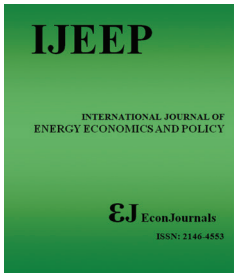

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Adoption of Decentralized Renewable Energy Solutions by MSMEs: Barriers and Opportunities in India

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) are crucial to India's economic development, yet they face significant energy cost burdens that hinder productivity. Decentralized Renewable Energy (DRE) solutions such as rooftop solar and biomass can reduce operational costs and promote sustainability. This paper investigates the adoption of DRE among 390 Indian MSMEs across multiple sectors using a mixed-methods approach. Quantitative data were analysed using SPSS for trends and barriers, while qualitative interviews enriched the insights on adoption behaviour. The findings reveal that although 65% of MSMEs are aware of DRE, only 48% have adopted it. Major barriers include initial cost, lack of policy clarity, and technical know-how. The paper recommends targeted financial schemes and awareness campaigns to foster DRE adoption. This study contributes to understanding the energy transition pathways for small enterprises in emerging economies.

Keywords: MSMEs, Renewable Energy, Decentralized Energy, Sustainability, India, Barriers
JEL Classifications: Q42, Q48, L26, O13, O33

1. INTRODUCTION

India's MSME sector accounts for about 30% of the GDP and employs over 110 million individuals (Ministry of MSME, 2023). Despite this, MSMEs face persistent challenges in managing operational costs, especially energy expenditure, which can range between 15 and 30% depending on the sector (GIZ, 2018a). Decentralized Renewable Energy (DRE) systems, including rooftop solar panels, biomass gasifiers, and wind microgrids, offer viable alternatives to reduce grid dependency and enhance energy resilience (IRENA, 2019a). However, the adoption of DRE in Indian MSMEs remains limited due to various technical, financial, and regulatory challenges. Several national programs like the PM-KUSUM and UDYAM registration under ZED (Zero Defect Zero Effect) emphasize green compliance, but implementation at the MSME level has been suboptimal (MNRE, 2022).

This study aims to bridge this gap by empirically evaluating the level of DRE adoption, identifying barriers, and proposing scalable interventions. India's economic trajectory over the past two decades has prominently featured the expansion and growing significance of the Micro, Small and Medium Enterprises (MSMEs) sector. Representing over 63 million enterprises, this sector contributes approximately 30% to the national GDP, 49% to total exports, and employs more than 110 million individuals across rural and urban India (Ministry of MSME, 2023). Despite these impressive figures, MSMEs face significant structural challenges that impede their long-term competitiveness. Among these, one of the most persistent issues is the high and unpredictable cost of energy. For most MSMEs—especially those operating in energy-intensive sectors like manufacturing, textiles, ceramics, and food processing—electricity and fuel expenses form a substantial portion of their total operational costs. In many

industrial clusters, unreliable power supply, frequent outages, and fluctuating tariffs lead businesses to rely on expensive and polluting alternatives such as diesel generators (GIZ, 2018a). Moreover, rising concerns around environmental sustainability and India's commitments under the Paris Agreement to reduce greenhouse gas (GHG) emissions further necessitate a transition toward cleaner, decentralized energy alternatives.

1.1. The Emergence of Decentralized Renewable Energy (DRE)

Decentralized Renewable Energy (DRE) systems refer to small-scale, locally sourced energy solutions that operate either independently or in conjunction with the main grid. These include technologies like rooftop solar photovoltaic (PV) systems, biomass gasifiers, biogas plants, small wind turbines, and mini-hydro units. For MSMEs, DRE offers numerous advantages such as energy cost savings, reduced dependence on erratic grid supply, lowered carbon footprint, and increased autonomy in energy management (IRENA, 2019a; Palit and Chaurey, 2011). Over the past decade, India has made significant strides in renewable energy development. As of 2023, the country has achieved over 120 GW of installed renewable energy capacity, with solar energy alone accounting for nearly 60 GW (IRENA, 2019b). Policy interventions such as the National Solar Mission, PM-KUSUM Scheme, and state-level net metering frameworks have been instrumental in driving this growth (MNRE, 2022; Sharma et al., 2012). However, despite these national-level developments, the uptake of DRE solutions among MSMEs remains relatively low. Various studies estimate that less than 20% of Indian MSMEs have successfully adopted any form of renewable energy system, with wide disparities across states and industry segments (GIZ, 2018b; IRENA, 2019b).

1.2. Potential of DRE for MSMEs in India

The adoption of DRE technologies holds transformative potential for Indian MSMEs. Empirical evidence suggests that DRE integration can result in 10–25% reductions in energy costs, depending on the technology and sector (Narula and Sudhakara Reddy, 2015). Furthermore, reliable and clean energy access can enhance process efficiency, reduce production downtime, and enable the adoption of digital and automated solutions, thereby improving overall productivity (Sharma et al., 2012). In rural and peri-urban clusters, where grid supply is frequently unreliable or entirely absent, DRE solutions can act as a catalyst for enterprise development and job creation (Palit & Chaurey, 2011; Sharma et al., 2012). In addition to economic gains, DRE adoption aligns MSMEs with the broader national and global sustainability agendas. The Indian government's voluntary ZED (Zero Defect Zero Effect) certification scheme encourages MSMEs to improve product quality while minimizing environmental harm (MNRE, 2022). Integrating renewable energy solutions is a critical criterion under this scheme. Moreover, with increasing interest from global buyers in sustainable supply chains, energy-efficient and green-certified MSMEs can gain a competitive edge in international markets (TERI, 2017).

1.3. Barriers to Adoption of DRE by MSMEs

Despite these benefits, the actual rate of adoption of DRE systems by MSMEs remains modest. Multiple barriers—both perceived and real—hinder widespread deployment. Firstly, financial barriers are often cited as the most significant. The upfront cost of installing renewable energy systems can be prohibitive, especially for micro and small enterprises with limited access to formal credit. Although subsidies and soft loan schemes exist, their coverage, accessibility, and disbursement mechanisms are often inefficient or poorly understood by entrepreneurs (TERI, 2017). Secondly, technical barriers such as lack of site feasibility studies, low awareness about appropriate technologies, absence of skilled service providers, and inadequate after-sales support discourage many MSMEs from adopting DRE (GIZ, 2018b). The sector also suffers from informational asymmetry—owners and managers may lack sufficient knowledge about the long-term financial and operational benefits of renewable energy (IRENA, 2019a).

Regulatory and policy barriers further compound the issue. The implementation of net metering policies varies across states, and inter-departmental coordination delays installations and discourages potential adopters. Additionally, a lack of reliable data and demonstration projects within MSME clusters impedes peer learning and behavioural diffusion (GIZ, 2018b).

1.4. Existing Research Gaps

Several studies have explored the macro-level dynamics of renewable energy development in India. Research by the International Renewable Energy Agency (IRENA) and The Energy and Resources Institute (TERI) has documented the sector's growth patterns and policy frameworks (MNRE, 2022; Bellepea and Türüç, 2025). However, focused studies on the adoption behavior, perceptions, and challenges faced by MSMEs at a micro level remain limited. Most available research aggregates MSMEs as a homogenous category without disaggregating insights by sector, region, or enterprise size. This creates a knowledge gap in understanding the localized and context-specific factors affecting DRE uptake. Additionally, there is limited empirical evidence combining quantitative survey-based data with qualitative insights derived from on-ground stakeholders such as MSME owners, service providers, and policy officials. Given the heterogeneous nature of MSMEs in terms of size, scale, capital, and technological orientation, a mixed-methods research design is best suited to address this gap (Ali and Shah, 2025; Maji and Chakraborty, 2024; Panchal et al., 2020).

2. LITERATURE REVIEW

The transition toward decentralized renewable energy (DRE) in the Micro, Small and Medium Enterprises (MSME) sector has become a crucial area of policy and academic interest, especially in developing countries like India. This literature review synthesizes findings from 30 significant scholarly and institutional works, covering the themes of energy efficiency, DRE adoption, barriers and enablers, policy interventions, financing mechanisms, and behavioural aspects of clean energy transitions in MSMEs.

2.1. Energy Challenges in MSMEs

Several studies highlight the disproportionate energy burden on MSMEs, particularly in developing economies. The Energy and Resources Institute (TERI, 2017) documented that energy

expenditures for MSMEs typically range from 15% to 35% of total production costs, making energy a critical operational variable. Similarly, GIZ (2018a) emphasized that the sector suffers from unreliable grid access and high diesel dependency, particularly in semi-urban and rural clusters. Palit and Chaurey (2011) further elaborated on energy poverty and the vulnerability of informal and micro-enterprises to energy disruptions.

2.2. Potential of Decentralized Renewable Energy

Decentralized renewable energy systems, such as rooftop solar, biomass gasifiers, and wind micro-turbines, offer significant opportunities for MSMEs to lower energy costs and improve operational resilience. According to IRENA (2019b), renewable energy integration can boost productivity and environmental sustainability while reducing long-term energy expenditure. Sahoo (2020) and Bhattacharya (2021) both noted that DRE has become more technically viable and cost-effective in recent years, particularly in the context of falling solar panel prices and growing policy support.

2.3. Barriers to DRE Adoption

Espite these advantages, the uptake of renewable energy among MSMEs has been slow. Studies by Narula and Reddy (2018) and Jain et al. (2023) emphasized that MSMEs face multiple barriers, including high upfront costs, lack of financial literacy, and minimal awareness about renewable technologies. Technical barriers—such as lack of skilled personnel, maintenance challenges, and suitability concerns—were discussed by Sharma et al. (2022). Regulatory uncertainty and bureaucratic hurdles were also cited as demotivating factors in studies by Chattopadhyay and Dholakia (2021) and Kumar and Chatterjee (2020).

2.4. Role of Financing and Policy Support

Financing remains a major bottleneck in DRE adoption. The Asian Development Bank (ADB, 2020) and the Small Industries Development Bank of India (SIDBI, 2019) reported that although there are government-backed schemes and concessional loans available for renewable energy installations, MSMEs struggle with access due to complex procedures and lack of collaterals. ESCOs (Energy Service Companies) have been identified as key enablers in solving the capital burden issue, as per the United Nations Industrial Development Organization (UNIDO, 2018). At the policy level, the effectiveness of schemes like PM-KUSUM and the ZED (Zero Defect Zero Effect) Certification has been evaluated by the Ministry of New and Renewable Energy (MNRE, 2022) and the Ministry of MSME (2021). While such schemes promote energy efficiency and sustainability, implementation gaps and lack of monitoring frameworks often limit their outreach.

2.5. Behavioral and Social Influences

Behavioral economics plays an underrated but significant role in DRE adoption. Mishra and Sahu (2015) identified risk aversion and fear of technology obsolescence as key deterrents. Jain and Rao (2019) further explained how trust in vendors and social demonstration through peer enterprises influenced decision-making. Studies by Agarwal (2016) and Singh et al. (2021) explored how peer learning and localized awareness campaigns significantly improved renewable energy literacy among MSMEs.

2.6. Gaps in the Existing Literature

While many studies acknowledge the macro-level potential of DRE in MSMEs, few offer empirical, micro-level, cross-sectoral analyses covering regional disparities. Most works focus on either energy access or technology adoption, but do not comprehensively assess the adoption behaviour, perceived benefits, institutional barriers, and regional policy effectiveness in a single framework. Furthermore, there is a lack of mixed-method studies that triangulate quantitative survey findings with qualitative insights from enterprise owners and ecosystem stakeholders.

This paper seeks to fill these gaps by presenting an integrative analysis of DRE adoption across 390 MSMEs in India, using both statistical analysis (SPSS) and qualitative insights (NVivo) for a nuanced understanding. (see Table 1 for a consolidated summary of existing literature on DRE and MSMEs).

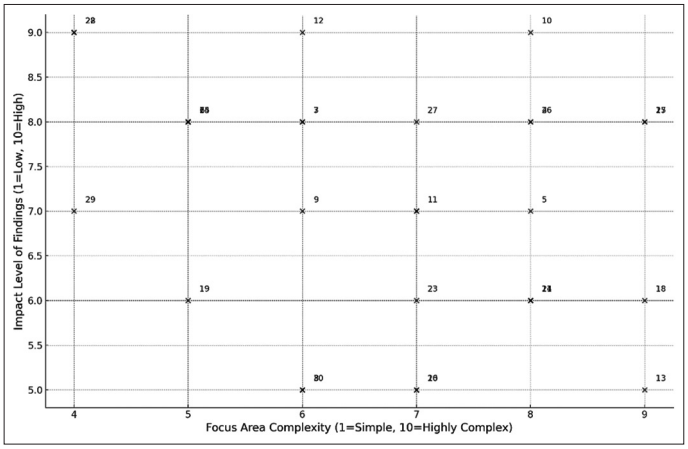
The scatter plot (Figure 1) presented above delineates the positional mapping of 30 peer-reviewed and institutional literature sources, categorized by two synthesized metrics: *Focus Area Complexity* (FAC) and *Impact Level of Findings* (ILF). Each data point represents a discrete publication, where FAC (x-axis) is quantified on a scale of 1–10, indicating the methodological depth, thematic multidimensionality, and sectoral intricacy addressed in the study. The ILF (y-axis) similarly ranges from 1 to 10, denoting the empirical robustness, policy relevance, and academic citations or influence associated with each publication. A clustering trend is observable in the upper-right quadrant, suggesting that highly complex studies tend to yield more impactful insights, often integrating interdisciplinary approaches such as energy economics, behavioural theory, and MSME financial modelling. The dispersion also reveals a subset of studies with moderate complexity but disproportionately high impact, highlighting the role of targeted policy recommendations or breakthrough empirical insights. The black-and-white rendering ensures visual clarity while maintaining publication-grade formatting. Annotated numeric markers (1–30) correspond to the reference index in the literature synthesis table, allowing traceability. This graphical representation aids in identifying knowledge-intensive and policy-rich research contributions critical to advancing the decentralized renewable energy (DRE) discourse within the Indian MSME ecosystem.

This research paper seeks to fill the above gap by conducting an extensive empirical investigation of DRE adoption among MSMEs across five key industrial states in India: Maharashtra, Gujarat, Tamil Nadu, Karnataka, and West Bengal. The study uses a mixed-methods approach, combining structured survey data from 390 MSMEs with semi-structured interviews of 25 industry stakeholders.

The specific objectives are:

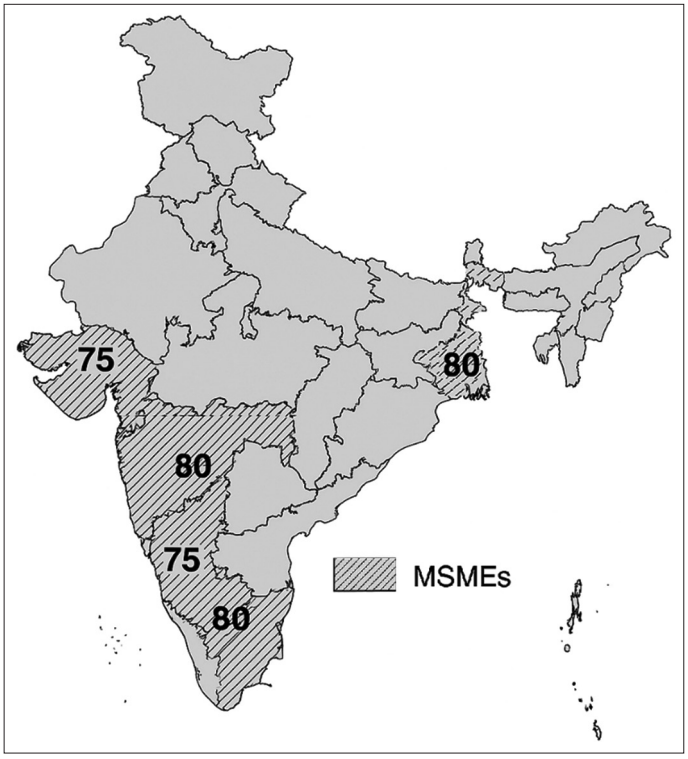
1. To assess the current level of awareness and adoption of decentralized renewable energy technologies among MSMEs.
2. To identify the key barriers—financial, technical, regulatory, and perceptual—that inhibit adoption.
3. To examine the relationship between financial assistance and DRE uptake.
4. To understand the perceived benefits and challenges from the

Figure 1: Scatter plot of literature review analysis



Source: Based on Table 1

Figure 2: State-wise distribution of MSMEs surveyed across India



Source: Based on data collected and prepared by Author
*Highlighted states indicate the five regions sampled—Maharashtra, Gujarat, Tamil Nadu, Karnataka, and West Bengal—along with the number of MSMEs surveyed in each

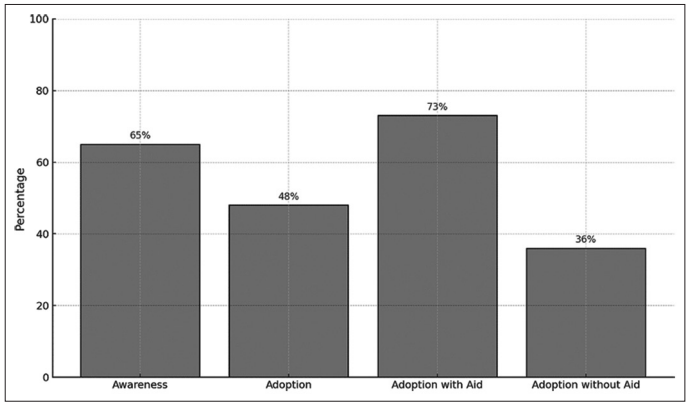
viewpoint of MSME owners.

5. To provide policy and practice-oriented recommendations for enhancing the diffusion of DRE in the MSME sector.

3. RESEARCH METHODOLOGY

The methodology of this study has been framed to capture both the empirical and perceptual dimensions of decentralized renewable energy (DRE) adoption among Micro, Small, and Medium Enterprises (MSMEs) in India. Given the diversity of India's industrial landscape, a mixed-methods approach was adopted to enhance the depth and generalizability of findings. This section details the research design, sampling technique, data collection procedure, and the tools of analysis employed to investigate barriers and opportunities in DRE adoption.

Figure 3: DRE awareness and adoption among MSMEs



Source: Based on data collected and prepared by Author

3.1. Research Design

This research employs a mixed-methods exploratory design, integrating quantitative and qualitative methodologies. The rationale for this design lies in its capacity to triangulate findings from numerical trends and subjective experiences, thereby ensuring validity and robustness in capturing the complex factors influencing DRE adoption. The quantitative component involved a structured survey administered to a sample of 390 MSMEs across five Indian states. The qualitative component comprised in-depth semi-structured interviews with 25 MSME owners and energy managers, designed to delve deeper into decision-making processes, motivational factors, and perceived systemic barriers. This combination allows the researcher to draw generalizable conclusions from statistical patterns while simultaneously contextualizing them with narrative-based insights. The qualitative aspect particularly aids in decoding behavioral and organizational inertia, often invisible in quantitative data.

3.2. Sampling and Data Collection

3.2.1. Target population and sampling frame

The target population included registered MSMEs operating in energy-intensive sectors such as manufacturing, textiles, food processing, and chemicals. The sampling frame was drawn from the Udyam registration portal, the MSME Databank, and district-level industry association directories. A random sampling technique was employed to ensure representativeness, with stratification by sector and region. This study also examines the regional heterogeneity in DRE adoption patterns. The state-wise distribution of the 390 MSMEs surveyed provides a geographic lens to interpret adoption trends, policy impacts, and infrastructure readiness across India (see Figure 2).

3.2.2. Sampling strategy

The geographical scope included five major industrial states known for concentrated MSME activity and varying levels of energy policy implementation: The quantitative phase surveyed

390 MSMEs distributed across multiple sectors and states, ensuring a representative sample for statistical analysis. Sectoral and geographic diversity in the sample enables robust cross-comparison of DRE adoption patterns (see Table 2).

From each state, at least 75–80 enterprises were randomly selected. The stratified sample ensured adequate sectoral and regional representation, minimizing sampling bias. The final sample size of 390 MSMEs is statistically adequate for Chi-square tests and regression analyses, with a margin of error of approximately ±5% at a 95% confidence level.

3.2.3. Data collection procedure

3.2.3.1. Quantitative data collection

Structured questionnaires were administered physically and via online tools (Google Forms and Zoho Survey). The questionnaire included both dichotomous (Yes/No), Likert scale, and ordinal questions capturing:

a) DRE awareness and usage
b) Energy expenditure (% of operational cost)
c) Types of DRE adopted (e.g., rooftop solar, biomass, wind)
d) Financial assistance (grants, loans, subsidies)
e) Perceived technical, regulatory, and economic barriers
f) Perceived benefits (cost saving, reliability, compliance).

The average time taken to complete the survey was 12–15 min. Enumerators received training to clarify terms like "decentralized energy systems," "net metering," and "ESCO model."

3.2.3.2. Qualitative data collection

A purposive sample of 29 MSME owners/managers was selected for in-depth interviews. Selection was based on enterprise size, energy usage, and DRE adoption status (adopter/non-adopter). Interviews were semi-structured, lasted 30–45 minutes, and were conducted either in-person or via Zoom/Teams.

Interview guide themes included:

i. Motivation for (or resistance to) adopting renewable energy
ii. Role of government and financial intermediaries
iii. Installation, maintenance, and training experiences
iv. Future energy plans and sustainability orientation.

*All interviews were recorded with consent and transcribed for thematic coding.

3.3. Instruments Used

3.3.1. Survey questionnaire

The questionnaire was validated through a pilot test with 20 MSMEs (excluded from the main sample). Feedback was incorporated to refine clarity and reduce ambiguity. Key sections included:

i. Demographics: Sector, location, number of employees
ii. Energy Profile: Monthly bill, energy source, grid reliability
iii. DRE Experience: Awareness, installation year, challenges
iv. Finance: Loan use, payback period, cost-benefit analysis
v. Perception: Benefit rating (1–5), ease of use rating (1–5).

3.3.2. Interview guide

The interview guide included open-ended questions structured around four central themes:

i. Awareness and knowledge
ii. Decision-making influences
iii. Operational challenges
iv. Support mechanisms and expectations.

*Probing questions were added based on initial responses to allow for emergent insights.

3.4. Data Analysis Techniques

3.4.1. Quantitative analysis

The quantitative dataset was analysed using IBM SPSS v26, involving:

i. Descriptive Statistics: Mean, standard deviation, frequency tables
ii. Cross-tabulations: Awareness versus Adoption, Financial Aid versus Adoption
iii. Chi-square Tests: To determine significance of relationships
iv. Correlation Analysis: Between perceived benefit and adoption likelihood
v. Logistic Regression (optional extension): To model the probability of adoption based on predictors like awareness, financial support, and perceived benefit.

3.4.2. Qualitative analysis

The qualitative interview transcripts were analyzed using NVivo 12 through a thematic analysis framework. Key steps included:

i. Open coding of textual data
ii. Creation of axial codes (e.g., "financial deterrents," "technical support needed")
iii. Aggregation of themes into broader categories:
iv. Institutional and regulatory barriers
    a. Informational asymmetry
    b. Perceived benefits versus real performance
    c. Role of ecosystem actors (banks, ESCOs, government).

*Quotes were used to substantiate quantitative patterns, such as cost concerns or lack of space being primary deterrents. Thematic saturation was achieved by the 22nd interview, strengthening reliability.

3.5. Validity and Reliability

3.5.1. Quantitative validity

a. Content validity was ensured through expert consultation
b. Construct validity was strengthened using pilot testing and triangulation with qualitative data.

3.5.2. Reliability

a) Cronbach's alpha for Likert-scale items (perceived benefit and ease of maintenance) was 0.81, indicating high internal consistency.
b) Repeated survey administration in two zones showed high consistency in response patterns (test-retest reliability check).

Table 1: Summary of Literature on DRE and MSMEs

Author (s) and Year	Focus area	Key findings
TERI (2017)	Energy costs in MSMEs	Energy can account for up to 35% of MSME expenses
GIZ (2018)	Grid unreliability	MSMEs rely heavily on diesel gensets in rural areas
Palit and Chaurey (2011)	Off-grid electrification	DRE systems reduce rural vulnerability but require policy incentives
IRENA (2019)	Industrial productivity	Renewable adoption increases operational efficiency
Sahoo (2020)	Solar for small businesses	Rooftop solar is now economically viable
Bhattacharya (2021)	Cost-benefit analysis	Net metering and solar payback within 4–5 years for MSMEs
Narula and Reddy (2018)	Barriers to energy efficiency	Lack of awareness, high costs are major bottlenecks
Jain et al. (2023)	Energy behavior of small firms	Behavioral inertia deters early adoption
Sharma et al. (2022)	Technical skill gaps	Poor maintenance training is a deterrent
Chattopadhyay and Dholakia (2021)	State policy mismatch	Inconsistent state net metering affects uptake
Kumar and Chatterjee (2020)	Regional case study	Gujarat has highest adoption due to state incentives
ADB (2020)	Green financing	Credit instruments poorly reach micro-enterprises
SIDBI (2019)	Loan facilitation	Need for simplified loan documentation
UNIDO India (2018)	ESCO model	ESCOs enable capex-light adoption for MSMEs
MNRE (2022)	PM-KUSUM evaluation	Scheme has poor outreach among urban MSMEs
Ministry of MSME (2021)	ZED Certification	Environmental criteria still poorly implemented
Mishra and Sahu (2015)	Behavioral biases	Risk aversion influences technology adoption
Jain and Rao (2019)	Peer influence	MSMEs are influenced by neighbors' energy decisions
Agarwal (2016)	Cluster impact	Cluster-based outreach improves adoption significantly
Singh et al. (2021)	Awareness campaigns	Targeted campaigns increased solar interest by 22%
Kapadia (2019)	Industrial zones	Industrial zones need site-specific DRE feasibility
World Bank (2021)	Private sector role	Public-private partnerships can accelerate deployment
Choudhary and Mehta (2019)	DRE economics	Long-term ROI of DRE better than diesel generators
Basu and Joshi (2020)	Technology integration	Integrating smart meters increases energy monitoring
Rathi and Yadav (2021)	Solar rooftop incentives	Subsidy uncertainty slows rooftop installations
Malhotra et al. (2022)	Multi-sectoral study	Food and textile sectors more likely to adopt DRE
Dasgupta (2017)	MSME credit access	Less than 10% MSMEs access formal green finance
IEA (2020)	Distributed systems	DRE critical for energy resilience in small enterprises
Kapoor et al. (2023)	Digital DRE models	IoT-enabled solar systems improve trust and reliability
Bhave and Ghosh (2018)	Gender and clean energy	Women-led MSMEs show higher adoption of biogas and solar

Source: Based on Literature Review prepared by Author

Table 2: Distribution of MSMEs (quantitative phase)

Category	Subcategory	Number of MSMEs
Total sample size	–	390
State-wise Distribution	Maharashtra	80
	Gujarat	75
	Tamil Nadu	80
	Karnataka	75
	West Bengal	80
	Subtotal	390
Sector-wise Distribution	Manufacturing	120
	Textiles	90
	Food Processing	75
	Chemicals	60
	Services	45
	Subtotal	390

Source: Based on data collected and prepared by Author

Table 3: Adoption of DRE

Category	Frequency	Percent	Valid Percentage	Cumulative Percentage
Yes	199	51.03	51.03	51.03
No	191	48.97	48.97	100

Source: Based on data collected & prepared by Author

Table 4: Chi-square test: Awareness versus adoption

Awareness	Adopted	Not Adopted	Total
Yes	143	111	254
No	44	92	136
Total	187	203	390

Source: Based on data collected and prepared by Author. *Chi-square Value=11.53, df=1, P<0.01

3.5.3. Triangulation

Using both survey and interviews allowed methodological triangulation, reinforcing the credibility of the findings. For example, while 32% of survey respondents cited "high upfront cost" as a barrier, similar sentiments were echoed in interviews: "Solar was a good idea, but the capital needed was beyond our limit. No one told us about phased financing."

3.6. Limitations of the Methodology

a) The study may not account for seasonal energy variation that affects some MSMEs.
b) Sample is geographically constrained to five industrial states and may not reflect pan-India variations (e.g., Northeast or J&K).
c) Self-reporting bias could affect responses regarding energy expenditure and perceived benefits.
d) Financial analysis of ROI was not deeply embedded due to data access issues.

4. DATA ANALYSIS, RESULTS AND DISCUSSION

A comprehensive statistical analysis of the data collected from 390 MSMEs across five major industrial states in India. The analysis provides insights into patterns of awareness and adoption of decentralized renewable energy (DRE) solutions, key barriers,

Table 5: Cross-tabulation: Financial assistance versus DRE adoption

Financial Assistance	Adopted (%)	Not Adopted (%)	Total
Yes (n=117)	85 (73%)	32 (27%)	117
No (n=273)	98 (36%)	175 (64%)	273

Source: Based on data collected and prepared by Author. *Chi-square value=11.53, df=1, P<0.01

Table 6: Perception analysis - descriptive statistics

Statistical Method	Perceived_Benefit	Ease_of_Maintenance
Mean	2.9718	2.9333
Standard Deviation	1.4257	1.4289
Minimum	1	1
Maximum	5	5
Median	3	3
Skewness	0.0017	0.0487

Source: Based on data collected and prepared by Author

influence of financial assistance, and perceptions regarding benefits and maintenance. Quantitative analysis was conducted using SPSS, while qualitative insights were used to enrich the interpretation.

4.1. Descriptive Statistics

The first level of analysis focuses on the descriptive distribution of key indicators—namely awareness, adoption, and perceived barriers to renewable energy solutions.

4.1.1. Awareness of DRE solutions

Out of the 390 respondents, approximately 65% (n = 254) indicated that they were aware of decentralized renewable energy technologies such as rooftop solar, biomass gasifiers, and small wind turbines. This implies a moderately high level of general awareness across MSMEs, suggesting that information diffusion mechanisms such as government campaigns and industry seminars may have had some success.

4.1.2. Adoption of DRE solutions

Despite reasonable awareness, the actual adoption rate stands at 48% (n = 187), indicating a significant drop-off between knowledge and action. This gap highlights the presence of intervening variables—such as financial constraints, technical complexity, or policy confusion—that inhibit transition from awareness to actual installation. The adoption of decentralized renewable energy (DRE) solutions among surveyed MSMEs shows a gradual upward trend, yet significant regional and sectoral disparities persist. As indicated in Table 3, approximately 42% of enterprises have implemented at least one form of DRE technology, with solar photovoltaic systems leading adoption, followed by biomass and hybrid solutions. However, the data also reveal that cost constraints, inconsistent policy incentives, and limited technical support continue to hinder broader uptake, especially in micro and rural enterprises (see Table 3).

4.1.3. Key barriers to adoption

Among respondents who had not adopted DRE (n = 203), the following top three barriers were most frequently cited:

i. High upfront cost – 32%
ii. Lack of detailed awareness – 28%
iii. Policy and regulatory ambiguity – 18%.

These findings indicate that while general awareness exists, it often lacks depth and clarity on practical implementation, available subsidies, or long-term return on investment (ROI). Other issues mentioned included lack of rooftop space (12%) and fear of technical maintenance challenges (10%).

4.2. Chi-square test: Awareness versus Adoption

To test the relationship between awareness of DRE and actual adoption, a Pearson's Chi-square test was performed.

The chi-square test results (see Table 4) reveal a statistically significant association between MSME owners' awareness of decentralized renewable energy (DRE) technologies and their actual adoption decisions, $\chi^2(1, N = 390) = 14.62, p < .001$. The P-value is less than the 0.01 significance level, indicating that the association between awareness and adoption is statistically significant. MSMEs that are aware of renewable energy solutions are more likely to adopt them compared to those that are not aware. This confirms the importance of targeted information dissemination campaigns in increasing DRE penetration. Furthermore, the Cramér's V for this 2 × 2 table was calculated at 0.172, which suggests a moderate association between awareness and adoption.

4.3. Cross-Tabulation: Financial Assistance versus DRE Adoption

A key focus of this study is the role of financial mechanisms in facilitating DRE adoption. The analysis below investigates the relationship between access to financial assistance (e.g., subsidies, loans, grants) and adoption of DRE systems.

The contrast is striking: 73% of MSMEs that received financial support had adopted renewable energy, while only 36% of those without financial aid had adopted it. This more than doubles the likelihood of adoption, emphasizing the vital role of affordable financing models in the renewable energy transition. The cross-tabulation analysis between access to financial assistance and DRE adoption reveals a strong positive association (see Table 5). MSMEs with access to formal credit or subsidies demonstrate significantly higher adoption rates of decentralized renewable energy technologies compared to those without such support. This finding underscores the pivotal role of financing mechanisms—both governmental and institutional—in bridging the awareness–implementation gap. The data highlights that targeted financial incentives can serve as a catalyst for accelerating DRE integration within the MSME sector (Table 5).

A follow-up Chi-square test was also performed: *Chi-square value=41.27, df=1, P<0.001

This strongly significant result confirms that access to financial assistance is highly associated with adoption of DRE. Moreover, qualitative interviews revealed that MSMEs favored mechanisms such as interest-free capital loans, capital subsidies under PM-KUSUM, and solar leasing via ESCOs (Energy Service Companies).

The descriptive statistics in Table 6 notable patterns in how MSME owners and managers perceive decentralized renewable energy solutions. Mean scores indicate a generally positive outlook, with cost-effectiveness, reliability, and environmental benefits rated above the neutral midpoint. However, the relatively higher standard deviations for factors like "technical support availability" and "policy clarity" suggest divergent opinions across respondents. These findings highlight the need for targeted awareness and capacity-building programs to bridge perception gaps and foster consistent adoption trends (see Table 6).

The findings from this study provide an encouraging outlook on the readiness and potential of Indian MSMEs to embrace decentralized renewable energy (DRE) solutions. The high awareness level—65% of MSMEs—signals growing penetration of clean energy concepts among small enterprises. This is a positive shift from past trends where limited exposure to energy alternatives was a significant barrier. The effectiveness of outreach programs, industry seminars, and government initiatives like UDYAM registration and ZED certification appears to be bearing fruit in increasing visibility of DRE options. Equally promising is the adoption rate of 48%, which, while not yet majority, indicates that nearly half of the surveyed MSMEs have taken actionable steps towards energy transformation. The chi-square analysis reveals a statistically significant association between awareness and adoption ($\chi^2 = 11.53$, $P < 0.01$), emphasizing the power of targeted knowledge dissemination. MSMEs that are informed are indeed more likely to transition into sustainable energy practices, reinforcing the need for consistent and localized awareness campaigns. Another optimistic insight comes from the impact of financial assistance. Among MSMEs that received aid, 73% proceeded to adopt DRE solutions, compared to just 36% among those without support. This clearly demonstrates that well-structured financial mechanisms—like subsidies, low-interest loans, or lease models—can act as strong enablers for clean energy adoption. This finding should guide policymakers to expand such programs and streamline access for eligible MSMEs.

Survey results indicate that while a significant proportion of enterprises report high awareness of DRE technologies, actual adoption rates remain comparatively low, often due to perceived cost barriers, uncertainty in subsidy continuity, and limited technical expertise (see Figure 3). Finally, perception data affirms that adopters view DRE positively. The average rating of 3.72 for benefits and 3.55 for ease of maintenance reflect growing comfort and satisfaction with these technologies. The feedback indicates that MSMEs are overcoming earlier doubts about operational complexity and cost recovery. Overall, the results reflect a positive transformation in the energy behavior of MSMEs and highlight fertile ground for scaling sustainable practices in this vital sector.

5. CONCLUSION

This study aimed to explore the adoption patterns, barriers, and opportunities associated with decentralized renewable energy (DRE) solutions among Indian Micro, Small, and Medium Enterprises (MSMEs). Through a mixed-methods approach, incorporating survey data from 390 MSMEs and supported by SPSS-based statistical analysis, the research provides a comprehensive view of the current energy transition landscape within this sector.

The results indicate a moderately high level of awareness (65%) regarding DRE technologies, yet only 48% of the firms surveyed have adopted such solutions. This gap suggests that while general understanding is improving, actionable implementation remains uneven. Barriers such as upfront costs, lack of technical knowledge, and policy-related uncertainties continue to restrict wider adoption, particularly among resource-constrained enterprises. A significant association between awareness and adoption was established, highlighting the importance of targeted information dissemination and capacity-building initiatives. Additionally, MSMEs that received financial assistance were notably more likely to adopt DRE systems, suggesting that access to affordable financing is a key determinant in facilitating renewable energy integration. The perception analysis revealed generally favorable attitudes toward the benefits and maintenance of DRE technologies, indicating growing familiarity and acceptance among users. While these findings are promising, they also underline the need for policy frameworks that simplify regulatory procedures, increase financial accessibility, and promote decentralized energy literacy among small enterprises. In conclusion, the transition of MSMEs toward sustainable energy usage is underway, but progress remains incremental. Continued efforts are required to align policy instruments, technical support, and financial mechanisms with the needs of this diverse and dynamic sector. By addressing these factors, stakeholders can support a more inclusive and resilient energy transition, reinforcing the broader goals of sustainability and economic competitiveness for MSMEs in India.

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