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### Adoption, impacts and social acceptance of clean energy technologies: A comprehensive review

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#### Abstract

The transition from fossil-fuel-based energy systems to clean and renewable energy technologies is central to achieving environmental sustainability, energy security, and public health improvements. This review synthesizes empirical and theoretical evidence from multidisciplinary studies on solar energy systems (rooftop solar, solar home lighting, off-grid solar, and solar water-pumping systems), other renewable technologies (biomass, biogas, wind, hydro, and geothermal energy), and broader clean energy frameworks. Drawing on studies conducted in India and selected international contexts, the review examines determinants of adoption, socio-economic and environmental impacts, policy and institutional mechanisms, behavioural and community acceptance dimensions, and persistent barriers. Evidence shows that government policy support, economic incentives, awareness, perceived functional benefits, reliability of conventional energy supply, and institutional facilitation strongly influence adoption, while socio-cultural factors, inequities, maintenance challenges, and limited participation in decision-making constrain diffusion. The review highlights the need for integrated policy design, inclusive governance, lifecycle sustainability, and context-specific interventions to scale clean energy equitably. Key research gaps and future directions are identified to guide scholars and policymakers toward a just and sustainable energy transition.

**Keywords:** Clean energy, renewable energy adoption, solar energy, geothermal energy, environmental sustainability, energy justice, community acceptance

#### Introduction

In the twenty-first century, escalating climate change, environmental degradation, and energy insecurity have intensified the urgency to transition toward clean and renewable energy systems. Fossil fuels continue to dominate the global energy mix, contributing substantially to greenhouse gas emissions, air pollution, and adverse health outcomes. Clean energy derived from renewable sources such as solar, wind, hydropower, biomass, and geothermal heat offers a pathway to decarbonization while supporting sustainable development goals.

India represents a critical case in the global energy transition. Despite rapid expansion of grid electrification, significant segments of rural and peri-urban populations experience unreliable supply and energy poverty. Consequently, decentralized renewable energy technologies, particularly solar-based systems, have emerged as viable complements or alternatives. Alongside solar energy, geothermal and other renewables play an increasing role in national and global energy strategies. Understanding the drivers, impacts, and social acceptance of these technologies is essential for effective scale-up.

This review integrates evidence from peer-reviewed articles, conference papers, policy-oriented studies, and doctoral

seminar material to present a comprehensive synthesis of clean energy adoption and sustainability outcomes.

#### Conceptual Framework and Theoretical Perspectives

Research on clean energy adoption draws on multiple theoretical lenses, including diffusion of innovations, technology acceptance models (TAM/UTAUT), energy justice, and socio-technical transition frameworks. Behavioral intention, shaped by awareness, perceived usefulness, ease of use, social influence, and facilitating conditions, is a recurring determinant of household and community adoption. Energy justice perspectives emphasize equity, affordability, participation, and distribution of benefits, while socio-technical approaches highlight the co-evolution of technology, institutions, and social practices.

#### Review Methodology

##### Review Design

This study adopts a narrative-systematic hybrid review design, integrating elements of systematic literature review with thematic narrative synthesis. This approach is appropriate given the interdisciplinary nature of clean energy research, which spans engineering, environmental science, social science, public policy, and health studies. The

objective of the review is not only to summarize existing literature but also to critically analyze determinants of adoption, impacts, and social acceptance of clean energy technologies.

### Data Sources and Literature Selection

The review is based exclusively on peer-reviewed journal articles, conference papers, policy reports, and doctoral seminar materials provided by the author. The core literature includes studies published between 2010 and 2024, covering national (India-focused) and international contexts. Major databases and publication platforms from which the reviewed studies originate include Science Direct, Springer, Taylor & Francis, Oxford University Press, Research Gate, and Google Scholar.

### Overview of Clean Energy Technologies

#### Solar Energy Technologies

Solar energy systems include rooftop photovoltaic (PV) installations, solar home lighting systems, solar lanterns, off-grid solar home systems, and solar water-pumping systems. These technologies are widely promoted in rural and agricultural contexts due to abundant solar resources, modularity, and declining costs.

#### Other Renewable Energy Technologies

Biomass cookstoves, biogas plants, wind energy, hydropower, and geothermal energy contribute to diversified clean energy portfolios. Geothermal energy, in particular, provides reliable baseload power and heat but faces unique social acceptance challenges related to land use, environmental perceptions, and community engagement.

### Determinants of Clean Energy Adoption

#### Economic and Policy Factors

Across studies, government policies subsidies, incentives, credit mechanisms, and supportive regulations emerge as the strongest predictors of adoption. Economic benefits such as reduced energy costs, income generation (e.g., surplus power sales), and productivity gains motivate households and farmers to invest in renewable systems.

#### Technical and Infrastructural Factors

Reliability of conventional grid supply, availability of after-sales service, maintenance infrastructure, and technology performance significantly affect sustained use. In rural contexts, poor service networks and spare-part availability remain critical barriers.

#### Awareness, Education, and Behavioral Factors

Awareness of environmental benefits, functional advantages, and long-term savings positively influences willingness to adopt and pay for clean energy. However, information asymmetries and misconceptions can hinder uptake.

#### Socio-Cultural and Equity Dimensions

Caste, income, occupation, and gender dynamics shape access to and benefits from clean energy technologies. Lower-income and marginalized groups often face higher barriers despite policy support, raising concerns of energy inequality.

### Socio-Economic and Environmental Impacts

#### Livelihood and Economic Outcomes

Evidence from rural India demonstrates improvements in lighting quality, time savings, educational outcomes, agricultural productivity, and income diversification following adoption of solar and other renewable technologies.

#### Environmental and Health Benefits

Clean energy technologies reduce reliance on fossil fuels and traditional biomass, thereby lowering greenhouse gas emissions, indoor air pollution, and associated health risks. Lifecycle assessments indicate that while solar technologies have some environmental impacts during manufacturing and disposal, their overall footprint is substantially lower than that of fossil fuels.

#### Community Acceptance and Governance

Community acceptance is a critical determinant of project success, particularly for large-scale renewable projects such as geothermal energy. Studies highlight that inadequate communication, exclusion from decision-making, perceived environmental risks, and inequitable benefit sharing can lead to resistance. Inclusive governance, transparent grievance mechanisms, and culturally sensitive engagement enhance acceptance and trust.

#### Barriers and Challenges

Despite progress, multiple challenges persist: high upfront costs, uneven policy implementation, weak rural supply chains, limited financing access, and social resistance. Technical issues such as system durability and maintenance further constrain long-term sustainability.

#### Research Gaps and Future Directions

Future research should prioritize longitudinal impact assessments, gender- and equity-focused analyses, comparative studies across renewable technologies, and integrated evaluations of environmental, social, and health outcomes. Strengthening interdisciplinary approaches will be essential for advancing clean energy transitions.

### Conclusion

The reviewed literature demonstrates that clean energy technologies play a vital role in promoting environmental sustainability, socio-economic development, and energy security. Adoption is strongly influenced by policy support, economic incentives, awareness, and institutional facilitation, while social equity and community participation determine long-term acceptance. A holistic, inclusive, and context-sensitive approach is required to scale clean energy systems effectively and equitably.

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