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Modeling the Drivers for Renewable Energy in Developing Economies: A Case Study of India

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ABSTRACT

Renewable energy sources provide sustainable alternatives for fulfilling the energy needs of developing economies. India, as a developing country, has taken important initiatives to promote renewable energy, driven by various factors. Increased awareness of clean energy options, growing concerns about environmental degradation, and the emphasis on Sustainable Development Goals (SDGs) are among the factors encouraging countries to consider renewable energy as a viable and sustainable alternative to fossil fuels. This paper aims to explore the key factors that facilitate the development and adoption of renewable energy as a clean and sustainable energy source. It also seeks to examine the hierarchical relationships among these enablers and analyze the connections between them. To achieve these goals, the study employs Total Interpretive Structural Modeling (TISM) and Fuzzy MICMAC approaches. The findings identify six main enablers: environmental, institutional, regulatory, economic, technological, and social factors. The TISM model reveals three levels of hierarchy among these enablers, while the Fuzzy MICMAC analysis categorizes them into driver and dependent clusters. The discussion contextualizes these results within India. The study offers significant insights for theory, management, and societal progress.

1. INTRODUCTION

Fossil fuels remain the primary energy source in many nations, and with ongoing growth and economic development, countries continue to depend on them for a consistent energy supply. However, their use presents significant challenges, most notably the rapid increase in carbon dioxide emissions. Carbon dioxide, a well-known byproduct of fossil fuel combustion, has raised global concern due to its role in climate change (Gyimah et al. 2022, Wang et al. 2023). The rise in CO_2 levels has been a focal point of discussion in various international forums. Developing economies, in particular, exhibit high dependence on fossil fuels (Gyimah et al. 2022), leading to extensive chemical emissions that have severe environmental impacts (Li et al. 2020, Yang et al. 2022). Climate activists consistently emphasize the importance of balancing economic growth with ecological sustainability. Both developing and developed nations are re-evaluating their energy production and consumption patterns to achieve a better balance between growth and environmental preservation (Chenyang et al. 2023). Historical events such as the oil crises of the 1970s, along with increasing awareness of global warming and climate change, stimulated efforts to find sustainable alternatives to fossil fuels (Lal & Kumar 2022). Growing recognition of clean energy sources, concerns about environmental degradation, and the goals outlined in the Sustainable Development Goals (SDGs) have further motivated countries to adopt renewable energy as a viable alternative. Over recent decades, nations have actively explored renewable energy sources and initiated various projects in this field. The SDGs have gained significant emphasis, prompting countries to align their policies accordingly, which has accelerated the adoption of sustainable options like renewable energy to meet national energy needs. Renewable energy offers social, economic, and environmental benefits (Virah-Sawmy & Sturmberg 2025) and facilitates a transition to cleaner energy for all. Expanding renewable energy infrastructure enhances access and affordability, especially in remote areas, thereby contributing to poverty reduction and improved livelihoods (Charfeddine & Kahia 2021). Investing in renewable energy technologies also fosters innovation and supports the development of sustainable infrastructure.

Countries are increasingly exploring various forms of renewable energy. One particularly popular option is solar energy. With proper prioritization and strategic planning, solar power can serve as a valuable complement to existing energy needs (Wang et al. 2024). Despite its abundance, solar energy faces challenges related to storage and transfer (Ukoba et al. 2024), requiring significant initial investments in equipment for heating, storage, and transmission. Nonetheless, the advantages of solar energy are compelling, including its plentiful supply, long-term cost-effectiveness, and status as a clean energy source, making it a promising option for sustainable economic growth (Kishore et al. 2025, Maka & Alabid 2022). Another widely utilized renewable energy source is wind power, which research highlights as a sustainable long-term solution. Wind turbines enable electricity generation, and the benefits include scalability for various applications, environmental friendliness, and suitability for coastal and high-wind regions (Boadu & Otoo 2024, Liu et al. 2025). Additionally, countries are investing in geothermal energy, derived from natural heat beneath the Earth's surface. These resources are located at various depths—ranging from shallow ground to several kilometers below the surface—and are used in agriculture, heating, and cooling applications (Pambudi & Ulfa 2024, Rohit et al. 2023). Hydrogen energy also plays a significant role, with hydrogen gas being produced from sources such as oil, natural gas, biomass, and coal (O[DOI]-Yorke et al. 2025). Based on geographic, resource, and feasibility considerations, nations are focusing efforts to harness available energy sources to meet their needs while demonstrating environmental responsibility.

1.1. Renewable Energy in Developing Economies

A significant portion of the world's population lives in developing countries, which play an essential role in the global economy due to their growing economies and expanding populations. These countries differ from developed nations mainly in terms of economic growth and energy stability, with the latter being primary focus areas for developing nations. Their development strategies are largely centered around economic expansion (Raza et al. 2025). The Global Carbon Project highlights China, the United States, India, Russia, and Japan as the leading countries in carbon dioxide emissions. Developing countries' energy choices heavily influence their progress, and much of their economic growth has been driven by fossil fuels (Briera & Lefèvre 2024, Chaikumbung 2025). However, there is an increasing push towards investing in renewable energy sources, which promise long-term benefits including energy security, reduced import costs, new economic opportunities, and better access in rural areas. India has actively invested in renewables since the 1980s, launching numerous initiatives to promote solar and wind energy (Lal et al. 2025). It is among the world's largest producers of renewable energy and has committed to generating 50% of its total energy from non-fossil fuel sources by 2030 (Khare et al. 2023). Additionally, India announced its goal to become carbon neutral by 2070 during the twenty-sixth UN Climate Conference in Glasgow, demonstrating its environmental commitment (Alam et al. 2023). In 2020, renewable energy accounted for 38% of India's total installed capacity.

As a developing nation, Bangladesh is experiencing rapid growth in energy demand. The country views renewable energy as a vital solution to replace fossil fuels. Government institutions in Bangladesh have begun promoting large-scale renewable energy initiatives (Joardee et al. 2024). Bangladesh aims to replace its fossil-fuel fleet with solar-powered vessels. The country has a robust off-grid renewable energy system, with approximately 6% of its energy needs met by renewable sources. To support this, the government has taken measures to encourage electric vehicles by developing solar charging stations (Mahbub & Islam 2023). A study by Islam et al. (2022) identified demographic shifts, urbanization leading to an environmentally conscious population, and technological progress as key drivers behind increased renewable energy consumption. Bangladesh's institutional and regulatory frameworks have prioritized establishing renewable energy plants, leveraging the country's geographical advantages. As a semi-tropical nation with year-round sunlight, Bangladesh offers multiple incentives to public and private developers to promote renewable energy projects (Hossain et al. 2024). Meanwhile, Sri Lanka has set ambitious targets for achieving energy independence. Its primary electricity sources include thermal power, hydroelectricity, and other non-conventional renewable resources (Koswatte et al. 2024). Investment in renewable energy and strategic planning in developing economies can enhance energy security, reduce dependency on imports, foster economic growth, create jobs, improve access to electricity and basic services, and support sustainable long-term development. From a societal perspective, a cleaner environment for future generations and job creation through funded renewable projects are key factors fostering a positive outlook on renewable energy in Sri Lanka (Herath et al. 2022).

1.2. Rationale and Objectives of the Study

It is essential to find a balance between economic growth and environmental conservation. Energy production, transmission, and consumption are critical to a country's development, particularly in emerging economies like India. As the population grows, along with industrialization and urbanization, India's energy needs are projected to rise substantially in the coming years. India has set an ambitious goal to reduce its reliance on fossil fuels and lower its carbon footprint. While previous research on renewable energy has explored general drivers of its adoption, this study will concentrate on India-specific enablers that demonstrate how India is working to meet its future energy demands while decreasing dependence on fossil fuels. Additionally, past studies have examined these enablers individually, this research aims to integrate them into a comprehensive framework and analyze their interconnections. With this context, the study's objectives are:

O1: To analyze the key drivers that aid the implementation of renewable energy sources with special reference to India.

O2: To interpret the critical linkages between the identified enablers through a comprehensive framework using the Total Interpretive Structural Model (TISM).

O3: To infer the nature of linkages between the identified enablers using Fuzzy MIC MAC analysis.

2. BACKGROUND RESEARCH

This section examines the key constructs that facilitate the implementation of renewable energy in India, based on a comprehensive literature review. Environmental and geographical factors play a crucial role in influencing renewable energy adoption (Nieboer et al. 2025, Obuseh et al. 2025). Regions characterized by minimal cloud cover, abundant sunlight, and low population density are particularly suitable for solar power generation. The plentiful sunshine makes solar energy storage highly feasible (Erol et al. 2024). India, with its diverse geography and climate zones (Beck et al. 2018), possesses significant potential for renewable energy. Its tropical location ensures extensive solar and wind resources. Effective harnessing of wind energy depends on environmental factors such as consistent wind patterns, mountain ranges, or coastal areas, with an average wind speed of at least 13 mph (Vaidya 2025). Hydroelectric power relies on high rainfall and mountainous terrain, while biomass energy depends on agricultural outputs and byproducts (Dashtpeyma & Ghodsi 2021). The country's varied landscape, including mountain ranges, rivers, ample sunshine, and monsoon rains, creates ideal conditions for multiple renewable sources. Institutional enablers, such as policies, reforms, government initiatives, and private sector participation, further support renewable energy deployment (Apolonia & Simas 2021). In India, collaboration between the government and private players has bolstered renewable energy projects. The nation is committed to reducing greenhouse gas emissions and scaling up renewable energy efforts on a global stage. National policies offer financial incentives that motivate corporations to invest in renewable energy (Mohammadi & Mohammadi 2024, Rincón et al. 2021). Decentralized policies foster support for participatory energy planning. Effective regulatory frameworks are essential to oversee the implementation of renewable energy initiatives. In India, the Ministry of New and Renewable Energy (MNRE) is the key agency responsible for renewable energy policies, playing a crucial role in promoting wind energy through policy support and a favorable regulatory environment. MNRE has introduced generation-based incentives, renewable purchase obligations, competitive bidding, and other reforms to stimulate wind energy development (Kumar et al. 2022).

Overcoming institutional constraints is essential for effective stakeholder engagement in sustainable decision-making for renewable energy. Similarly, building institutional capacity is crucial for raising awareness (Wretling et al. 2021). The Solar Energy Corporation of India (SECI), a Central Public Sector Undertaking under MNRE, is dedicated to capacity building for large-scale solar, wind, and hybrid projects.

Regulatory enablers include policies that ensure long-term contracts, providing renewable energy investors with secure returns (Oduro et al. 2025). Regulations permitting green credits and tradable certificates offer benefits to companies adopting renewable energy. The National Renewable Energy Act (NREA) in India establishes a legal framework and trajectory for renewable energy expansion. The renewable purchase obligation requires a certain percentage of energy procurement from renewable sources.

Technology is vital to renewable energy development. Regulatory frameworks should promote grid modernization to facilitate efficient installation, maintenance, and flexibility, enabling effective management of renewable sources. Technological innovations can help lower energy consumption and reduce reliance on fossil fuels. They support energy storage, improve access to clean energy, and enhance grid stability, contributing to a sustainable energy system (Behera et al. 2024). Renewable energy technologies (RETs) are key in advancing environmental sustainability (Tabrizian 2019). Technological advances significantly impact renewable energy (Tigabu 2018). It is essential to deploy technologies that enable energy storage, smart grids, and power electronics.

Financial incentives and subsidies serve as economic enablers, encouraging the shift to renewable sources (Guy 2022, Hao & Khan 2025). Numerous central and state government schemes offer subsidies and incentives, such as the flagship rooftop solar program "PM Surya Ghar: Muft Bijli Yojana," which supports residential rooftop solar installations. Additionally, schemes provide up to 30% subsidies for farmers using solar pumps. Policies like feed-in tariffs (Kurbatova et al. 2023, Azhgaliyeva & Mishra 2022), which boost investment in clean energy, and renewable portfolio standards (Joshi 2021, Feldman & Levinson 2023), which mandate a minimum percentage of power from renewable sources, promote environmental sustainability (Malik et al. 2019).

Strong public awareness and support are essential for the successful adoption of renewable energy sources. Engaging communities positively by raising awareness of environmental sustainability through renewables encourages acceptance (Opstal & Smeets 2022, De Simone et al. 2025). Local organizations play a vital role in sensitizing communities, thus aiding the mobilization of community-led projects (Granit 2023). Green governance fosters trust, which enhances community confidence and acceptance. Additionally, job creation for local populations is a key factor contributing to regional economic development. Examples in India include solar cooperatives, village-level biomass, and biogas plants, which actively involve local communities in renewable energy initiatives.

Table 1 presents the identified enablers, along with their descriptions and contributing authors.

3. MATERIALS AND METHODS

The study employs a mixed research approach that integrates both qualitative and quantitative analyses. The qualitative data were derived from a comprehensive literature review, the Delphi technique, and case study discussions focused on India. Quantitative methods utilized include Total Interpretive Structural Modeling (TISM) and Fuzzy MICMAC analysis. Initially, the authors examined existing literature from databases such as Scopus, Web of Science, EBSCOhost, and Google Scholar, reviewing both national and international studies to encompass all relevant sources. Recurrent themes were identified as key enablers of successful renewable energy implementation. The team collaboratively determined the final list of enablers, which were then validated through expert input. A structured Delphi method was employed to both identify and confirm these enablers. Experts were selected based on predefined criteria, including a minimum of five years of experience in renewable energy policy, sustainability, or related fields. Participants included academicians and professionals from the private sector and government. Academic experts demonstrated their expertise through peer-reviewed publications in relevant areas. A total of twenty-five experts with pertinent experience were identified, with eighteen agreeing to participate (Table 2). These experts came from academia, government, policy sectors, and industry, all possessing relevant experience in renewable energy and sustainable development. The experts were assured of anonymity and confidentiality. Informed consent was obtained before the interview. They completed a semi-structured questionnaire and participated

Table 1: Details of identified enablers.

Enabler Nomenclature	Enabler Name	Description	Key Authors
Enb1	Environmental Enablers	The enabler discusses the country's geographical and climatic conditions that support renewable energy initiatives.	Nieboer et al. 2025, Obuseh et al. 2025, Erol et al. 2024, Vaidya 2025, Dashtpeyma & Ghodsi 2021.
Enb2	Institutional Enablers	The enabler highlights forums, platforms, governance initiatives, and agencies that improve the ease of renewable energy implementation.	Apolonia et al. 2021, Rincón et al. 2021, Dlamini 2023, Wretling et al. 2021.
Enb3	Regulatory Enablers	The enabler looks at policies, regulators, and certificates that authenticate renewable energy practices and help build trust.	Oduro et al. 2024, Agupugo et al. 2022, Tian et al. 2024.
Enb4	Technological Enablers	This enabler discusses digitalization, grid modernization, energy storage technologies, and renewable energy technologies that are essential.	Hwang & Venter 2025, Eleksiani et al. 2025, Tabrizian 2019, Agupugo et al. 2022, Tigabu 2018
Enb5	Economic Enablers	The enabler looks at incentives, subsidies, feed-in tariffs, and renewable portfolio standards that help to attract investors and corporations for renewable energy investment and adoption.	Guy 2022, Hao & Khan 2025, Kurbatova et al. 2023, Azhgaliyeva & Mishra 2022, Joshi 2021, Feldman & Levinson 2023.
Enb6	Social Enablers	The enabler elaborates on the role of local communities, local organisations, and community engagement, which are crucial.	Opstal & Smeets 2022, De Simone et al. 2025, Granit 2023, Tian et al. 2024.

in three iterative rounds of interaction. In the first round, the experts validated the identified enablers through a monitored questionnaire and follow-up interviews. These six enablers were rated on a scale of 1 to 5; a mean score of 3 or higher was required for validation, as shown in Table 3. During the second round, the experts evaluated the contextual relationships and the direction of influence among the enablers, as depicted in the structural self-interaction matrix (Table 4). In the third round, they discussed the associability of the variables (Table 11).

The identified six enablers were validated through a monitored questionnaire with further interview discussions. A scale of 1 to 5 was used to rate the enablers; a mean score of greater than 3 was used for validation, as shown in Table 3.

3.1. Data Analysis and Interpretation

In the subsequent phase, the steps defined by TISM were employed to develop the interpretive model, which uncovered the hierarchical relationships among the identified enablers. TISM extends the well-established Interpretive Structural Modelling (ISM) technique, used to determine hierarchical relationships among interacting variables. This method is widely accepted and especially valuable when there is limited existing literature. It is preferred over other modeling techniques because it is interpretive—relying on the knowledge and experience of field experts. Their opinions are structured to illustrate the hierarchy among variables, facilitating the development of a conceptual framework or model.

3.2. Structural Self-Interaction Matrix (SSIM)

The SSIM table is constructed based on the knowledge, experience, and opinions of experts. These experts completed a questionnaire designed to explore the relationship dynamics among the identified enablers. According to TISM, the row is labeled as “i” and the column as “j”; the relationship between

Table 2: Summary of experts.

Expert	Years of relevant experience	Type of sector	Designation
Expert 1	5-10 years	Industry-Government	Energy Economist
Expert 2	11-15 years	Industry-Government	Project Manager
Expert 3	5-10 years	Industry-Private	ESG officer
Expert 4	15-20 years	Academia-Government	Professor and Researcher
Expert 5	15-20 years	Academia-Private	Professor and Researcher
Expert 6	Above 20 years	Industry-Government	Senior Operations Manager
Expert 7	5-10 years	Academia-Government	Assistant Professor-Sustainability
Expert 8	15-20 years	Industry-Private	Fund Manager
Expert 9	5-10 years	Academia-Private	Junior Research Fellow
Expert 10	15-20 years	Industry-Government	Senior Project Manager
Expert 11	5-10 years	Academia-Private	Assistant Professor-Sustainability
Expert 12	15-20 years	Industry-Government	Senior Consultant
Expert 13	15-20 years	Industry-Government	Consultant
Expert 14	11-15 years	Academia-Government	Associate Professor
Expert 15	Above 20 years	Academia-Private	Professor
Expert 16	11-15 years	Academia-Private	Associate Professor
Expert 17	11-15 years	Industry-Private	Consultant
Expert 18	Above 20 years	Industry-Private	Senior Policy Advisor

Table 3: Mean scores of enablers.

Enabler Nomenclature	Enabler Name	Mean Score	Comments
Enb1	Environmental Enabler	3.21	Acceptable
Enb2	Institutional Enabler	3.43	Acceptable
Enb3	Regulatory Enabler	3.63	Acceptable
Enb4	Technological Enabler	3.05	Acceptable
Enb5	Economic Enablers	3.75	Acceptable
Enb6	Social Enabler	3.45	Acceptable

Table 4: Structural Self-Interaction Matrix (Source: Authors' own contribution).

	Enb6	Enb5	Enb4	Enb3	Enb2	Enb1
Enb1	V	V	A	V	V	
Enb2	X	X	X	V		
Enb3	V	X	V			
Enb4	V	X				
Enb5	A					
Enb6						

i and j is represented by "V, A, X, O," where V and A indicate unidirectional relations, X indicates a bidirectional relation, and O signifies no relation. If i impacts j but j does not impact i, the relation is denoted as 'V'. Conversely, if j impacts i but i does not impact j, it is labeled as 'A'. When both i and j mutually influence each other, the relation is marked as 'X'. If there is no relation between i and j, it is denoted as 'O'. Table 4 presents the results of the SSIM.

3.3. Interpretations of the SSIM

The interpretive logic of the Structural Self-Interaction

Table 5: Interpretive logic-knowledge base.

Code	Pairwise Comparison	Interpretation
Enb1-Enb6	Environmental Enablers have an impact on Social Enablers	Environmental degradation and climate risks raise public awareness and concern, resulting in greater social acceptance, pro-renewable attitudes, and community participation.
Enb1-Enb5	Environmental Enablers have an impact on Economic Enablers	Environmental goals justify green investments, subsidies, and carbon pricing, thereby creating markets for green jobs, renewable manufacturing, and clean energy finance.
Enb1-Enb4	Technological Enablers have an impact on Environmental Enablers	Technology and innovation in renewable energy make it affordable and scalable, thereby strengthening environmental outcomes.
Enb1-Enb3	Environmental Enablers have an impact on Regulatory Enablers	Environmental pressures drive regulations that encourage renewable energy sources through initiatives such as renewable purchase obligations (RPOs), emissions norms, and environmental clearances.
Enb1-Enb2	Environmental Enablers have an impact on Institutional Enablers	Environmental objectives, commitment to sustainable development, and commitment to reducing carbon footprints result in institutional frameworks that encourage and incentivise renewable energy initiatives.
Enb2-Enb6	Institutional Enablers and Social Enablers influence each other.	Institutions help to shape awareness programs and trust in renewable energy initiatives. This, in turn, helps to generate social awareness and acceptance. The rising awareness and environmental consciousness among the community have also pushed institutions to take up initiatives that promote clean energy.
Enb2-Enb5	Institutional Enablers and Economic Enablers influence each other.	Institutions are responsible for developing incentive schemes and subsidies to attract investors in renewable energy. Economic enablers influence institutional enablers because improved financial viability and investment flows enhance institutional capacity and long-term sustainability.
Enb2-Enb4	Institutional Enablers and Technological Enablers influence each other.	Institutional enablers support research and development, investment in renewable energy technology(RET). Emerging technologies necessitate capacity building and institutional adaptation.
Enb2-Enb3	Institutional Enablers have an impact on Regulatory Enablers	Institutional enablers influence regulatory enablers as institutional capacity and governance structures are essential for designing, implementing, and enforcing renewable energy regulations.
Enb3-Enb6	Regulatory Enablers have an impact on Social Enablers	Regulatory enablers influence social enablers, as clear, supportive regulations build public confidence, increase awareness, and foster societal acceptance of renewable energy systems.
Enb3-Enb5	Regulatory Enablers and Economic Enablers influence each other.	Regulatory enablers influence economic enablers, as stable, transparent regulations reduce investment risk and facilitate market growth in renewable energy. Economic enablers influence regulatory enablers because evolving market conditions and investment dynamics necessitate regulatory adaptation and reform.
Enb3-Enb4	Regulatory Enablers have an impact on Technological Enablers	Regulatory enablers influence technological enablers, as regulatory standards, mandates, and compliance requirements shape the development, deployment, and innovation in renewable energy.
Enb4-Enb6	Technological Enablers have an impact on Social Enablers	Technology has enabled the community to connect. Social media helps generate curiosity and interest among the community about renewable energy, which results in smoother adoption.
Enb4-Enb5	Technological Enablers and Economic Enablers influence each other.	Technology can help scale renewable energy projects with economic consequences. Funding RET can increase research and innovation.
Enb5-Enb6	Social Enablers have an impact on Economic Enablers.	Social enablers influence economic enablers by increasing demand, reducing implementation risks, and improving the economic viability of renewable energy projects.

Table 6: Initial reachability matrix (Source: Authors' own contribution).

	Enb1	Enb2	Enb3	Enb4	Enb5	Enb6
Enb1	1	1	1	0	1	1
Enb2	0	1	1	1	1	1
Enb3	0	0	1	1	1	1
Enb4	1	1	0	1	1	1
Enb5	0	1	1	1	1	0
Enb6	0	1	0	0	1	1

Matrix (SSIM) is presented in Table 5, which explains the direction of influence among the identified renewable energy enablers. The table shows that environmental enablers strongly influence institutional, regulatory, economic, and social enablers, while several relationships, such as institutional-economic, institutional-technological, and regulatory-economic enablers, are mutually reinforcing. Overall, Table 5 provides the knowledge base used to justify the pairwise relationships and establish how different enablers interact in supporting renewable energy adoption.

3.4. Reachability Matrix

The SSIM is translated into binary digits following the rules of TISM. A unidirectional relation of V is denoted as (1,0), while A is represented as (0,1). The bidirectional relation X is indicated by (1,1), and the absence of a relation O is shown as (0,0). Table 6 displays the initial reachability matrix constructed based on these rules. To determine the final reachability matrix, the principle of transitivity is applied, as illustrated in Table 7.

3.5. Hierarchical Level Partitioning

Level partitioning helps to develop the hierarchical relationship among the different factors. It considers the intersection between the "antecedent" (AS) and the "reachability set" (RS) derived from the FRM. Iterations are repeated for all the factors to arrive at the different levels of the model, as shown in Tables 8, 9, and 10.

3.6. TISM Model

Fig. 1 illustrates the TISM model, which is derived from the level partitioning. The first level of the model comprises Institutional Enablers (Enb2) and Technological Enablers (Enb4), while Regulatory Enablers (Enb3) are positioned at the second level. Environmental Enablers (Enb1), Economic Enablers (Enb5), and Social Enablers (Enb6) constitute the third level of the model. A detailed discussion of the TISM model can be found in the Results and Discussion section.

Table 7: Final reachability matrix (Source: Authors' own contribution).

	Enb1	Enb2	Enb3	Enb4	Enb5	Enb6
Enb1	1	1	1	0	1	1
Enb2	0	1	1	1	1	1
Enb3	1*	0	1	1	1	1
Enb4	1	1	0	1	1	1
Enb5	0	1	1	1	1	0
Enb6	0	1	0	1*	1	1

3.7. Fuzzy MICMAC Analysis

The third objective of the study aims to understand the nature of linkages between the identified enablers, which is achieved through fuzzy MICMAC analysis. Fuzzy MICMAC

Table 8: Level Partitioning Iteration Matrix 1 (Source: Authors' own contribution).

	Antecedent Set (AS)	Reachability Set (RS)	AS RS	Level
Enb1	(1,2,3,5,6)	(1,3,4)	(1,3)	
Enb2	(2,3,4,5,6)	(1,2,4,5,6)	(2,4,5,6)	Level 1
Enb3	(1,3,4,5,6)	(1,2,3,5)	(1,3,5)	
Enb4	(1,2,4,5,6)	(2,3,4,5,6)	(2,4,5,6)	Level 1
Enb5	(2,3,4,5)	(1,2,3,4,5,6)	(2,3,4,5)	
Enb6	(2,4,5,6)	(1,2,3,4,6)	(2,4,6)	

Table 9: Level Partitioning Iteration Matrix 2 (Source: Authors' own contribution).

	Antecedent Set (AS)	Reachability Set (RS)	AS RS	Level
Enb1	(1,3,5,6)	(1,3)	(1,3)	
Enb3	(1,3,5,6)	(1,3,5)	(1,3,5)	Level 2
Enb5	(3,5)	(1,3,5,6)	(3,5)	
Enb6	(5,6)	(1,3,6)	(6)	

Table 10: Level Partitioning Iteration Matrix 3 (Source: Authors' own contribution).

	Antecedent Set (AS)	Reachability Set (RS)	AS RS	Level
Enb1	(1,3,5,6)	(1,3)	(1)	Level 3
Enb5	(3,5)	(1,3,5,6)	(5)	Level 3
Enb6	(5,6)	(1,3,6)	(6)	Level 3

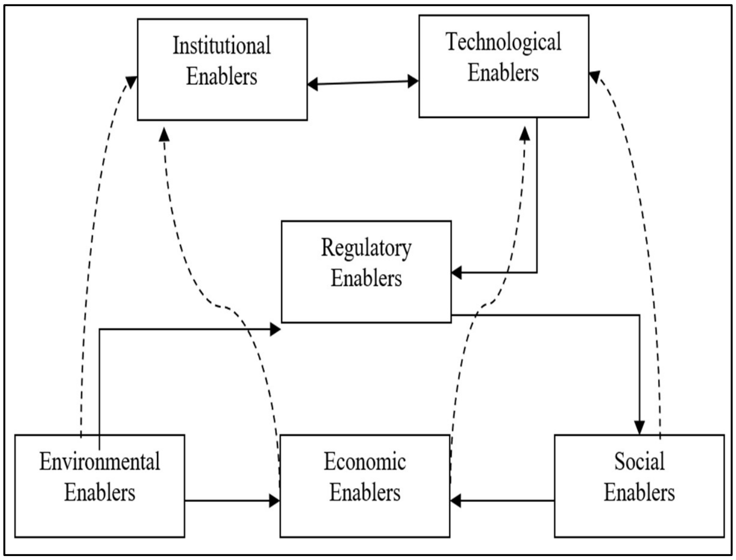

Fig. 1: TISM model of Enablers of Renewable Energy(Source: Authors' Contribution).

analysis considers the driving and dependent powers of the enablers from Table 7, which helps to classify the factors into four clusters.

Tables 11 and 12 examine the associability of values and the fuzzy reachability matrix. Expert judgment regarding the influence among enablers was based on the associability of variables presented in Table 11. This approach helped minimize bias that could arise from using rigid binary judgments. The experts reviewed the associability table to assess the degree of connection between the identified enablers. Associability values ranged from 0 to 1, where 0 indicated no association and 1 indicated complete association.

As illustrated in Fig. 2, the Fuzzy MICMAC analysis categorizes the enablers into four distinct clusters. The first, known as the autonomous cluster, is characterized by low "driving power" and low "dependence power." The second, the driving cluster, consists of enablers with high "driving" power but lower "dependence" power. The third, the linkage cluster, includes enablers with both high "driving" and high "dependence" powers. The final cluster, called the dependent cluster, features enablers with weak "driving" power yet higher "dependence" power. The findings of the Fuzzy MICMAC analysis are discussed in the following section. 1

Table 7: Final Reachability Matrix (Source: Authors' own contribution).

	Enb1	Enb2	Enb3	Enb4	Enb5	Enb6
Enb1	1	1	1	0	1	1
Enb2	0	1	1	1	1	1
Enb3	1*	0	1	1	1	1
Enb4	1	1	0	1	1	1
Enb5	0	1	1	1	1	0
Enb6	0	1	0	1*	1	1

Table 11: Associability of values for expert opinion.

0	0.1	0.3	0.5	0.7	0.9	1
No relation	Very Low	Low	Average	High	Very High	Complete

4. RESULTS AND DISCUSSION

4.1. TISM Model

The TISM Model identifies both institutional and technological enablers at level 1. In India, institutional enablers include a broad network of government-supported entities such as the Ministry of New and Renewable Energy (MNRE), Solar Energy Corporation of India (SECI), NITI Aayog, and State Renewable Energy Development Agencies (SREDAs). These organizations are tasked with policy formulation, subsidies, and the execution of large-scale projects. For instance, NITI Aayog develops long-term strategies for integrating renewable energy, while MNRE oversees initiatives like the National Solar Mission, which emphasizes grid-connected, rooftop, and off-grid solar capacities. MNRE also manages subsidies through DISCOMs and supports various bioenergy programs. SREDAs serve as state-level nodal agencies focusing on energy efficiency and conservation initiatives. These institutional structures foster investment in renewable energy technologies. Globally, India ranks as the fourth-largest wind energy producer and possesses advanced technology

Table 12: Fuzzy Reachability Matrix.

	Enb1	Enb2	Enb3	Enb4	Enb5	Enb6	Driving Power
Enb1	1	0.7	0.5	0.3	0.9	0.7	4.1
Enb2	0	1	0.9	0.7	0.5	0.7	3.8
Enb3	0.7	0.3	1	0.5	0.9	0.9	4.3
Enb4	0.7	0.5	0.1	1	0.7	0.9	3.9
Enb5	0.3	0.7	0.7	0.9	1	0.3	3.9
Enb6	0.1	0.9	0.3	0.7	0.7	1	3.7
Dependence Power	3.5	4.1	3.5	4.1	4.7	4.5	

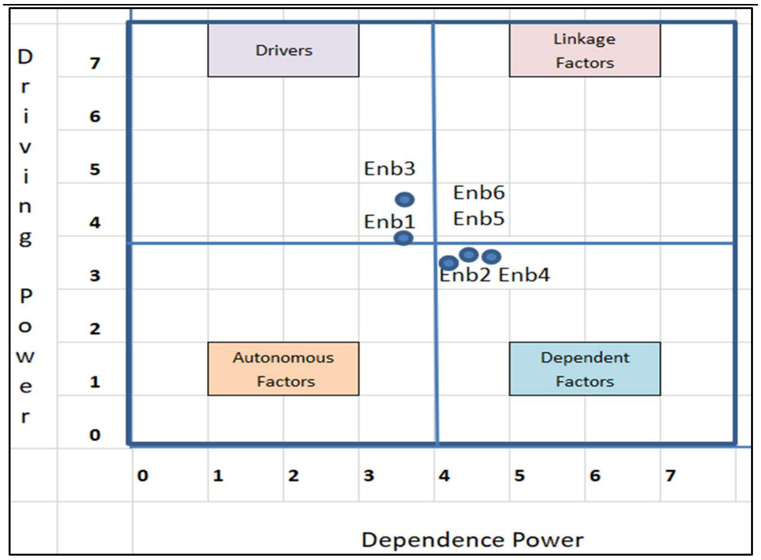

Fig. 2: Fuzzy MICMAC Analysis (Source: Authors' contribution).

to support its deployment. Under the National Solar Mission, India has adopted diverse solar technologies, including rooftop, off-grid, and utility-scale systems. The second level of the model emphasizes regulatory frameworks. The bidirectional relationship depicted in Fig. 1 illustrates how institutional and technological enablers mutually reinforce each other: institutions facilitate technology deployment via funding, coordination, and capacity building, while technological progress requires institutional adaptation and learning. Regulations convert institutional objectives into enforceable rules, standards, and incentives, promoting social acceptance and economic participation. India's regulatory framework includes provisions like the Renewable Purchase Obligation (RPO), renewable energy certificates, and grid standards for renewable energy. These frameworks are vital for infrastructure development, providing policy stability and safeguarding investor interests.

The third level of the model consists of environmental, social, and economic enablers. Environmental enablers form the foundation within the TISM framework, exerting strong driving forces with minimal dependence on other enablers. They have a direct influence on economic enablers and an indirect effect on institutional and regulatory enablers, making them key initiators of the renewable energy system. Social acceptance and economic viability are outcomes of the system, not driving forces—challenging the common assumption that awareness or finance alone can propel renewable energy transitions. India benefits from abundant sunlight, mountain ranges, and coastal areas, which facilitate wind energy harnessing. The agricultural sector contributes biomass that can be used for fuel production. Increasing environmental awareness among Indians about climate change, energy security, and pollution caused by fossil fuels has grown. Many have shown interest in solar energy, installing solar panels on their homes. Indian universities and educational institutions have incorporated sustainability modules into curricula, raising awareness. Social enablers play a vital role in promoting understanding of renewable energy. The Indian government has launched initiatives like PM-KUSUM that offer subsidies to farmers for solar pumps and small solar power plants, enabling excess energy to be sold back to the grid. The UJALA scheme, introduced in

2015, aimed to improve energy efficiency by distributing affordable LED bulbs. Additionally, India provides various subsidies and incentives to encourage the adoption of renewable energy sources. The PM Surya Ghar Muft Bijli Yojana offers subsidies for residential solar rooftop installations, and solar modules are taxed at only 5%.

4.2. Fuzzy MICMAC Analysis

The results of the Fuzzy MICMAC analysis reveal that the model comprises Drivers and Dependent Variables. Environmental and regulatory enablers serve as the primary drivers, playing a vital role in the successful deployment of renewable energy sources. These enablers are independent, meaning they do not depend on others; however, their absence can negatively impact the model. To effectively harness renewable energy, access to a diverse array of energy sources is essential. The positioning confirms that environmental concerns—such as climate change mitigation and emission reduction—are not merely outcomes of the system but are initiators that influence policy priorities, institutional responses, and market behavior. Regulatory enablers ensure that appropriate systems and processes are established to promote and oversee renewable energy adoption for enhanced energy efficiency and sustainable development. Institutional, technological, economic, and social enablers are classified as dependent variables within the model. Institutional enablers depend on regulatory frameworks, public demand for clean energy, and the international sustainability agenda and goals. This feedback loop positions institutional and technological enablers at an intermediate yet influential level, functioning as system stabilizers rather than independent drivers. Typically, institutional, regulatory, and technological enablers are found here, reflecting continuous policy revisions, regulatory learning, and technology-policy feedback cycles. This underscores their central but sensitive role, as observed in the TISM structure. Technology relies on supportive policies, available funding for innovation, and market demand for renewable energy technologies. Economic enablers are outcomes of fiscal policies, funding support, and regulatory frameworks for renewable energy. Social enablers depend on campaigns, consumer attitudes, accessibility, and affordability.

5. CONCLUSIONS

The authors in the study aimed to analyze three specific objectives. The primary goal was to identify the key drivers that contribute to the successful implementation of renewable energy sources, with a particular emphasis on India. This was accomplished through an extensive review of existing literature and consultations with experts. The findings revealed six enablers: environmental, institutional, regulatory, technological, economic, and social, all of which facilitate the adoption and integration of renewable energy as a clean energy option in India. The second objective centered on exploring the relationships between these enablers. The TISM model represents three levels, illustrating the hierarchical relationships among the six enablers. Various initiatives and institutions established by the Government of India have played a significant role in streamlining and regulating the renewable energy sector. The third objective involved analyzing the nature of the linkages between the enablers using Fuzzy MICMAC Analysis. The results classified the enablers into driving and dependent variables, both essential for the success of the model.

5.1. Implications of the Study

The study has significant implications for theory, management, and society. The identified enablers add value to the existing body of literature in this area. Moreover, the study enhances understanding of the relationships between these enablers. The TISM method offers a framework for grasping the hierarchical connections among the three levels of enablers, clarifying how they interlink. This framework aids in identifying and prioritizing key enablers. Expert insights provide valuable qualitative feedback, laying a foundation for further exploration and future research. The study highlights practices adopted by India that could be examined and adapted into policies for other developing nations. Results suggest that policymakers should prioritize high-driving enablers over dependent outcomes. Improving environmental commitments, such as emission standards and sustainability policies, can trigger positive effects across institutions, regulations, and markets. Strengthening institutional capacity and ensuring regulatory consistency are crucial, as high-driving enablers transform environmental intentions into actionable strategies and technology adoption. Policies focused solely on social acceptance or financial incentives may fall short unless supported by robust institutional and regulatory frameworks. Consequently, this study offers policymakers a systemic approach for targeted interventions rather than isolated outcomes. For project developers, investors, and implementing agencies, the findings imply that economic viability and social acceptability stem from system readiness. Engagement strategies must align with clear regulatory frameworks to reduce project risks. Additionally, institutional learning and regulatory adaptation are essential alongside technological advancements to facilitate scaling. Recognizing each enabler's position in the system enables practitioners to anticipate potential bottlenecks and develop more resilient renewable energy projects.

6. REFERENCES

Abdullah-Al-Mahbub, M. and Islam, A.R.M.T., 2023. Current status of running renewable energy in Bangladesh and future prospects: A global comparison. *Heliyon*, 9(3), pp.1-15. [DOI]

Alam, M.S., Duraisamy, P., Siddik, A.B., Murshed, M., Mahmood, H., Palanisamy, M. and Kirikkaleli, D., 2023. The impacts of globalization, renewable energy, and agriculture on CO_2 emissions in India: contextual evidence using a novel composite carbon emission-related atmospheric quality index. *Gondwana Research*, 119, pp.384-401. [DOI]

Apolonia, M. and Simas, T., 2021. Life cycle assessment of an oscillating wave surge energy converter. *Journal of Marine Science and Engineering*, 9(2), p.206. [DOI]

Azhgaliyeva, D. and Mishra, R., 2022. Feed-in tariffs for financing renewable energy in Southeast Asia. *Wiley Interdisciplinary Reviews: Energy and Environment*, 11(3), p.e425. [DOI]

Beck, M., Rivers, N. and Wigle, R., 2018. How do learning externalities influence the evaluation of Ontario's renewables support policies? *Energy Policy*, 117, pp.86-99. [DOI]

Behera, P., Sethi, L. and Sethi, N., 2024. Balancing India's energy trilemma: assessing the role of renewable energy and green technology innovation for sustainable development. *Energy*, 308, p.132842. [DOI]

Boadu, S. and Otoo, E., 2024. A comprehensive review on wind energy in Africa: challenges, benefits and recommendations. *Renewable and Sustainable Energy Reviews*, 191, p.114035. [DOI]

Briera, T. and Lefèvre, J., 2024. Reducing the cost of capital through international climate finance to accelerate the renewable energy transition in developing countries. *Energy Policy*, 188, p.114104. [DOI]

Chaikumbung, M., 2025. The influence of national cultures on preferences and willingness to pay for renewable energy in developing countries: a meta-analysis. *Renewable and Sustainable Energy Reviews*, 207, p.114972. [DOI]

Charfeddine, L. and Kahia, M., 2021. Do information and communication technology and renewable energy use matter for carbon dioxide emissions reduction? Evidence from the Middle East and North Africa region. *Journal of Cleaner Production*, 327, p.129410. [DOI]

Chenyang, W., Wei, W., Xi, C., Ming, L. and Hansheng, C., 2023. Suggestions on mineral resources management from the perspective of grass-roots government openness in the field of natural resources. *China Mining Magazine*, 32(S1), pp.8-12.

Dashtpeyma, M. and Ghodsi, R., 2021. Developing the resilient solar energy management system: a hybrid qualitative-quantitative approach. *International Journal of Ambient Energy*, 42(16), pp.1892-1911. [DOI]

De Simone, E., Rochira, A. and Mannarini, T., 2025. Individual and community catalysts for renewable energy communities (RECs) development. *Current Opinion in Psychology*, 62, p.101987. [DOI]

Erol, I., Peker, I., Benli, T., Ar, I.M. and Searcy, C., 2024. Exploring the enablers for building resilience in solar photovoltaic energy supply chains. *Operations Management Research*, 17(3), pp.1100-1125. [DOI]

Feldman, R. and Levinson, A., 2023. Renewable portfolio standards. *The Energy Journal*, 44(5), pp.1-20. [DOI]

Granit, I., 2023. What makes Colombia's indigenous peoples adopt microgrids? Social acceptance and financial constraints in renewable energy diffusion. *Energy Research & Social Science*, 101, p.103132. [DOI]

Guy, L., 2022. *Exploring investment enablers and barriers for mature and novel renewable energy technologies using the Delphi method* (Master›s thesis). University of Technology Sydney, pp.120.

Gyimah, J., Fiati, M.K., Nwigwe, U.A., Vanessa, A.E. and Yao, X., 2023. Exploring the impact of renewable energy on economic growth and carbon emissions: evidence from partial least squares structural equation modeling. *PLOS ONE*, 18(12), p.e0295563. [DOI]

Hao, Y. and Khan, I., 2025. Impact of decarbonization enablers, energy supply between transition and disruption, on renewable energy development. *Energy*, 324, p.135863. [DOI]

Herath, P., Dissanayake, P. and Kumarasiri, B., 2022. Enablers to facilitate industrial symbiosis for better waste management of industrial zones in Sri Lanka. In: *Proceedings of the 10th World Construction Symposium*, pp.429-440. [DOI]

Islam, M.M., Irfan, M., Shahbaz, M. and Vo, X.V., 2022. Renewable and non-renewable energy consumption in Bangladesh: the relative influencing profiles of economic factors, urbanization, physical infrastructure, and institutional quality. *Renewable Energy*, 184, pp.1130-1149. [DOI]

Joarder, M.S.A., Raihan, A., Salehi, M., Walasek, R. and Zimon, G.R.Z.E.G.O.R.Z., 2024. Analysis of the current development of renewable energy technologies in Bangladesh. *WSEAS Transactions on Environment and Development*, 20, pp.883-894. [DOI]

Joshi, J., 2021. Do renewable portfolio standards increase renewable energy capacity? Evidence from the United States. *Journal of Environmental Management*, 287, p.112261. [DOI]

Khare, V., Jain, A. and Bhuiyan, M.A., 2023. Perspective of renewable energy in the BRICS countries. *E-Prime: Advances in Electrical Engineering, Electronics and Energy*, 5, p.100250. [DOI]

Kishore, T.S., Kumar, P.U. and Ippili, V., 2025. Review of global sustainable solar energy policies: significance and impact. *Innovation and Green Development*, 4(2), p.100224. [DOI]

Koswatte, I., Iddawala, J., Kulasekara, R., Ranaweera, P., Dasanayaka, C.H. and Abeykoon, C., 2024. Can Sri Lanka be a net-zero nation by 2050?—Current renewable energy profile, opportunities, challenges, and recommendations. *Cleaner Energy Systems*, 8, p.100126. [DOI]

Kumar, A., Pal, D., Kar, S.K., Mishra, S.K. and Bansal, R., 2022. An overview of wind energy development and policy initiatives in India. *Clean Technologies and Environmental Policy*, 24(5), pp.1337-1358. [DOI]

Kurbatova, T., Sotnyk, I., Prokopenko, O., Bashynska, I. and Pysmenna, U., 2023. Improving the feed-in tariff policy for renewable energy promotion in Ukraine's households. *Energies*, 16(19), p.6773. [DOI]

Lal, R. and Kumar, S., 2022. Energy security assessment of small Pacific Island Countries–sustaining the call for renewable energy proliferation. *Energy Strategy Reviews*, 41, p.100866. [DOI]

Lal, S.R.S., Herbert, G.M.J., Arjunan, P. and Suryan, A., 2025. Advancements in renewable energy transition in India: a review. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 47(2), p.2024921. [DOI]

Li, H.X., Edwards, D.J., Hosseini, M.R. and Costin, G.P., 2020. A review on renewable energy transition in Australia: an updated depiction. *Journal of Cleaner Production*, 242, p.118475. [DOI]

Liu, X., Shi, H., Yang, D., Chen, X., Xia, X.A. and Xie, Y., 2025. Reducing the impact of climate change on renewable energy systems through wind–solar blending: a worldwide study with CMIP6. *Solar Energy*, 290, p.113365. [DOI]

Maka, A.O. and Alabid, J.M., 2022. Solar energy technology and its roles in sustainable development. *Clean Energy*, 6(3), pp.476-483. [DOI]

Malik, K., Rahman, S.M., Khondaker, A.N., Abubakar, I.R., Aina, Y.A. and Hasan, M.A., 2019. Renewable energy utilization to promote sustainability in GCC countries: policies, drivers, and barriers. *Environmental Science and Pollution Research*, 26(20), pp.20798-20814. [DOI]

Mohammadi, M. and Mohammadi, A., 2024. Empowering distributed solutions in renewable energy systems and grid optimization. In: *Distributed Machine Learning and Computing: Theory and Applications*. Springer International Publishing, pp.141-155. [DOI]

Mohazzem Hossain, S., Biswas, S. and Raihan Uddin, M., 2024. Sustainable energy transition in Bangladesh: challenges and pathways for the future. *Engineering Reports*, 6(1), p.e12752. [DOI]

Nieboer, S., Hansmeier, H., Beers, P.J., Seus, S. and Hebinck, A., 2025. *The*

Impact of Geographical Enablers and Barriers on the Scaling of Grassroots Innovation Initiatives: Findings and Recommendations of the Secondary Data Analysis of the SHARED GREEN DEAL SSH Priority Themes. SHARED GREEN DEAL, Cambridge, pp.45. [DOI]

Obuseh, E., Eyenubo, J., Alele, J., Okpare, A. and Oghogho, I., 2025. A systematic review of barriers to renewable energy integration and adoption. *Journal of Asian Energy Studies*, 9, pp.26-45. [DOI]

O[DOI]-Yorke, F., Bain, J., Agyekum, E.B., Dzebre, D.E., Sekyere, C.K., Quansah, D.A. and Adaramola, M.S., 2025. Mapping Ghana's renewable energy research landscape: a bibliometric insight into trends, progress, and policy relevance for sustainable development. *International Journal of Ambient Energy*, 46(1), p.2577223. [DOI]

Oduro, S., Pittri, H., Baah, B., Simons, B., Gyamfi, J., Botchway, B. and Afful, A.E., 2025. Strategies for the implementation of net zero energy buildings in the Ghanaian construction industry. *Built Environment Project and Asset Management*. [DOI]

Pambudi, N.A., Yuniar, W., Ulfa, D.K., Nanda, I.R. and Widiastuti, I., 2024. Assessing the readability of renewable energy education material from geothermal resources in vocational high school textbooks: a case study in Indonesia. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 12(3), pp.1-28. [DOI]

Raza, M.A., Aman, M.M., Kumar, L., Al-Khasawneh, M.A., Faheem, M. and Ehyaei, M.A., 2025. Carbon neutrality and economic stability nexus: an integrated renewable energy transition to decarbonize the energy sector. *Energy Reports*, 13, pp.4586-4608. [DOI]

Rincón, C.A.R., Santos, J., Volker, L. and Rouwenhorst, R., 2021. Identifying institutional barriers and enablers for sustainable urban planning from a municipal perspective. *Sustainability*, 13(20), p.11231. [DOI]

Rohit, R.V., Kiplangat, D.C., Veena, R., Jose, R., Pradeepkumar, A.P. and Kumar, K.S., 2023. Tracing the evolution and charting the future of geothermal energy research and development. *Renewable and Sustainable Energy Reviews*, 184, p.113531. [DOI]

Tabrizian, S., 2019. Technological innovation to achieve sustainable development—renewable energy technologies diffusion in developing countries. *Sustainable Development*, 27(3), pp.537-544. [DOI]

Tigabu, A.D., 2018. Analysing the diffusion and adoption of renewable energy technologies in Africa: the functions of innovation systems perspective. *African Journal of Science, Technology, Innovation and Development*, 10(5), pp.615-624. [DOI]

Vaidya, A., 2025. *Exploring Alternative Energy Sources*. Educohack Press, pp.220.

Van Opstal, W. and Smeets, A., 2022. *Sustainable Production and Consumption*. Springer, pp.180.

Virah-Sawmy, D. and Sturmberg, B., 2025. Socio-economic and environmental impacts of renewable energy deployments: a review. *Renewable and Sustainable Energy Reviews*, 207, p.114956. [DOI]

Wang, L., He, Y. and Wu, R., 2024. The green engine of growth: assessing the influence of renewable energy consumption and environmental policy on China's economic sustainability. *Sustainability*, 16(8), p.3120. [DOI]

Wang, Y., Wang, D., Yu, L. and Mao, J., 2023. What really influences the development of renewable energy? A systematic review and meta-analysis. *Environmental Science and Pollution Research*, 30(22), pp.62213-62236. [DOI]

Yang, Z., Zhang, M., Liu, L. and Zhou, D., 2022. Can renewable energy investment reduce carbon dioxide emissions? Evidence from scale and structure. *Energy Economics*, 112, p.106181. [DOI]