentage of commercial consumers reporting the existence of bills due for over a month by grid and district types (Main Grid – left, Solar Mini Grid – right)

In aspiring districts, the majority of commercial consumers with only main grid supply and half of the consumers of villages with both main grid and mini grid connections, have electricity bill payments due for over one month for their main grid connection. In laggard districts, the proportion of consumers with overdue main grid bill payments is substantially higher. Across all categories, the majority of respondents do not have overdue bill payments for over one month for mini grid connections.

Level of satisfaction with electricity services:



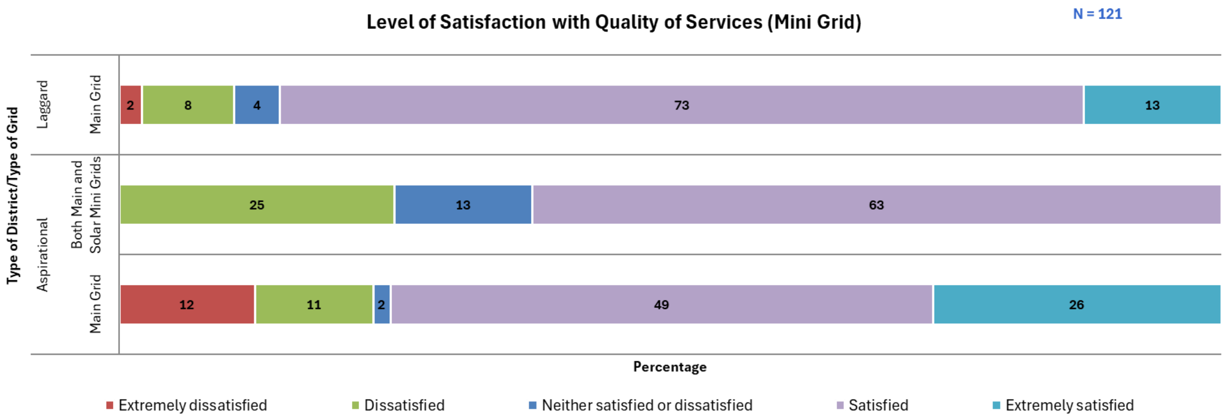


Figure 35: Percentage of commercial consumers rating the quality of electricity supply by grid and district types (Main Grid – top, Solar Mini Grid – bottom)

For both main grid and mini grid electricity services, the majority of consumers across all categories in both aspiring and laggard districts are satisfied with the service. The proportion of satisfied and extremely satisfied consumers are higher for mini grid electricity services, as they have demonstrated better performance across quality parameters such as service reliability, adequate voltage, quick resolution of technical faults, etc.

Summary:

- Most small commercial enterprises attached to households have connections from the main grid, and face challenges such as unreliability in terms of timing and duration of supply, inadequacy in terms of load capacity, high bills, frequent breakdown of electrical assets, and frequent power outages/disruptions.
- Electricity-operated rice dehuller, mill for grinding wheat, rice, soyabean, lentils, etc., oil mill, packaging machine, refrigerator, electric heater, cutters, and drilling machines are the commonly owned electrical assets by commercial consumers.
- Across all categories, commercial consumers have majorly reported unreliable supply from the main grid which makes it difficult to undertake business activities throughout the day in a planned manner, especially in laggard districts. The duration of supply, round the clock availability of electricity supply, voltage stability are higher for mini grids in comparison to the main grid. The majority of main grid consumers have reported daily power outages and disruptions, while the majority of mini grid consumers have reported that they happen infrequently.
- In laggard districts, the proportion of consumers with overdue main grid bill payments is substantially higher. Across all categories, the majority of respondents do not have overdue bill payments for over one month for mini grid connections.
- In comparison to the main grid, a higher proportion of mini grid consumers reported that they are either satisfied or extremely satisfied with the quality of mini grid electricity services.

4.2.3 Institutional Consumers[53]

A total of 238 institutions were covered by the study, out of which 48% were in aspiring districts and 52% were in laggard districts. Out of this, almost 32% of institutions do not have an electricity connection, and another 7% have an electricity connection that is non-functional at present.

Energy consumption patterns of institutions:

Schools (43%), Anganwadi Centres (27%), and Panchayat Bhawan (13%) made up the majority of the sample for institutional consumers. The most commonly owned electrical assets by institutional consumers include lights, ceiling fans, mobile phones and other chargeable devices, computers and laptops, printers and photocopiers. A higher proportion of mini grid institutional consumers in aspiring districts own refrigerators, television sets, and water pumps, while respondents across all categories aspire to own coolers, air conditioners, drinking water filters, etc. The peak load requirement period is from April to June.

[53] **Total number of institutional respondents = 238 (institutions without electricity connection = 76; institutions without functional electricity connection = 11. Therefore, effective sample for analysis = 238-76-11 = 151)**
Aspiring Districts = 75 (Main Grid = 66; Solar Mini Grid = 6; Both Main and Solar Mini Grids = 3)
Laggard = 77 (Main Grid = 61; Solar Mini Grid = 15; Both Main and Solar Mini Grids = 1)

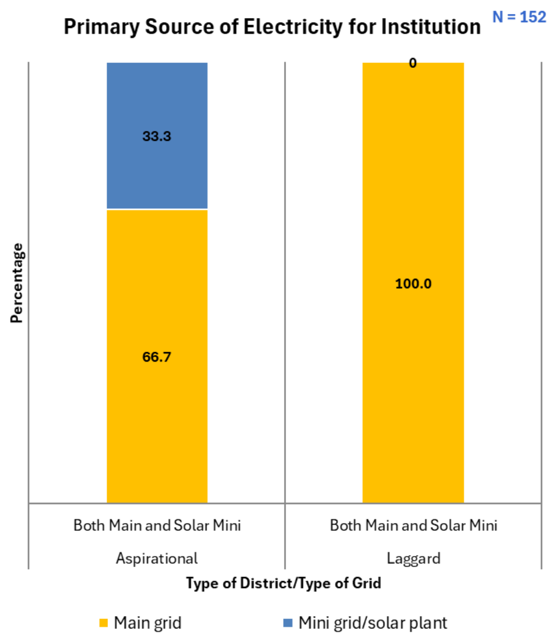


Figure 36: Percentage of institutional consumers using either main grid or solar mini grid as their primary source of electricity for consumers connected to both by district type

In aspiring districts, the majority of institutions (67%) with both main grid and mini grid connections have main grid as the primary source of electricity. In laggard districts, all institutions in this category have the main grid as the primary source of electricity.

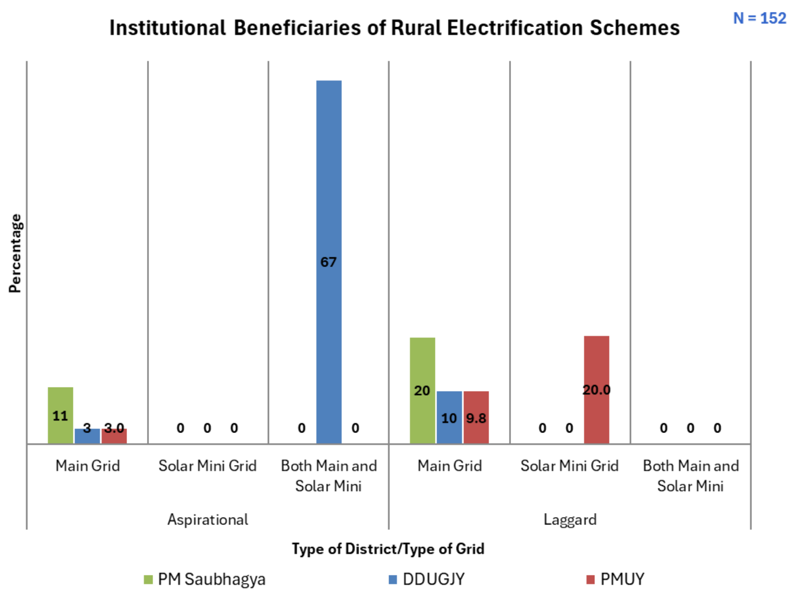


Figure 37: Percentage of institutional consumers benefitting from government schemes by grid and district types

There is considerable variation in the distribution of government scheme beneficiaries among institutional consumers. In aspiring districts, PM SAUBHAGYA and DDUGY are dominant. No institution in the villages having only mini grid reported receiving benefits from any scheme. In laggard districts, PM SAUBHAGYA and PMUY are dominant. No institution in villages with both main grid and mini grid connections reported receiving benefits from any scheme.

Quality of electricity services – Comparison between main grid and solar mini grid:

The main grid electricity supply was reported to be reliable with adequate voltage across all categories. However, frequent electricity outages were also reported throughout the year, on a daily basis. Across all categories, the majority of respondents (60%) reported that institutions are not able to follow any set schedule of work due to the unpredictable nature of electricity supply from the main grid.

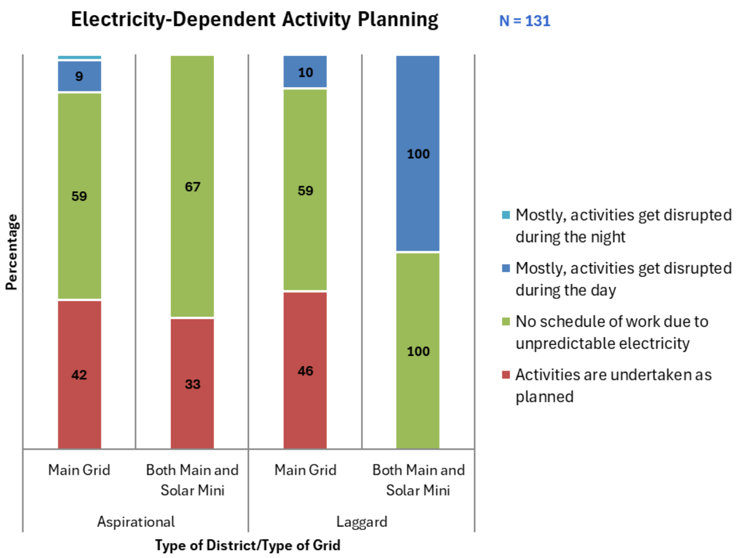


Figure 38: Percentage of institutional consumers reporting on their work schedule planned around electricity supply by district type

Most of the mini grid consumers (84%) reported that they receive round-the-clock supply of electricity from the mini grid on a daily basis, with adequate voltage maintained throughout the day. However, majority of the respondents (68%) reported that they do not operate high wattage equipment with mini grid supply. A higher proportion of consumers reported that they are satisfied with the quality of electricity services from the mini grid (92%) as compared to the main grid (76%).

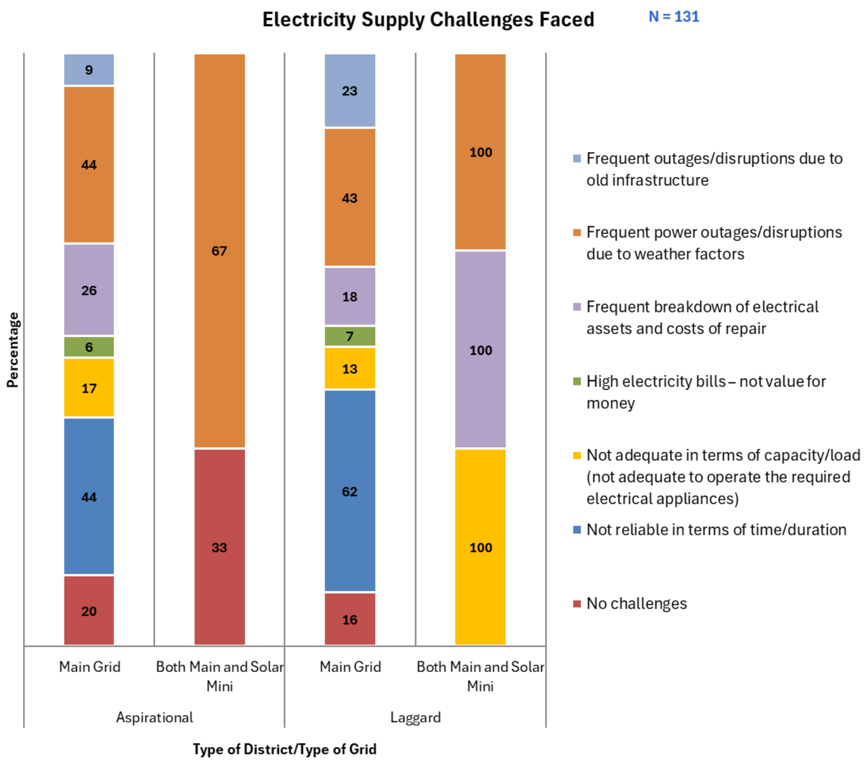


Figure 39: Percentage of institutional consumers reporting on challenges faced with main grid electricity supply by district type

Most commonly faced challenges in main grid electricity supply in aspiring and laggard districts for main grid consumers include frequent power outages and disruptions due to weather related factors as well as unreliable timing and duration of supply. For hybrid consumers in aspiring districts, the only challenge reported was frequent power outages and disruptions. In laggard districts, hybrid consumers also reported challenges such as frequent breakdown of electrical assets and high repair costs, as well as inadequate load capacity, in addition to the above.

> "Solar energy is good for the environment as it comes from a renewable source and reduces pollution. It has reduced our dependence on kerosene that emits smoke and causes health problems among children. Local authorities and NGOs have been raising awareness about the same." – Institutional consumer, Lohardaga, Jharkhand

Billing and payments:

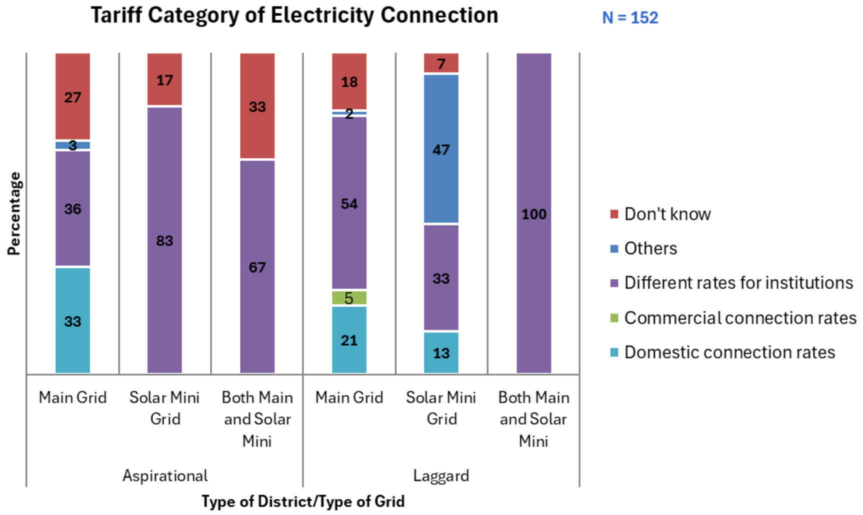


Figure 40: Percentage of institutional consumers falling under different tariff structures by grid and district types

In all categories, the majority of the respondents reported that different rates are charged for institutional consumers. A substantial proportion of institutional consumers in the only main grid category in aspiring districts as well as of those in the only main grid category and only mini grid category in laggard districts reported that they are charged the same rates as domestic connections. A higher proportion of institutions in laggard districts (33.9%) receive electricity supply for free as compared to aspiring districts (17.4%). There seems to be no standard policy for billing for institutional consumers.

Summary:

- The most commonly owned electrical assets by institutional consumers include lights, ceiling fans, mobile phones and other chargeable devices, computers and laptops, printers and photocopiers. A higher proportion of mini grid institutional consumers in aspiring districts own refrigerators, television sets, and water pumps, while respondents across all categories aspire to own coolers, air conditioners, drinking water filters, etc.
- Most commonly faced challenges in main grid electricity supply include frequent power outages and disruptions due to weather related factors, unreliable timing and duration of supply, frequent breakdown of electrical assets and high repair costs, as well as inadequate load capacity.
- Most of the mini grid consumers reported that they receive round-the-clock supply of electricity daily with adequate voltage. However, they do not operate high wattage equipment with mini grid supply.
- A higher proportion of consumers reported that they are satisfied with the quality of electricity services from the mini grid as compared to the main grid.
- Most of the institutions are charged different rates, while some of them are charged the same rates as domestic connections, and others receive electricity for free. There is no standard policy for billing institutional consumers.

4.2.4 Willingness to Pay

Domestic consumers:

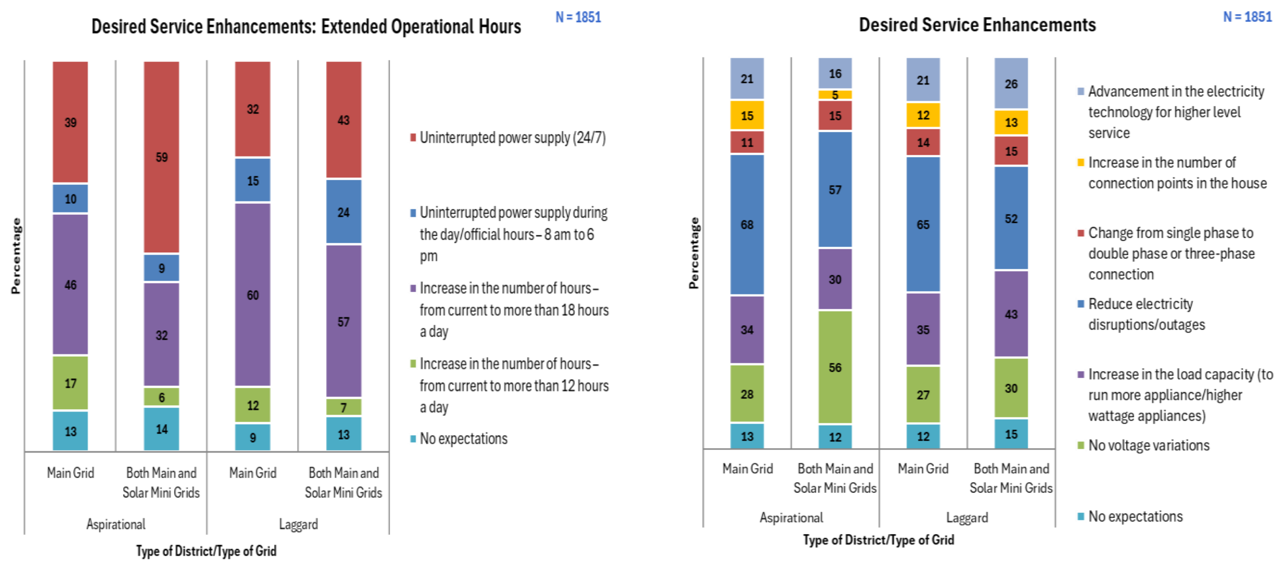


Figure 41: Percentage distribution of desired service enhancements by domestic consumers by grid and district types

In both aspiring and laggard districts, the majority of domestic consumers desire an increase in the number of hours of supply to more than 18 hours a day. Additionally, most consumers also desire uninterrupted 24/7 power supply in aspiring districts, which is not the case in laggard districts. A very small proportion of consumers across all categories reported that they have no expectations of service improvement. Across all categories, a majority of consumers also reported that they want a reduction in electricity disruptions and outages. A substantial proportion also want an increase in load capacity to be able to run higher wattage equipment, and no voltage variation.

For service improvements in the duration of supply with adequate voltage, the highest proportion of respondents (>35%) are unwilling to pay any additional amount over and above their current electricity bill. However, when further probed, the average amount of additional expenses that households were willing to incur was Rs. 221 for 8-12 hours of supply with adequate voltage and 3 hours of assured supply in the evening; Rs. 196 for 12-16 hours of supply with adequate voltage and 4 hours of assured supply in the evening; and Rs. 203 for 16-20 hours of supply with adequate voltage and 5 hours of assured supply in the evening. For more than 20 hours of supply from the main grid with adequate voltage and 6 hours of assured supply in the evening, the highest proportion of consumers (41%) are willing to pay 5% additional amount from their current electricity bill. For improvement in load capacity from the mini grid, the highest proportion of the consumers (74%) are willing to pay 5% additional amount as well.

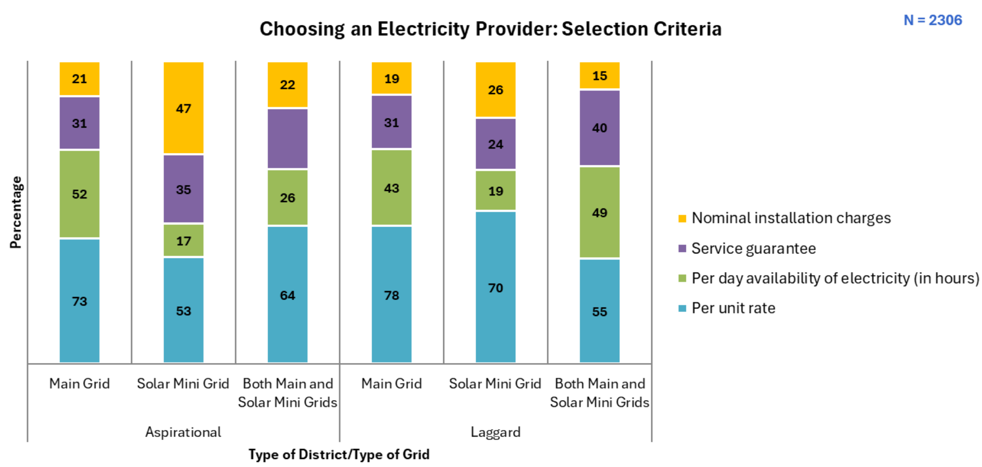


Figure 42: Percentage of domestic consumers selecting an electricity service provider based on given criteria by grid and district types

Majority of domestic consumers across all categories reported that their criteria of focus when selecting an electricity service provider would be the per unit rate charged, followed by duration of per day availability of electricity. Service guarantee and installation charges were chosen as criteria by lesser proportion of consumers.

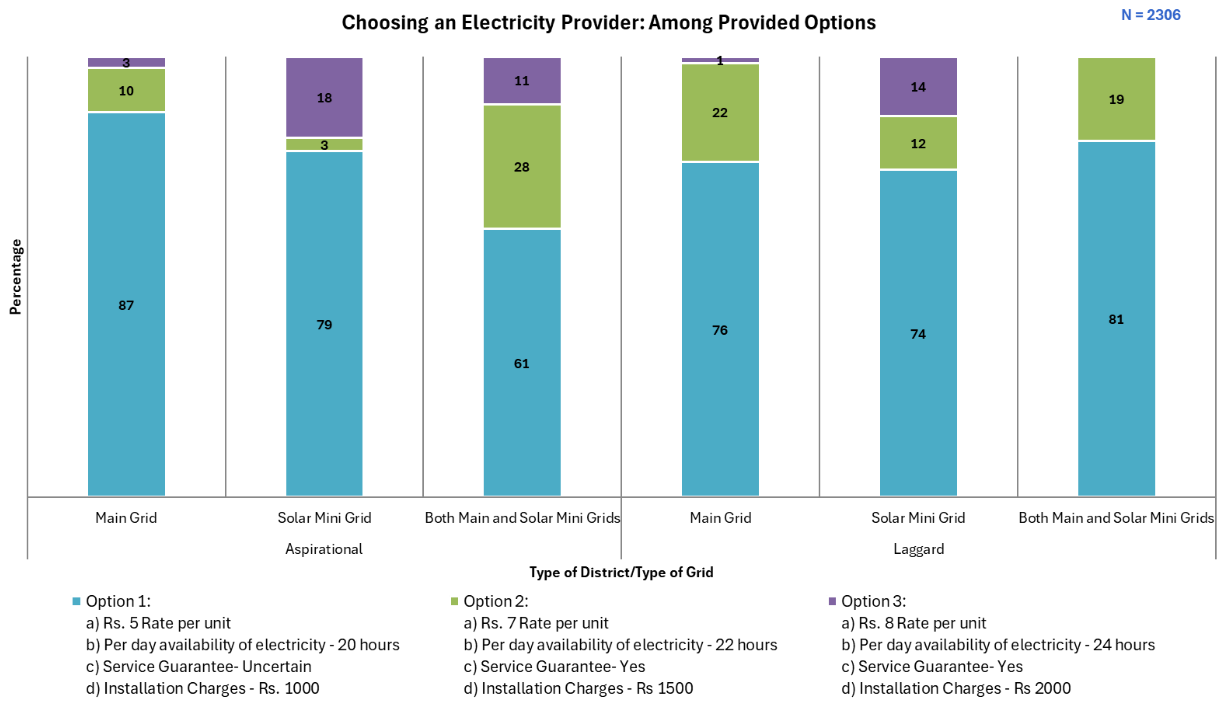


Figure 43: Percentage of domestic consumers selecting an electricity service provider from three hypothetical options by grid and district types

A hypothetical situation was presented to all respondents with three service providers offering varying per unit rates, installation charges, duration of daily supply, and service guarantee. Across all categories, a majority of consumers chose Option 1 – showing their preference for the provider offering the lowest per unit rate and installation charges, for 20 hours of supply, even though service guarantee is uncertain.

Commercial consumers:

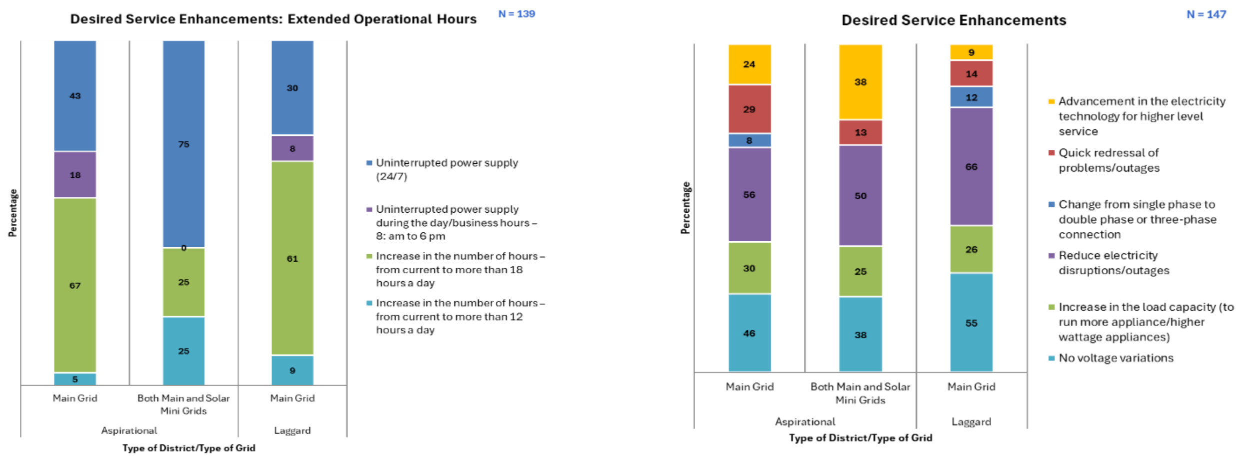


Figure 44: Percentage distribution of desired service enhancements by commercial consumers by grid and district types

The most desired service improvements reported by commercial consumers include uninterrupted 24/7 power supply, increase in the number of hours of supply to 18 hours a day especially among only main grid consumers who use electricity for their business enterprise from their domestic connections, reduction in electricity disruptions and outages, voltage stability, and increase in load capacity to run more appliances and higher wattage equipment for business activities.

For 12-16 hours of supply from the main grid with adequate voltage, the highest proportion of commercial consumers (35%) are willing to pay 5% additional amount from their current electricity bill. For improvement in load capacity from the mini grid, 47% of the consumers are willing to pay 10% additional amount from their current electricity bill.

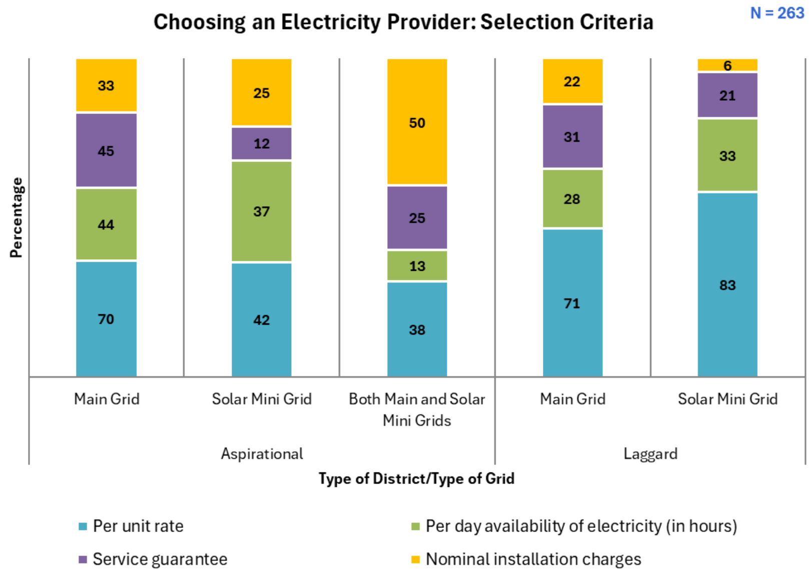


Figure 45: Percentage of commercial consumers selecting an electricity service provider based on given criteria by grid and district types

Across all categories of consumers, per unit rate emerged as the most important selection criteria for choosing an electricity service provider, followed by per day availability of electricity in hours. For consumers with both main grid and mini grid connections in aspiring districts, nominal installation charges emerged as the most important selection criteria.

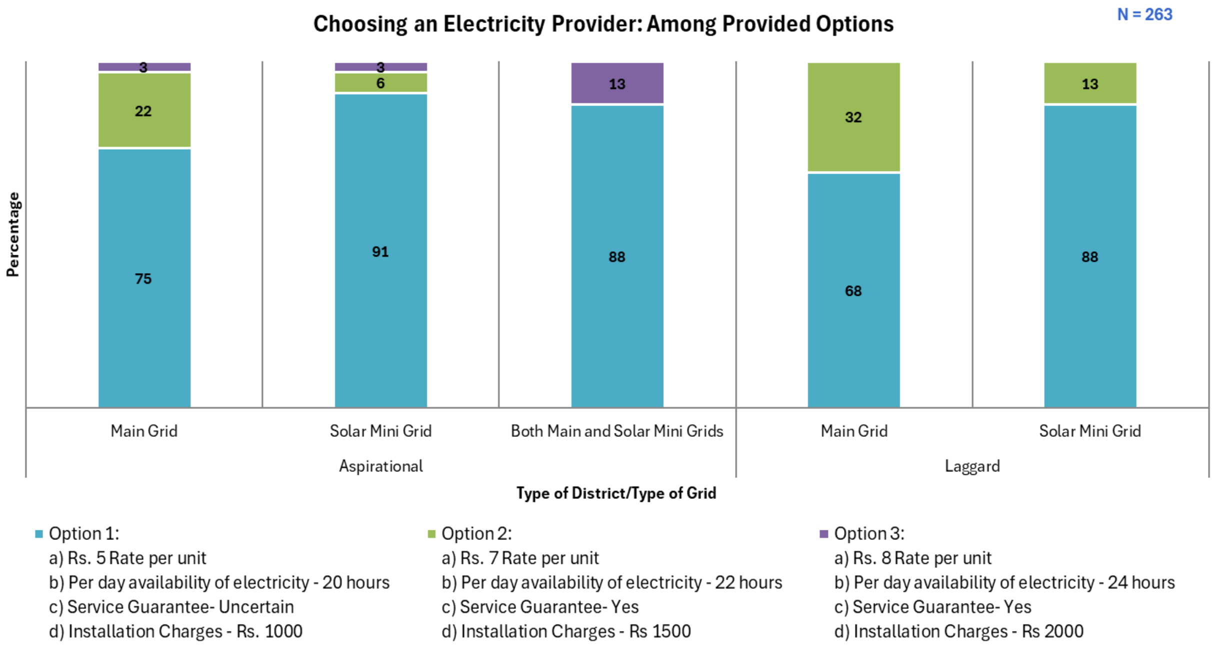


Figure 46: Percentage of commercial consumers selecting an electricity service provider from three hypothetical options by grid and district types

When the same hypothetical situation with three different service provider options was presented to commercial consumers, a majority of respondents across all categories chose Option 1 – showing their preference for the provider offering the lowest per unit rate and installation charges, for 20 hours of supply, even though service guarantee is uncertain.

Institutional consumers:

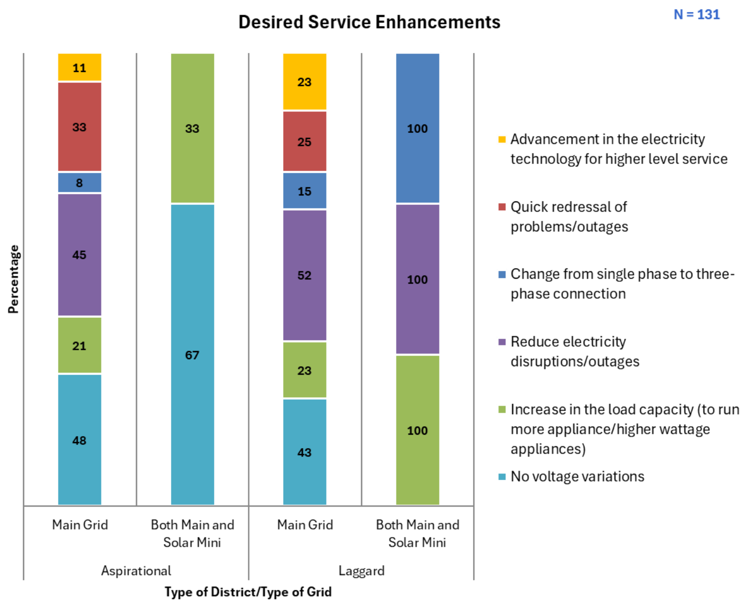


Figure 47: Percentage distribution of desired service enhancements by institutional consumers by grid and district types

Across all categories, most desired service improvements reported by institutional consumers include voltage stability, increase in load capacity, reduction in electricity disruptions and outages, quick redressal of technical issues, and change from single phase to three phase connection.

For 12-16 hours of supply from the main grid with adequate voltage, the highest proportion of consumers (45%) are willing to pay 5% additional amount from their current electricity bill. For improvement in load capacity from the mini grid, the highest proportion of the consumers (36%) are willing to pay 5% additional amount as well.

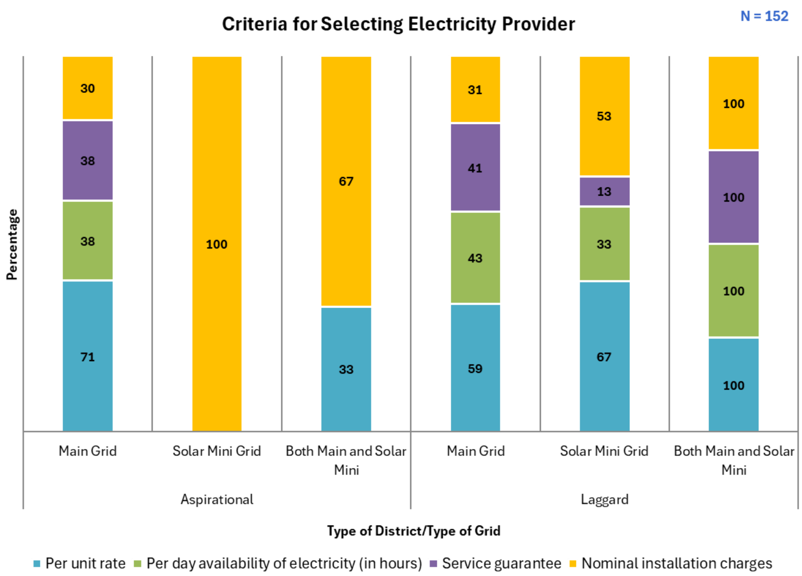


Figure 48: Percentage of commercial consumers selecting an electricity service provider based on given criteria by grid and district types

The majority of consumers of villages with only main grid institutions in both aspiring and laggard districts chose per unit rate as the main criteria for selecting an electricity service provider. For intuitions in villages having only mini grid, the important criteria reported were nominal installation charges in aspiring and laggard districts, along with per unit rate in laggard districts. For institutions with both main grid and mini grid connections, the majority of respondents in aspiring districts chose nominal installation charges and per unit rate as the main criteria. In laggard districts for this same category, all the given criteria were chosen by all respondents.

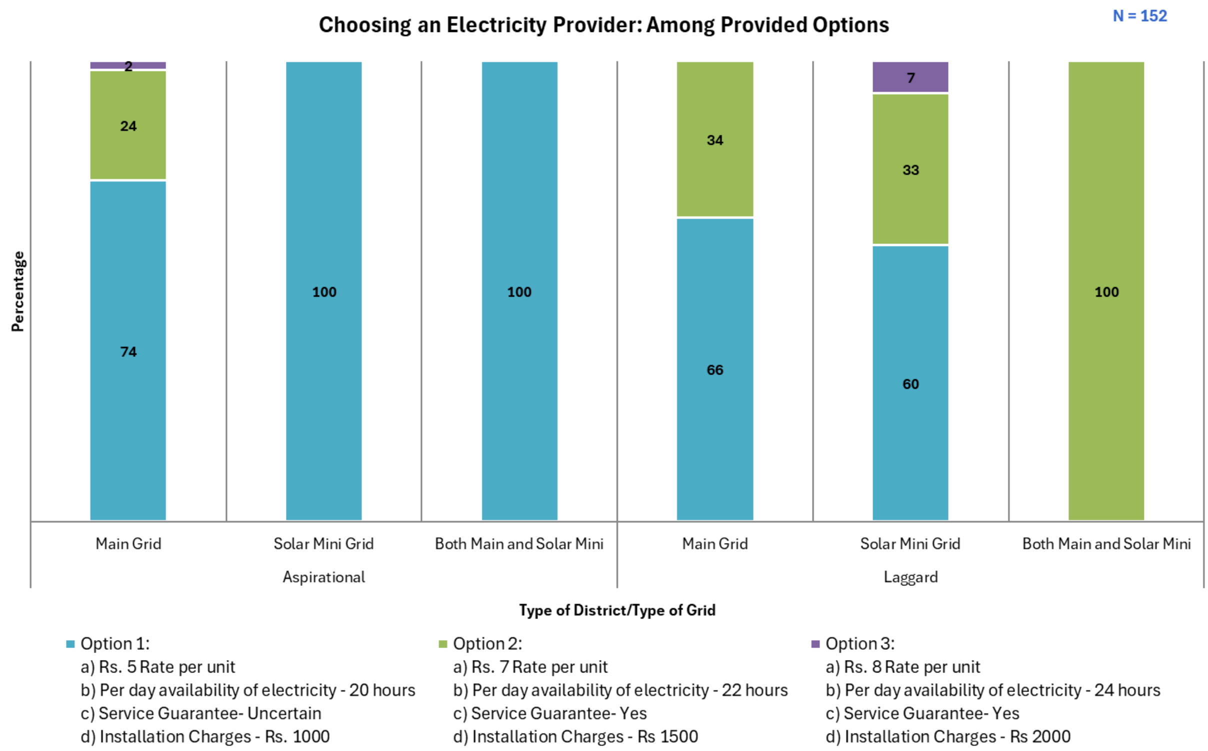


Figure 49: Percentage of institutional consumers selecting an electricity service provider from three hypothetical options by grid and district types

Institutional consumers were also presented with the same hypothetical situation with three different electricity service providers. Across all categories in aspiring districts, the majority of consumers chose Option 1 – showing their preference for the provider offering the lowest per unit rate and installation charges, for 20 hours of supply, even though the service guarantee is uncertain. Although Option 1 is the choice for almost two-thirds of institutions in villages with main grid and only mini-grid supply in laggard districts, it is seen that the majority of institutions in villages with both main grid and mini grid connection in laggard districts chose Option 2 – with a slightly higher per unit rate and installation charges, 22 hours of supply, and service guarantee.

Summary:

- Across all categories, the desired service improvements include 24/7 supply of electricity or more than 18 hours of supply per day, voltage stability, reduced power outages, increase in load capacity, and quick redressal of technical issues.
- Although most domestic consumers are unwilling to pay additional amount for service improvements, upon further probing most of them across all consumer categories agreed that they were willing to pay 5-10% extra from their current bill for both main grid and mini grid connections.
- Per unit rate emerged as the most important criteria for selection of an electricity service provider across all consumer categories, followed by per day availability of electricity (duration) and installation charges. In a hypothetical situation in which they were asked to choose between three different service providers with different per unit rates, installation charges, duration of supply and service guarantee, most consumers across all categories chose the option with the lowest per unit rate and installation charges along with a comparable duration of supply, even though the service guarantee for this option is uncertain.

4.3. Supply-Side Dynamics[54]

4.3.1 Operations, Financing, Opportunities and Constraints of Solar Mini Grids

Mini grid Details	Mini grid Operator Profile	Infrastructure and Safety
• Mini grids have been established relatively recently, with an average operational time of about 6 months. Laggard districts have a slightly longer establishment period of up to 12 months, suggesting early adoption or longer project implementation times in these regions. • A significant majority of mini grids at 93% are not integrated with the main grid, indicating standalone operations and the independent nature of these energy solutions. In aspiring districts, there's a small but notable presence of partial integration with 25% of the mini grids, pointing to a potential trend for grid interconnectivity but no such trend is witnessed in the laggard districts. • Half of the mini grids (50%) have a plant capacity between 5 kW to 10 kW, signifying a focus on small to medium-scale operations, catering to localized demand or specific community needs. Aspiring districts feature higher capacities with 21 kW to 50 kW in 75% of cases, which may reflect higher energy demands or proactive scaling of infrastructure in these districts.	• Aspiring districts feature younger operators with an average age of 25 years, compared to 37 years in laggard districts. The overall age range spans from 19 to 62 years, indicating diverse age representation across operators. • The workforce is overwhelmingly male across both districts, with 100% of operators in the aspiring district being male and about 92% in the laggard district. Women represent only about 8% of the operators in laggard districts, reflecting significant gender imbalance in this field. • Laggard district operators average around 6 months of service versus 5 months in aspiring districts, hinting at greater experience or established operations in the former. • A notable 62.5% of operators in aspiring districts are engaged with more than one mini/microgrid, while 44.4% in laggard districts also work with multiple grids. This suggests a trend of multi-grid management, potentially indicating a robust operational landscape or a need for operators to manage multiple projects for viability. • A vast majority of operators reside in the serviced villages, especially in laggard districts (97.22%), signifying strong community ties and potential for tailored energy solutions with higher responsiveness. • Half of the operators overall received partial training, and around 30% received extensive training, revealing a mix of training adequacy which points to a potential gap in comprehensive capacity building. • Additionally, informal learning pathways are present, highlighting the adaptability of operators and perhaps pointing to on-the-job learning as a crucial mode of skills development in the absence of formal training structures. • There's a high demand for additional training, particularly in technical skills for maintenance, where 75% of aspiring district operators and 86.1% in laggard districts see a need. Financial management and customer service also emerged as significant areas for development, with 37.5% and 66.7% of operators in aspiring and laggard districts, respectively, seeking training in customer service, while 37.5% and 38.9% respectively see the need for financial management training.	• Number of Solar Panels: Aspiring districts have a considerably higher average number of solar panels at around 84 units compared to laggard districts which is closer to 25 units, possibly to compensate for lower individual panel capacities or a strategic focus on solar energy in these districts. • Panel Wattage Capacity: In all mini grids across all districts, the wattage capacity of an individual solar panel for a particular mini grid remains the same. The mean wattage capacity in laggard districts (1052.9W) vastly outstrips that in aspirational districts (303.1W), with the maximum capacity reaching up to 14,850W, suggesting some laggard district plants are designed for high-output requirements. • Battery Storage: Aspiring districts show a more substantial investment in battery storage capacity, with an average of 47.9 kWh, suggesting a focus on energy storage and reliability whereas the average storage capacity for laggard districts stands at 29.4kWh. • Inverter Systems: Inverter systems are more numerous in aspiring districts, with a mean of 6.1 systems, compared to 1.4 in laggard districts, possibly indicating more complex energy management needs. • Inverter Capacity: Laggard districts have a significantly higher average inverter capacity (585.5 kW) than aspiring districts (23.7 kW). This could imply a broader scope of energy distribution or future readiness for scale in laggard districts, whereas aspiring districts may be operating on a scale appropriate for their current needs. • Metering Systems: Aspiring districts utilize a higher number of metering systems, with a significant maximum number (330), which may point towards advanced metering infrastructure and consumer engagement in energy usage tracking. • Infrastructure Elements: There's a larger infrastructure setup in aspiring districts, as indicated by the number of poles and streetlights at 188 and 9 on average respectively as compared to 33 and 7 on average respectively in laggard districts. This can signify a more extensive reach of the mini grid within the community in the aspiring districts. • Circuit Breakers: Universal in aspiring districts (100%), and present in two-thirds of laggard districts (66.7%), circuit breakers are a critical component in ensuring system safety.

[54] **Total number of mini grid operators interviewed = 44**
Aspiring Districts = 8
Laggard = 36

Operator Satisfaction and Perspectives

- All operators in the aspiring districts are very aware that solar power is a clean and environmentally friendly energy source, compared to 69.4% in laggard districts, demonstrating a high overall environmental awareness (75% total).
- Operators in both districts have been largely successful in providing connections to consumers who approached them for solar energy, with a 100% success rate in aspiring districts and 94.4% in laggard districts.
- In cases where connections could not be provided, the primary reason in laggard districts (41.7%) is the lack of capacity in the solar plant to supply more consumers, whereas in the aspiring district, half of the cases are due to consumers' ability to pay.
- Reliability of solar supply is the leading reason for consumer preference across districts (100% aspiring and 77.8% laggard), followed by environmental friendliness (87.5% aspiring and 58.3% laggard).
- Consumers also prefer solar connections for more hours of supply per day and less hassle in obtaining connections.
- Universal optimism exists among operators regarding the future increase in demand for solar energy, with 100% agreement across both districts.
- On the satisfaction scale, the majority of operators in both districts express satisfaction with their job and with providing quality solar energy supply, indicating a positive work environment and a sense of fulfillment.

- Safety Audits: Regular safety audits are more common in aspiring districts (100%) than laggard districts (69.4%), highlighting a more consistent approach to safety management.
- Grounding Systems: Found in 87.5% of aspiring district grids, grounding systems are less common in laggard districts (38.9%), pointing to an area where safety infrastructure can be improved.
- Surge Protectors: Surge protectors are in place in 62.5% of aspiring district grids but only 33.3% of laggard districts, which might leave the latter more vulnerable to power surges.
- In summary, mini grids in aspiring districts display a uniform approach to infrastructure with a higher number of standard solar panels and consistent safety measures. Laggard districts show a high variation in solar panel types and high-capacity setups, yet with less uniformity in safety practices. Aspiring districts excel in regular safety audits and protective equipment use, suggesting a prioritization of safety.

Consumer Engagement and Payment

- Mini/micro-grids are diversifying their consumer base. Aspiring districts have increased their household connections significantly, from a mean of 92 when the grid began operations to 247 currently, while commercial consumers have grown from around 5 to 16 on average with a small increase in institutional consumers. Laggard districts show a modest rise in household connections from a mean of 48 to 50 on average and a similar increase in commercial consumers from about 17 to 20 and are now also serving institutional consumers which they weren't before. This points to an overall market expansion with a more pronounced growth in aspiring districts.
- Payment models in aspiring districts are exclusively prepaid (100%), contrasting with laggard districts where post-paid and other specified methods are more common, representing 97.2% combined. This suggests a strategic move towards upfront payment structures in aspiring districts, potentially enhancing financial sustainability.
- Billing methods in aspiring districts are primarily based on meter readings or consumption (50%), while laggard districts have a significant proportion of consumers who are uncertain about their billing determinants (38.9% don't know/can't say), which could indicate a need for clearer communication and billing transparency.
- Service provision to households in aspiring districts has increased significantly, as indicated by the growth in the number of households/domestic connections served, with a mean increase from 92.1 to 247.1. Laggard districts show a more modest increase, from 48.2 to 49.6 on average.
- Both aspiring and laggard districts have expanded their consumer base, particularly in domestic households, with aspiring grids reporting a high average bill amount of Rs. 250, indicating a potentially higher usage or tariff rate compared to laggard districts which average at Rs. 91.5.
- Commercial sectors show a marked contrast, with aspiring districts billing significantly higher on average (Rs. 1050) than laggard districts (Rs. 366.7), suggesting either greater commercial activity or higher tariffs in aspiring districts.

Operations and Management

- There's a substantial variance in the capital costs to set up solar plants, with aspiring districts averaging Rs. 900,000 and laggard districts significantly higher at an average of Rs. 1,358,650, possibly due to differences in scale, technology, or additional infrastructure needs.
- Ownership predominantly lies with non-private sources, especially in laggard districts where community ownership and other specified sources account for the majority (44.4% and 77.8% respectively). Only 25% of the mini grids in the aspirational districts are owned by private sources. This suggests a reliance on collective investment and possibly external aid or grants.
- The responsibility for operation and maintenance predominantly lies with the operators in both aspiring (87.5%) and laggard (97.2%) districts, indicating that the majority of these grids are operator managed.
- While operators in aspiring districts also handle the majority of billing and collection (87.5%), laggard districts show a more distributed responsibility with 30.6% being others, reflecting a diverse approach to financial management.
- A majority of laggard districts claim their current capacity is sufficient to manage peak loads (63.9%), whereas a portion cannot manage peak loads and resort to power cuts (27.8%). Aspiring districts tend to rely on generators to manage peak loads (75%).
- In aspiring districts, 100% of mini grids provide over 12 hours of electricity daily, compared to only 30.6% in laggard districts, indicating disparities in service delivery. Regarding peak load, aspiring districts report a higher mean capacity (2015.4 kW) compared to laggard districts (1203.2 kW).
- Outages occur most frequently during bad weather, about 52% of the situations (52.3%), and in one third of the cases the outages last less than 1 hour (33.3%). However, technical issues take longer to resolve in laggard districts, where less than half the cases (43.5%) are addressed within a day, compared to more than two thirds of the cases (71.4%) in aspiring districts.
- Both aspiring and laggard districts face challenges with managing supply during peak loads, though it's significantly more pronounced in aspiring districts (75%) compared to laggard districts (11.1%).

• The total average monthly bill collections for domestic consumers are substantially higher in aspiring districts (Rs. 31,562.5) versus laggard districts (Rs. 5,192.3), underscoring a more substantial revenue generation in aspiring districts. • Payment consistency is significantly higher in aspiring districts with 75% of consumers always paying on time, while laggard districts struggle with 44.4% rarely making payments, which may affect the financial viability and cash flow for the operators in these districts. • Aspiring districts have a higher mean overdue amount of Rs. 7,500 compared to Rs. 3,343.2 in laggard districts, potentially indicating stricter credit control measures that may be in place or a higher tariff being imposed.	• Irregular payments from consumers are a concern, with 25% operators in aspiring and 19.4% in laggard districts indicating this issue. This could suggest that the operators in aspiring districts are more concerned about irregular payments than those in laggard districts, even though the instances of overdue payments are higher in the laggard districts. • A high percentage of operators in both districts report challenges due to natural calamities (75% in both) and cloudy weather (75% aspiring, 77.8% laggard), pointing to environmental vulnerability. • Technical problems with inverters are mentioned by 37.5% of aspiring and 16.7% of laggard district respondents, which may necessitate better technical training or equipment upgrades. • The compensation for operators is a noted concern, especially in the aspiring district (62.5%) and less so in the laggard district (44.4%). This could affect staff retention and service quality.

4.3.2 Insights from Key Informant Interviews (KIIs) with Implementing Partners

The Sambodhi team conducted interviews with members from implementing agencies such as Mlinda Charitable Trust and Transform Rural India Foundation, as facilitated by the ACPET team. The interviews were aimed at gaining valuable insights into the supply side aspects of the provision and establishment of solar mini grids based on the on-ground experience of these partners. The objective was to understand the intricacies of the project and get nuanced perspectives on energy transition financing in the Indian renewable energy sector.

The interview explored areas such as the capacity, coverage, and funding sources of the solar mini grids. It was revealed that the load design and supply capacity of a particular grid depended on the diverse demands of the community, with ranges between 10 kW and 50 kW. Insights into consumer demographics highlighted that an overwhelming majority of the consumers (up to 90%) were domestic, with the remaining minority (about 10%) represented by commercial consumers. Institutional consumers were supplied with electricity free of cost in many cases. The financial sustenance for the implementation projects stems from a diverse array of sources, including blended finance, equity investment, and philanthropic contributions from various CSR grants or philanthropic donors like Tata Capital, IKEA, Good Energies and TEWA pharmaceuticals.

Another focal point of the interview was the contribution and engagement level of the community. The establishment of the Energy Committee was explored, which is comprised mainly of local members, with a majority participation from women, who oversee installation, manage finances, and resolve disputes. Discussions uncovered the bifurcation between monetary and labour contributions from the community. Labour costs including chores related to earthwork, manual work, construction etc. were also listed. Exploring this topic revealed a deep involvement of community members, from project initiation to operation. During the interview, emphasis was placed on empowering local youth as operators and field engineers, fostering local enterprise growth, and supporting Self-Help Groups (SHGs) and Village Organizations (VOs).

Furthermore, this interview wanted to capture the cost incurred by both the consumers and the implementing partners. While in some cases, a one-time deposit of Rs. 1000 per household for installation was made followed by monthly recharges, other cases presented the prevalence of a tier-based model for consumer prices and yet another case shed light on a fixed fee of Rs. 100 that is charged alongside Rs. 10 per unit cost to the consumers. At the partners' end, the capital expenditure for infrastructure setup was estimated at around Rs.70,000, including installation charges, hardware and money paid to the implementing bodies. The per unit cost of the provision of electricity was not readily available at the time of the interviews.

At the end of the interview, suggestions were made regarding leveraging existing village-level organizations for sustainability and scaling, emphasizing collaboration among stakeholders for decision-making and ownership. With over 80 villages involved, an ecosystem approach involving donors, support agencies, and the community is deemed essential for long-term success.

5. Learnings and Recommendations

The field study shows the important role that mini grids play in improving access to clean and reliable electricity to rural areas. This calls for the support of the sector so that it can meet its potential. Some of the ways to do this are as follows:

- **Encouraging supportive policies and regulatory frameworks:** The government can continue to implement policies and regulatory frameworks that are supportive of the mini grid sector. This includes providing financial incentives, simplifying regulatory procedures, and creating an enabling environment for private sector participation.

- **Increasing access to finance:** Access to finance remains a critical challenge for the mini grid sector in India. To address this, the government can encourage financial institutions to invest in the sector and offer innovative financing options, such as debt and equity financing, crowdfunding, and pay-as-you-go models.

- **Fostering innovation and collaboration:** The mini grid sector can benefit from greater innovation and collaboration between different stakeholders, including government, private sector, and civil society organizations. This can include initiatives to encourage research and development of new technologies, promote knowledge sharing, and support the creation of partnerships and networks.

- **Enhancing capacity building and skill development:** The successful operation of mini grids requires a range of technical and managerial skills. To address this, there is a need to enhance capacity building and skill development among local institutions and communities, including training on operations and maintenance, financial management, and community engagement.

- **Strengthening monitoring and evaluation:** It is important to have a robust monitoring and evaluation framework in place to measure the impact and effectiveness of mini grids in meeting their objectives. This can include the development of performance indicators, regular data collection and analysis, and the sharing of lessons learned and best practices.

By implementing these measures, the mini grid sector in India can be stimulated for growth and to meet its potential, ultimately contributing to the country's sustainable development goals and improving energy access for rural communities.

5.1. Village Level

Village Electrification

1. **Solar Mini Grid Electrification:** Recognizing the success of solar mini grids in electrifying villages, efforts should be made to ensure that solar mini grid installations are designed not only for irrigation needs but also for household electrification, especially in regions where access to electricity is limited.

2. **Combination of Main and Solar Mini Grids:** Leveraging a combination of the main grid and solar mini grids in laggard districts has proven to be effective in enhancing electricity access. This hybrid electrification setup should be further encouraged and replicated in other areas to diversify electricity sources and ensure more reliable access.

3. **Access Disparities:** Targeted interventions should be implemented to address access disparities within electrified villages, focusing on households that still lack electricity despite the village being classified as electrified. This includes identifying and addressing barriers such as affordability, infrastructure limitations, and geographic isolation to ensure equitable access to electricity for all households.

Source of Electricity Supply

India’s peak power demand of 210 GW is not even half of its total installed capacity of 428 GW. The gap between energy requirement and energy supplied is just 0.3%, which is due to system constraints and some DISCOMs not having funds to procure power. The gap between peak demand and peak met is just 1.4%. With increasing renewable energy supply, which is cheaper than conventional electricity, the power scenario is expected to further improve.

- **Main Grid (DISCOM):** Efforts should be directed towards ensuring reliable and uninterrupted supply from the DISCOMs. Infrastructure upgradation, improved maintenance, and improving metering, billing and collection can improve upon the power deficit situation experienced by some states. Investments in grid infrastructure and addressing issues like transmission losses and voltage stability can enhance the quality of electricity supply.
  In states like Uttar Pradesh and Bihar, which experience shortfalls, many consumers generally have 'inverters' as back-up during power cuts. It has been successfully demonstrated that mini-grid electricity is cheaper than such solutions as optimization of battery size placement and sizing happens at a larger scale (mini-grid service area) rather than at each individual consumer level.

- **Solar Mini Grid Supply** Although only 6% of sample habitations rely solely on mini grid plants, there is potential for expansion in solar mini grid installations. Initiatives to promote and subsidize solar energy solutions could accelerate electrification efforts, especially in remote or off-grid areas where extending the main grid may be economically unfeasible. Consumers in such areas are bound to benefit from the additional source of electricity. Ideally, such mini grids if connected to the grid can support the tail ends of the grid by increasing the energy supply and improving voltage levels. The interconnected mini grids can also be 'co-opted' by the grid thereby unifying the billing and collection which can be an advantage for the consumers.
  The higher proportion (20%) of sample habitations relying on solar mini grids in laggard districts highlights the importance of decentralized energy solutions. Expanding access to solar energy can play a significant role in bridging electricity access gaps, especially in areas where the main grid infrastructure is inadequate or non-existent. Government subsidies and support for solar initiatives can facilitate this expansion.

Billing and Payments

Main Grid:

- **Regular Billing Cycle:** In both aspiring and laggard districts, a significant percentage of villages receive monthly bills for electricity from the main grid (53.5% and 50% respectively). This indicates a regular billing cycle, which can contribute to better financial planning for households and utilities.

- **Variation in Billing Frequency:** There is variation in billing frequency within districts. For example, in aspiring districts, a smaller percentage receive bills once every 2 months (20.90%) or once every 6 months (16.30%). Similarly, in laggard districts, some villages receive bills every 2 months (22%) or every 6 months (7%). Understanding the reasons behind this variation can help identify areas for improvement in billing systems and ensure consistency in service delivery.

- **Addressing Non-Billing Issues:** While the majority of villages receive bills regularly, it's essential to address the issue of villages that do not receive bills. In aspiring districts, 7% of villages, and in laggard districts, 15% of villages reported not receiving bills. Investigating the reasons behind this discrepancy and implementing measures to ensure all households receive accurate and timely bills is crucial for revenue collection and accountability.

Solar Mini Grid:

- **Monthly Billing Dominance:** Among respondents, the majority receive monthly bills for solar mini grid electricity consumption (81.3%). This indicates a predominant mode of monthly billing, which aligns with regular utility billing practices and facilitates better financial management for households.

Overall, ensuring a regular and consistent billing cycle for electricity consumption, whether from the main grid, solar mini grid, or both, is crucial for promoting financial inclusivity, revenue collection efficiency, and sustainable energy access in both aspiring and laggard districts.

Electricity Supply Disconnection Due to Non-payment of Bills

1. Mitigating Electricity Supply Disconnection:

The high percentage of electricity supply disconnection due to non-payment of bills, particularly in laggard districts, highlights the urgency of addressing this issue to ensure uninterrupted access to electricity for households.

Implementing targeted interventions, such as flexible payment plans, financial assistance programs for vulnerable households can help in clearing accumulated backlogs and ensure regularity of bill payment, while community outreach initiatives to raise awareness about the consequences of bill non-payment can help reduce the incidence of disconnection. Additionally, enhancing the efficiency of billing and payment systems, along with improving communication channels between utilities and consumers, can facilitate timely bill settlement and minimize the need for disconnection.

2. Promoting Payment Assistance and Financial Literacy:

Providing support mechanisms such as payment assistance programs or installment plans for households facing financial difficulties can help alleviate the burden of overdue bills and prevent electricity supply disconnection. Moreover, promoting financial literacy initiatives within communities can empower villagers to manage their electricity expenses effectively, budget responsibly, and prioritize bill payments to avoid disconnection. Collaborating with local authorities, non-profit organizations, and community leaders can enhance the effectiveness of these initiatives and foster sustainable solutions to address the challenges associated with pending bills and electricity supply disconnection.

5.2. Household Consumers

Promoting Reliability and Consistency in Electricity Supply:

1. **Main Grid Infrastructure Enhancement:** Prioritize investments in main grid infrastructure upgrades and maintenance in both aspiring and laggard districts to ensure reliable and consistent electricity supply. This includes strengthening transmission and distribution networks, upgrading substations, and implementing advanced grid management systems to minimize downtime and improve service reliability.

2. **Solar Mini grid Expansion and Integration:** Encourage the expansion and integration of solar mini grid systems, particularly in areas with unreliable main grid supply, to complement existing infrastructure and enhance energy reliability. Promote the deployment of decentralized solar solutions in remote or underserved areas to provide uninterrupted electricity access, especially during periods of grid outages or load shedding.

3. **Hybrid Energy Solutions:** Explore the adoption of hybrid energy solutions that combine both main grid and solar mini grid technologies to maximize energy reliability and resilience. Hybrid systems can leverage the strengths of both grid-connected and off-grid solutions, providing households with a dependable and uninterrupted power supply while reducing dependency on a single energy source.

4. **Capacity Building and Training Programs:** Implement capacity building and training programs to equip local communities, energy stakeholders, and technicians with the skills and knowledge needed to maintain, operate, and manage both main grid and solar mini grid systems effectively. Foster collaboration between government agencies, utility providers, and renewable energy companies to facilitate knowledge exchange and promote best practices in energy management. This has been successfully piloted in Odisha in which Mahashakti Foundation with the financial and technical support of Smart Power for Rural Development Foundation India (SPI) established a Model Distribution Zone (MDZ) at Paradeep Division of CESU, the DISCOM owned by Tata Power. The objective of the pilot was to demonstrate a successful model of electricity distribution supply with enhanced efficiency and the highest level of customer service. Nearly one lakh consumers are served by the Division, with rural customer mix of greater than 94%. CESU found it financially unviable to service the consumers due to high degree of techno-commercial losses, high instances of supply interruptions, dilapidated electricity network, lower commercial loads, etc. To improve efficiency and enhance customer service, micro-franchisees under SEFA Guidelines, comprising of the members of the women Self Help Groups (SHGs) selected through the 79 Gram Panchayat Level Federations (GPLFs) was undertaken for metering, billing and collection services. These women are called Bijuli Didis and they earn Rs 1,500 to 8,000 per month as commission. The initiative is now being replicated in Uttar Pradesh under an ADB initiative.

5. **Consumer Awareness and Engagement:** Launch consumer awareness campaigns highlighting the benefits of reliable electricity supply and the role of solar mini grids in enhancing energy access and resilience. Educate households about the advantages of solar energy, including its environmental sustainability, cost-effectiveness, and ability to provide uninterrupted power during grid outages. Encourage community participation in energy planning and decision-making processes to ensure that local needs and preferences are considered in energy infrastructure development initiatives. The objective is to increase the awareness of consumers on the benefits of mini grids in enhancing the electricity supply scenario and improving their resilience. Ideally, Decentralised Renewable Energy

(DRE) solutions, of which solar mini grid is an example, should be all pervasive across the grid. This will not only improve the resilience of the grid to disruptions, but will also improve the power procurement portfolio of the DISCOMs.

6. **Investment in Smart Grid Technologies:** Explore the adoption of smart grid technologies, such as advanced metering infrastructure (AMI), distribution automation, and predictive maintenance systems, to enhance the monitoring, management, and control of the electricity grid. Smart grid solutions can help identify and address potential issues proactively, minimizing downtime and improving overall reliability.

7. **Continuous Monitoring:** Implement regular monitoring and evaluation mechanisms to assess the effectiveness of reliability improvement initiatives and identify areas for further improvement. Collect data on outage frequency, duration, and root causes to inform decision-making and allocate resources efficiently to enhance electricity supply reliability over time.

Billing and payments:

1. **Improving Billing Processes:** Implement measures to ensure that all consumers, especially those with both main grid and mini grid connections in aspiring districts, receive electricity bills for their main grid connection regularly. This could involve enhancing billing systems, providing options for online billing, and establishing clear communication channels for bill delivery.

2. **Enhancing Metering Infrastructure:** Consider upgrading metering infrastructure, particularly in villages with mini grid connections, to ensure accurate billing and transparency in electricity consumption. This may involve deploying both postpaid and prepaid electricity meters based on consumer preferences and usage patterns.

3. **Addressing Overdue Payments:** Develop strategies to address overdue payments, especially for main grid supply, in both aspiring and laggard districts. This could include promoting financial literacy programs to educate consumers about the importance of timely bill payments, offering flexible payment options, and implementing effective debt recovery mechanisms.

4. **Monitoring and Management of Dues:** Establish robust monitoring systems to track overdue payments and manage consumer dues effectively. This may involve regular follow-ups with consumers, providing assistance to those facing financial difficulties, and leveraging technology for automated billing and payment reminders.

5. **Promoting Financial Inclusion:** Explore initiatives to promote financial inclusion and improve access to banking services in rural areas, particularly in villages with mini grid connections. This could help facilitate electronic payments and enable consumers to manage their electricity bills more efficiently.

6. **Cross-Subsidization Mechanisms:** Consider implementing cross-subsidization mechanisms to ensure affordability of electricity services for low-income consumers while maintaining financial sustainability for electricity providers. This could involve redistributing revenue from higher-paying consumers to offset the costs of providing electricity to underserved communities.

5.3. Agriculture Sector

1. **Promotion of Solar-Powered Pump Sets:** Encourage the adoption of solar-powered pump sets, particularly in aspiring districts where a considerable proportion of households already utilize solar electricity for lifting water. This could involve providing subsidies, incentives, or access to financing options to make solar pump sets more affordable and accessible to farmers.

2. **Transition to Clean Energy Sources:** Promote the transition from diesel-powered pump sets to solar-powered alternatives to reduce dependence on fossil fuels, lower greenhouse gas emissions, and mitigate environmental pollution. Implement awareness campaigns highlighting the benefits of solar energy and offering technical assistance for the installation and maintenance of solar pump systems.

3. **Infrastructure Development for Solar Irrigation:** Invest in the development of solar irrigation infrastructure, such as community-based solar-powered water pumping stations or micro-grids, to serve multiple farmers in a cost-

effective manner. This approach can enhance agricultural productivity, water efficiency, and resilience to climate change while reducing operational costs and reliance on traditional energy sources.

4. **Capacity Building and Training:** Provide training programs and technical support to farmers on the operation, maintenance, and troubleshooting of solar-powered pump sets. Empower farmers with the knowledge and skills needed to maximize the performance and longevity of solar irrigation systems, including proper sizing, placement, and irrigation scheduling.

5. **Policy Support and Regulatory Frameworks:** Develop supportive policies, regulatory frameworks, and incentives to facilitate the widespread adoption of solar irrigation technologies. This could include net metering policies, feed-in tariffs, tax incentives, and streamlined permitting processes to incentivize investment in solar infrastructure and stimulate market growth.

6. **Research and Innovation:** Invest in research and innovation initiatives to improve the efficiency, affordability, and reliability of solar-powered pump sets. Support research institutions, universities, and technology startups in developing innovative solutions such as advanced solar panels, energy storage systems, and remote monitoring capabilities tailored to the needs of agricultural communities.

5.4. Commercial and Institutional Consumers

1. **Diversification of Energy Sources:** Encourage establishments to diversify their energy sources by incorporating renewable energy solutions such as solar mini grids alongside reliance on the main grid. This can help mitigate challenges related to reliability and capacity issues, providing a more resilient and sustainable energy supply.

2. **Investment in Energy Efficiency Measures:** Implement energy efficiency measures within establishments to optimize energy use and reduce electricity bills. This could include upgrading energy-efficient appliances, implementing lighting controls, and conducting energy audits to identify areas for improvement and cost savings.

3. **Maintenance and Asset Management:** Prioritize regular maintenance and asset management practices to minimize breakdowns of electrical assets and associated repair costs. Establishments reliant solely on the main grid should invest in proactive maintenance schedules and asset monitoring systems to address potential issues before they escalate.

4. **Tariff Reforms:** Advocate for tariff reforms and value-based pricing structures that offer better value for money and incentivize energy efficiency. Engage with policymakers and utility providers to explore options for tariff optimization, peak demand management, and incentive programs that reward energy-saving practices and investments in renewable energy technologies.

5. **Generating Awareness:** Awareness campaigns for commercial establishments on energy efficiency, management, best practices, resilience planning, and the benefits of renewable energy adoption. Empower businesses with the knowledge and skills needed to make informed decisions regarding energy investments and optimize their energy use for long-term sustainability.

6. **Main Grid Reliability:** Enhance the scheduling and predictability of electricity supply to institutions by investing in grid modernization technologies and implementing proactive maintenance practices. Address voltage fluctuations and ensure consistent voltage levels to support the operation of high-wattage equipment and meet the diverse needs of consumers.

7. **Enhancing Solar Mini Grid Performance:** Invest more in mini grid infrastructure to ensure future demand of electricity with adequate voltage levels to meet demand from commercial and institutional consumers. Develop innovative strategies to address the limitation of not operating high-wattage equipment with mini grid supply, such as exploring energy storage solutions or hybrid systems.

6. Policy Level Insights – The Way Forward

The policy and regulatory framework for mini grids in India is primarily governed by the Ministry of New and Renewable Energy (MNRE) and the State Electricity Regulatory Commissions (SERCs). The Government of India and MNRE has launched several policies and schemes to support the development of mini grids in India, including:

- **Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY):** This scheme aims to provide access to electricity to all rural households and electrification of all rural villages through a combination of grid and off-grid solutions, including mini grids.

- **National Solar Mission:** This scheme aims to promote the development of solar power in India, including the installation of solar mini grids.

- **Off-Grid and Decentralized Solar PV Applications Program:** This program provides financial support for the installation of off-grid solar PV systems, including mini grids.

In addition, the SERCs in each state are responsible for regulating the operation of mini grids and setting tariffs for electricity supplied by mini grid operators. The SERCs also play a role in approving the installation of mini grids and ensuring that they meet technical and safety standards.

There are also various policies and regulations related to renewable energy and electricity distribution that are relevant to the mini grid sector in India, including:

- **Electricity Act, 2003:** This act governs the regulation of the electricity sector in India and provides the framework for the development of renewable energy sources, including mini grids.

- **National Tariff Policy, 2016:** This policy provides guidelines for setting tariffs for electricity supplied by mini grids and other off-grid sources.

- **Renewable Purchase Obligation (RPO):** This policy requires power distribution companies to purchase a certain percentage of their electricity from renewable sources, including mini grids.

While there are supportive policies and regulations in place for the development of mini grids in India, there are also challenges related to regulatory barriers and inconsistent implementation of policies across different states. There are certain learnings that have emerged which needs highlighting and should be considered while designing future programs on mini grids.

- **Assured supply of electricity:** supply of adequate and quality electricity in rural areas remains a challenge. Inadequate electricity supply severely limits the functioning of commercial ventures as electricity is a key input in their processes. Enterprises like flour mills, oil expellers, etc which need mechanical power thus must depend on diesel engines which reduces their profitability and limits earnings of the entrepreneurs. Also, getting a connection for large loads like motor loads is expensive and entrepreneurs have to make their way through bureaucratic red tape, which is time consuming and costly. The tariff for such connections is also not as cheap as domestic supply tariff and coupled with poor quality of supply, is not attractive for such consumers.

- **Mini grids ability to meet large loads:** mini grid electricity, though comparatively expensive than the grid electricity, can meet large motor loads easily when such mini grids are designed to cater to such loads. More importantly, the quality of supply is much better and hence consumers can rely on its supply to run their business operations. Being a little expensive also encourages consumers to economize on its use and adopt energy efficient appliances and practices to reduce their costs of energy, which is a welcome development.

Considering the above, a few policy level insights can be gathered. Further work on these areas, including advocacy and generating adequate knowledge can help create a conducive environment for mini grids.

- **Create a policy and regulatory framework:** a policy and regulatory framework would be required which encourages the setting up of mini grids and provides them with a level playing field with the DISCOMs. The policy should also promote collaborations between mini grids and DISCOMs with the common objective of improving the access to clean and reliable electricity of the rural population.

- **Designing specific programs on rural enterprise development centered around mini grids:** till recently mini grids were able to meet only domestic electricity demands and were unable to cater to large loads, typical of enterprises. These days, mini grids are capable of powering motor loads. The cost of generation has also come down and reliability of such systems has improved tremendously. Properly designed, mini grid projects can become financially viable too, as demonstrated by the current project. Keeping this in mind, specific pilot projects/ programs in varied geographies may be required to generate more knowledge based on which large scale programs specifically targeting rural enterprises may be designed.

- **Grid interactive readiness of mini grids:** the grid is now omnipresent across the country and in the future mini grids need to interact with the grid. A grid-interactive mini grid can be beneficial for both the mini grid operator – electricity generated from additional capacity/ spare capacity can be fed into the grid thereby increasing the revenue of the mini grid and making it more profitable – and the grid – it can buy renewable energy closer to its points of use. However, for this to happen, standardization of equipment parameters and performance parameters of mini grids would be imperative so that they become grid ready. Standards and specifications adopted by mini grids vis-a-vis those of the technical standards for connectivity to the grid needs to be analyzed and for interconnection of mini grids to the grid, technical standards and adoption of appropriate technologies need to be worked out.

- **Potential business models for grid-interactive mini grids:** mini grids catering to rural areas meeting domestic and small enterprises' loads have come a long way and are now capable of supplying quality power 24X7. The developers need to come up with new business models whereby grid-interactive models can be set up selling surplus generation to the grid, importing energy from the grid during high demands and simultaneously meeting the consumptive and productive energy needs of their consumers.

- **Roles of stakeholders:** new business models will need the relevant stakeholders to play different roles than what they are currently playing. Possible roles of DISCOMs and other stakeholders like Government Ministries and Departments need to be identified and detailed out.

- **Policy and regulatory stability:** private investments are driven by certainty in policy direction and clarity in regulatory regime; more so for new business models.

- **Financing the transition:** Access to finance remains a critical challenge for the mini grid sector in India. To address this, the government can encourage financial institutions to invest in the sector and offer innovative financing options. There are several financing options available for the development and operation of mini grids in India, including:

  - Government subsidies and grants: The Ministry of New and Renewable Energy (MNRE) offers subsidies and grants for the installation of mini grids in India. For example, the Off-Grid and Decentralized Solar PV Applications Program provides a subsidy of up to 30% of the project cost for mini grid installations.

  - Debt financing: Mini grid developers can also access debt financing from commercial banks and other financial institutions. The Indian Renewable Energy Development Agency (IREDA) is a specialized financial institution that provides debt financing for renewable energy projects, including mini grids.

  - Equity financing: Equity financing is another option for mini grid developers, whereby investors provide funding in exchange for a share of ownership in the project. There are several venture capital firms and impact investors in India that focus on financing renewable energy and mini grid projects.

  - Crowdfunding: Crowdfunding is a relatively new financing option for mini grids in India. Platforms like Milaap and Kiva allow individuals to make small investments in mini grid projects, which can help to raise capital for project development.

  - Carbon financing: Carbon financing is another option for mini grid developers, whereby they can earn revenue by selling carbon credits generated from their renewable energy projects.

In addition to these financing options, mini grid developers can also explore innovative business models and financing structures to make their projects more financially sustainable. For example, some mini grid developers in India have implemented pay-as-you-go models, where customers pay for electricity on a per-use basis, which can help to reduce upfront costs and increase revenue.

Ways to address financing gaps:

Financing remains a critical challenge for mini grids in India. As rural economies are not well developed, the capacity to pay for electricity is lower as compared to their urban counterparts. This limits the revenues of mini grids making it difficult for them to become attractive as an investment for mainstream financing institutions. Addressing the financing gap for mini grids require a combination of strategies that includes structure of the initiative, designing innovate financing mechanisms, improving community participation and their capacity building, and bringing in more remunerative loads. Specifics of such a strategy could be a combination of the following:

- **Targeting Remunerative Loads:** Getting more and more remunerative loads can contribute to the improvement of financial viability of mini grids. Mini-grid electricity is much more reliable than the grid supply, as captured in the field surveys, and reliable electricity supply is essential in running enterprises. Although the cost of mini grid electricity is higher than that of grid electricity, the higher cost is recoverable if it is used in income generation enterprises. This should be one of the key focus areas around which mini grids should be developed. In addition, mini-grids should try to enlarge their customer base to include Anganwadis, health centres, etc. which can act as anchor loads thereby contributing to the financial viability of the mini-grids.
- **Public-Private Partnerships (PPPs):** Encourage partnerships between government entities, private investors, and local communities to develop mini-grid projects. The government can provide support through policies, regulatory frameworks, and financial incentives to attract private sector investment.
- **Blended Finance:** Utilize blended finance models that combine concessional funding, grants, and commercial capital to reduce investment risks and attract private investors. Blended finance structures can help bridge the gap between the high upfront costs of mini-grid projects and the revenue potential. Depending on the structure of projects, provision of grant-based CAPEX and minimal interest based OPEX support should be explored.
- **Risk Mitigation Instruments:** Introduce risk mitigation instruments such as guarantees, insurance, or loan guarantees to de-risk investments in mini grids. These instruments can provide assurance to investors and lenders, making investments in mini grid projects more attractive. The Government, in association with international multi and bilateral development agencies can design such instruments, and it could serve to mobilize private investment (equity and debt) for the sector, mitigate key to enable financial viability and bankability of projects, enhance the credit quality for investments, and reduce costs and improve financing terms for projects, thereby ensuring their long-term sustainability.
- **Innovative Financing Mechanisms:** Explore innovative financing mechanisms such as green bonds, impact investment funds, and crowdfunding platforms tailored specifically for mini grid projects. These mechanisms can mobilize capital from diverse sources and channel it towards mini grid development.
- **Community Participation, Ownership and Capacity Building**: Promote community participation and ownership in mini grid projects by involving local communities in project development, management, and ownership. Community-led initiatives can help mobilize resources, build trust, and ensure the sustainability of mini grid operations. Provide capacity building support and technical assistance to mini grid developers, investors, and policymakers to enhance project planning, implementation, and management capabilities. Strengthening local expertise can attract investment and facilitate the scaling up of mini grid initiatives. Increased community participation and capacity building can also help in local job creation.

Immediate action points:

- Energy transition financing in different load centres by balancing seasonality, anchor load profiling, ensuring mitigation of power outages within 2-3 hours, along with reduction of power thefts and protection of inverters.
- Business model specific investments, catalytic financing of OPEX (assuming CAPEX is free and grant-based), complemented with creation of replicators with anchor load profiling and assessment in different village and location contexts. Benefits of carbon trading can be further used for subsidy provisioning in financing.

- Consumer-specific blended catalytic financing is important to scale up energy transition financing in aspiring and laggard districts of India to reduce the risks of financing by fostering community belonging and trust-led financing.
- DRE-centric financing and outreach should be focused on areas and terrains where the main grid cannot reach, as there is scope to meet urgent energy access needs of underserved communities in remote areas. DRE-based initiatives also supplement the main grid supply wherever there are reliability and quality issues, and financing should be adequately channeled to such areas as well.
- Financing of mini grid villages should be based on their daily load profile as well as the degree and patterns of demand, and not based on their district category.
- Financing of small businesses in mini grid villages of laggard districts has a larger propensity to scale up in comparison to the small businesses in mini grid villages in aspiring districts and should therefore receive greater policy focus.
- The Pradhan Mantri Surya Ghar Muft Bijli Yojana is a rooftop solar scheme which aims to offer 300 units of free electricity per month to up to 1 crore homes nationwide and financial aid in the form of subsidies to homeowners who opt for rooftop solar plants. Subsidy-based financing through this scheme should consider the unaccounted houses of the Pradhan Mantri Gramin Awas Yojana and reach out to these households with average monthly load consumption of 2-3 units, to make clean energy transition financing more inclusive.

7. Conclusion

Through a detailed examination of survey findings (village level, household, commercial and institutional consumers, and mini grid operators) covering electricity access, billing practices, reliability, and challenges across aspiring and laggard districts, a nuanced understanding of the current state of energy infrastructure and its implications has emerged. The findings may offer valuable guidance for policymakers, state governments, distribution companies, and other community stakeholders seeking to enhance energy access, reliability, and sustainability.

In both aspiring and laggard districts, significant progress has been made in extending the main grid infrastructure. However, challenges such as partial electrification, irregular supply, frequent disconnection, and overdue bills persist, highlighting the need for targeted interventions to address access gaps and improve billing and related services.

Solar Mini Grid Electrification is at the core of India’s renewable strategy and has the potential to limit India’s carbon footprint. Our analysis reveals that the adoption of solar mini grids presents a promising solution, not only in villages where the main grid infrastructure may be inadequate, but also in villages where the main grid is dominant. Achieving 100% electrification supported by solar mini grids requires careful planning and investment, but it offers the potential to enhance energy access and resilience in off-grid areas. Hybrid electrification solutions combining both main grid and solar mini grids are prevalent, especially in laggard districts. This diversified approach leverages centralized and decentralized solutions to ensure better electricity access and reliability, catering to the diverse needs of rural communities.

The analysis of electricity supply frequency in both aspiring and laggard districts reveals a largely positive trend in daily electricity provision, signifying a relatively stable energy infrastructure across rural communities. In aspiring districts, where the majority of households are connected to either the main grid or solar mini grids, an overwhelming percentage reported receiving daily electricity supply, with solar mini grid connections demonstrating exceptional reliability. Similarly, in laggard districts, while the percentages are slightly lower compared to aspiring districts, the majority of households still receive daily electricity supply, with solar mini grid connections exhibiting higher reliability than the main grid.

Overall, the findings underscore the effectiveness of solar energy solutions, particularly in providing continuous electricity access, as evidenced by the higher percentages of daily supply coming via mini grid connections. However, it is noteworthy that a substantial proportion of households in both aspiring and laggard districts, especially those in hybrid electricity villages, still face challenges with daily electricity supply, indicating areas for improvement in grid reliability and infrastructure.

Moving forward, prioritizing investments in grid maintenance, upgrading infrastructure, and integrating renewable energy sources can further enhance the reliability and resilience of electricity supply in rural areas. Additionally, fostering community engagement, implementing smart grid technologies, and promoting energy efficiency measures are essential steps towards ensuring consistent and sustainable energy access for all rural households, regardless of their district classification.

Despite notable progress, supply side challenges persist within villages, and districts, highlighting the importance of targeted solutions to ensure efficient access for all households/commercial establishments. Billing practices vary, with monthly billing being predominant for both main grid and solar mini grid connections. However, challenges such as irregular billing cycles underscore the need for streamlining billing processes to enhance transparency and efficiency. The prevalence of overdue bills and electricity disconnections in the main grid villages due to non-payment underscores the need for improved billing and payment mechanisms, alongside efforts to enhance financial literacy and access to billing services. Consumers reported facing various challenges with the main and mini grid infrastructure, including reliability issues, inadequate capacity, high electricity bills, and frequent breakdowns. Addressing these challenges requires infrastructure upgrades, investment in smart grid technologies, capacity building, and community engagement.

The challenges faced by commercial consumers in both aspiring and laggard districts shed light on the multifaceted nature of issues affecting electricity supply reliability and affordability in rural areas. Reliance solely on the main grid poses significant risks of unreliable electricity supply, with a majority of establishments reporting challenges related to the time or duration of electricity availability. This underscores the pressing need for diversifying energy sources and integrating solar mini grids to mitigate the impact of supply interruptions and enhance grid stability. Moreover, concerns about inadequate capacity or load highlight the importance of infrastructure upgrades and capacity-building initiatives to meet the growing demands of electrical appliances in commercial establishments. Investments in modernizing electrical assets and implementing proactive maintenance strategies can help minimize breakdowns and repair costs, thereby improving operational efficiency and reducing disruptions to business operations. In conclusion, addressing the challenges faced by commercial respondents requires a holistic approach that combines technological innovation, policy support, and community engagement to build a resilient and sustainable energy ecosystem in rural areas, fostering economic growth, and improving livelihoods for all stakeholders involved.

The analysis of supply reliability in both aspiring and laggard districts further reveals nuanced perceptions among respondents regarding the consistency and adequacy of electricity services. In aspiring districts, while around half of the respondents perceive electricity supply as reliable on the designated days, a significant proportion highlights concerns about its unreliability. Similarly, in laggard districts, there is a slightly lower perception of reliability, with a slight majority reporting unreliability on supply days. Overall, the findings suggest a relatively balanced perception of electricity supply reliability between aspiring and laggard districts, indicating persistent challenges in ensuring consistent and dependable energy access across rural areas. Further investigation into factors such as infrastructure quality, maintenance practices, and service interruptions is warranted to address these challenges comprehensively. Moreover, households connected to the main grid, particularly in villages with hybrid electricity sources, express varying degrees of satisfaction with the adequacy and reliability of electricity supply. Notably, the implementation of solar mini grids in villages with both main and mini-grid connections reflect a strategic response to address inadequacies in main grid supply, highlighting the importance of diversifying energy sources to enhance reliability and resilience. Based on the conditions observed in the sites that were visited, the mini grids in villages in laggard districts have had a positive impact on energy access for underserved communities. This is reflected in the analysis of key indicators such as reliability of supply, where laggard districts are performing at par with aspiring districts.

Furthermore, the dissatisfaction with high electricity bills underscores the need for policy interventions to enhance the affordability and value for money of electricity services. Initiatives such as tariff reforms, energy efficiency programs, and financial incentives for renewable energy adoption can help alleviate the financial burden on both household and commercial establishments and promote sustainable energy practices. Addressing challenges related to frequent power outages or disruptions due to weather factors requires a comprehensive approach that integrates resilience planning, infrastructure strengthening, and disaster preparedness measures. Collaborative efforts between government agencies, utilities, and local communities are essential to develop robust contingency plans and deploy rapid response mechanisms to mitigate the impact of weather-related disruptions on business continuity. The findings underscore the complex landscape of electricity access and reliability in rural areas, with both opportunities and challenges across aspiring and laggard districts. By prioritizing infrastructure upgrades, promoting renewable energy adoption, streamlining billing processes, and fostering community engagement, stakeholders can work together to build a more inclusive, resilient, and sustainable energy future for all. This requires collaborative efforts, innovative solutions, and a commitment to addressing the diverse needs of rural communities.

Photo Gallery

Domestic Consumer Interview, Palamu, Jharkhand

Institutional Consumer Interview, Shravasti, Uttar Pradesh

Commercial Consumer Interview, Jamui, Bihar

Community Stakeholders FGD, Samastipur, Bihar

Mini Grid Operator Interview, Gumla, Jharkhand

Domestic Consumer with Solar Irrigation Pump, Banka, Bihar

Domestic Consumer with small business, Lakhimpur Kheri, Uttar Pradesh

Domestic Consumer Interview, Begusarai, Bihar

Community Stakeholder Interview, Khunti, Jharkhand

Consumer with Solar Irrigation Pump, Banka, Bihar

Battery Backup of a Solar Mini Grid, Gumla, Jharkhand

Women FPO FGD, Lakhimpur Kheri, Uttar Pradesh

Community Stakeholder Interview, Hardoi, Uttar Pradesh

Anganwadi Interview, Palamu, Jharkhand

Mini Grid Operator showing the solar panel set-up, Simdega, Jharkhand

Interview with ASHA, Begusarai, Bihar

Commercial Consumer operating heavy machinery, Shravasti, Uttar Pradesh

Set-up of a Solar Mini Grid, Simdega, Jharkhand

Disconnected Consumers FGD, Lohardaga, Jharkhand

Institutional Consumer Interview, Simdega, Jharkhand

Individual Solar Panel, Samastipur, Bihar

Electricity Meter, Hardoi, Uttar Pradesh

Commercial Consumer Interview, Bahraich, Uttar Pradesh

Renewable Energy Consumers FGD, Gumla, Jharkhand