



# NET ZERO TRANSITION TOWARDS DECARBONIZATION IN CONTEXT OF ENERGY SECTOR

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## ABSTRACT

The study provides an identification and analysis of potential enablers that facilitate transition towards net zero in the energy sector through Multi Criteria Decision-Making (MCDM) framework. The identified enablers and causal relationships between them in terms of decarbonization initiatives are studied using the DEMATEL method and combining trapezoidal fuzzy numbers (TFNs). The research design involves an overarching review of thirteen potential enablers to net zero transition within the energy sector, in order of their impact and causality. Top-ranked enablers that would have the greatest impact in achieving the energy transition were carbon pricing mechanisms, waste-to-energy conversion, decentralized energy systems and circular procurement policies. The research indicates that the enablers show causal pathways that are interconnected and can take place as both causes and effects in the decarbonization framework. Application of DEMATEL method using TFNs increases the strength of causal relationship derivation. The study adds to the literature on enabling net zero transition in energy and highlights the importance of a conceptual approach involving a combination of policy, technology and principles of the circular economy. Such lessons can guide policy makers, industry players and academics in planning and speeding up the process to sustainable energy systems and world climate targets.

**Keywords:** Multi-Criteria Decision Making (MCDM), DEMATEL method, Trapezoidal fuzzy numbers, Energy sector, Net zero transition, Decarbonization, Enablers, Circular economy, Carbon pricing, Sustainable energy

## 1. INTRODUCTION

The energy sector is a major component of the world's economy, covering vast field of activities concerning the production, distribution and uses of energy. The energy sector plays a huge contribution in powering industries, transportation systems and homes and it has at its disposal both renewable and non-renewable sources of energy (Manfren et al., 2021). The sector is dynamic, with fast-changing technology and regulations shifting towards sustainability and attracting development and investment interest in the future (Andoni et al., 2019). However, the energy sector has also been featured prominently among the large emitters of greenhouse (GHG) gases in the world. The energy sector accounts for one of the largest contributions to total GHG

emissions, with over three quarters of the aggregate emitted in areas like the European Union (EU) (Demartini et al., 2023). Therefore, decarbonizing this sector is very important to reach net-zero emissions by the mid-century and is a key target to avoid catastrophic results related to climate change. Some of the targets by EU were projects such as the European Green Deal and the Paris Agreement within the timeframe mentioned above, as indicated by (Slorach and Stamford, 2021). EU aims to achieve climate neutrality in the year 2050, increasing the demands for cleaner energy sources and system integration towards the achievement of this objective. For net-zero in energy, it must undergo an absolute transformation by replacing fossil fuels with solar, wind and hydropower, among other renewable sources. Such a transformation will further require the-grid integration of renewable energy, electrification of sectors like transportation and buildings and development of new technologies like carbon capture, utilization and storage, among others (Vallecha et al., 2021). Some of the sources of energy in the Indian context include the conventional sources: coal, natural gas, oil, hydro and nuclear, while others are renewable, such as wind and solar. While the capacity in renewables, especially solar, has been increasing very fast, it is coal, oil and biomass that cater to the bulk of India's energy demand (Das et al., 2023). In India, energy sector faces challenges such as electricity reliability issues, reliance on biomass for cooking and urban air pollution. Additionally, magnified increases in household appliances and electricity vehicles will drive the energy demand to multi-fold in the near future (Liang et al., 2023; Vats and Mathur, 2022). Against this backdrop, decarbonization of the energy sector assumes significance to arrest climate change. This will require both an increase in renewable sources and a reduction in emissions from transport and construction. Such initiatives will require intensive investment in new technologies with the potential to yield long-term benefits in terms of job creation and improved energy security (Tian et al., 2023; Ćorović et al., 2022). Additional motivation in the form of regulations and incentives from policymakers for the development of renewable energy is also needed.

The journey of net-zero in the energy sector is challenging but attainable. It is a call to overhaul the sector, scaling up renewable energy production capacity, electrical grids and battery storage (Tiwari, 2021). As of now, the speed of technological development in India is slow and needs public financing to fill the prevailing gap. Notwithstanding the obstacles, the shift towards net-zero emissions in the energy sector presents noteworthy prospects. It holds the promise of generating numerous new employment opportunities, propelling technological progress and bolstering energy resilience (Renné, 2022). The decarbonization of the energy sector, therefore, in view of the above facts, appears to be an essential undertaking towards combating climate change (Hafner et al., 2021).

Net-zero transition in the energy sector necessitates the complexity of attentive selections of suitable enablers that necessitate careful decision-making framework that can process multiple competing criteria and other stakeholder preferences. Multi-Criteria Decision-Making (MCDM) has become critical tools of analysing and ranking the alternatives in various fields (Mustafovski, 2025; Ullah et al., 2026; Sahoo et al., 2025). MCDM methods allow decision-makers to take into account several criteria at once, allowing transparent and well-structured evaluation procedures to take into account the trade-offs involved in the decisions of energy transition. The effectiveness of integrated MCDM methods can be seen in recent applications within the selection of renewable energy systems; e.g., Habiba et al., (2025) created an effective fractional fuzzy Criteria Importance Through Inter-criteria Correlation - Weighted Aggregated Sum Product Assessment (CRITIC-WASPAS) model to assess renewable energy systems to sustainable development in Industry 4.0 conditions, where geothermal energy was found to be a good renewable energy source. Shahin et al., (2026) introduced an Interval-Valued Circular Intuitionistic Fuzzy Measurement of Alternatives and Ranking according to the Compromise

Solution (MARCOS) approach to better capture uncertainty and expert hesitation in renewable energy source selection. Their real-world application showed that photovoltaic, biomass, and biodiesel are the most suitable options, with economic, technical, and environmental factors playing a decisive role. [Wu et al., \(2025\)](#) combined the DEMATEL (Decision-Making Trial and Evaluation Laboratory) approach with Analytic Interference Structure Modelling (AISM) in the analysis of factors that affect the longevity of prefabricated buildings at low-carbon emission environments, which confirms the usefulness of the causal relationship determination in a complex supply chain system. The AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), DEMATEL and VIKOR are examples of MCDM methods applicable to the renewable energy options evaluation and priority agents of decarbonization strategy. In a similar context, [Jameel et al., \(2026\)](#) proposed a hybrid MCDM framework combining Linear Diophantine Fuzzy Sets with Ranking Comparison (RANCOM), Method based on the Removal Effects of Criteria (MEREC), and Multi-Attribute Utility Theory (MAUT) to prioritize renewable energy alternatives under conflicting criteria. The results confirmed that integrating subjective and objective weighting improves robustness and supports more reliable sustainable energy decision-making.

The relationship between decarbonization and energy sector need to be studied because energy production and consumption drive almost all GHG emissions worldwide. Policymakers and stakeholders must know the pathways in decarbonization so as to design effective regulatory frameworks and invest in strategies that will facilitate shifting from fossil to renewable sources of energy ([Sokolnikova et al., 2020](#)). This interconnectedness underlines the demand for decarbonization at the systems level, which would secure the maximization of spill over benefits across economic sectors ([Arabzadeh et al., 2020](#)). Not least, technological innovation itself will be required to overcome the negative implications of renewable energy variability for reliable energy supply ([Arent et al., 2022](#)).

The most important aspect of sound energy transition analysis is dealing with uncertainty and imprecision of expert judgments and environmental data. Classical fuzzy set theory, proposed by [Zadeh \(1965\)](#), is a domain of classical mechanisms of expression of vague and ambiguous information. Some more sophisticated fuzzy set extensions have however been developed in order to better describe decision-maker hesitation as well as information that is not complete. The Intuitionistic Fuzzy Sets (IFS) was introduced by [Atanassov \(1986\)](#) as the natural extension of classical fuzzy sets which included the non-membership and membership degree to the fuzzy sets as further representation of uncertainty in the decision settings. The Pythagorean Fuzzy Sets (PFS) are an extension of this framework which allows the sum of squared membership values to be less restrictive and thus gives greater flexibility in the context of uncertainty modeling. These methods are further generalized in Fermatean Fuzzy Sets by [Senapati and Yager \(2020\)](#), where the total of cubic terms in terms of membership and non-membership degrees further constrained such sets so that more specific representations of expert ratings were possible. Neutrosophic Sets Building upon fuzzy logic, neutrosophic Sets integrate elements of truth and indeterminacy and falsity to offer highly developed mechanisms of dealing with unfinished and inconsistent information in multifaceted decision problems. More-recently, superior extensions exist including HyperFuzzy Control Systems and SuperHyperFuzzy Control Systems, introduced by [Fujita, Mehmood, and Ghaib \(2025\)](#) which show the edge of uncut modelling, which provide hierarchical structures in dealing with extreme complexity. Moreover, fuzzy f-g-h-fractional sets ([Gulistan et al., 2024](#)) are a generalized tool that allows membership values to reach maximum numbers and indeterminacy levels to be represented; it allows full confidence scores (value = 1) to be assigned by decision-makers where applicable. This theoretical development allows triangular fuzzy numbers (TFN), trapezoidal fuzzy numbers (TrFN) and

the representation of higher-order fuzzy numbers to be represented, and is useful in the quantification and aggregation of expert uncertainty, in studies on energy transition, that use multiple criteria and multiple options. Specifically, the fuzzy MCDM methods have been shown to be more effective when applied to the evaluation of renewable energy; as an example, Li et al., (2024) adopted TFN in a cumulative prospect theory model to assess structure of the paths of renewable energy development in Malaysia, confirming the benefits of fuzzy models in terms of the risk preferences held by decision makers. The use of pythagorean fuzzy MCDM has been widely reported in the selection of renewable energy sources, most recent works have used circular pythagorean fuzzy sets and interval-value circular intuitionistic fuzzy methods to achieve more realistic representation of non-linear hesitations behind expert judgments.

Given such gaps in research and the stakeholder needs, the present study makes an attempt to enable a detailed understanding of the enablers that can facilitate decarbonization in the energy sector. In doing so, it shall support the achievement of net zero, offer a promising future for the energy sector. The study also inspects the broader economic and social implications of decarbonization. The study frames the following Research Questions (RQs).

*RQ1.* What are the key enablers that facilitate the transition from fossil fuels to renewable energy sources in the energy sector to achieve net-zero?

*RQ2.* What are the relative importance and interrelationships between the identified potential enablers?

*RQ3.* What are the economical and societal implications of the transition to net-zero in the energy sector?

*RQ4.* How can policymakers ensure a just and equitable transition that addresses the needs of all stakeholders?

Following the introduction section, this study offers a comprehensive overview of the literature review and highlights the research methodology employed. The subsequent section provides an in-depth exploration of the enablers for the transition to net-zero emissions, along with a detailed description of the Trapezoidal Fuzzy DEMATEL model and its application steps. In the following section, a thorough description of the structure of these enablers and the criteria for their evaluation is presented, accompanied by the findings from the performed analysis. Finally, the discussion addresses the implications of the results and at the end concluding remarks that summarize the key insights and future directions of the research.

## 2. LITERATURE REVIEW

This section is divided into two subsections that establish the conceptual foundation for the study. The first subsection (2.1) examines net-zero emission in the energy sector. The second subsection (2.2) explores decarbonization mechanisms and enablers in the energy sector. Most of the literature was sourced from SCOPUS, a reputed database with access to more than 94 million records. A total of 118 articles were sorted based on systematic literature search using different keywords and keyword combinations considering defined inclusion and exclusion criteria shown in Table 1. This reflects the attention in the selection of articles to adhere to the importance of high academic standards and relevance in the research community.

Table 1. Criteria for literature search

Key word combination	Circularity, net zero, emission, energy sector, transition, carbon, renewable and decarbonising.
Exclusion criteria	Document type: Conference paper, article in review Areas: Article other than social science, finance, business and management, decision science and engineering Time period: Articles before 2016
Inclusion criteria	Time period: English Areas: Social science, finance, business and management, decision science and engineering Time period: 2016 – 2024 Document type: Journal articles

Source: The Author

## 2. 1. NET ZERO EMISSION IN ENERGY SECTOR

The important thing in net zero emissions in the energy sector is consider as combination of various strategies and technologies which is highlighted in academic research (Ferdaus et al., 2024). The important action is in the use of Renewable Energy Sources (RES) to achieve the transition for decarbonization of the sector. RES emits dramatically less amount of GHG as compared to conventional fossil fuels (Chaturvedi, 2021). The adoption of nuclear power plant technologies, which include both small modular reactors and large reactors, would further play an essential part in achieving targets to reach net zero emissions by the year 2060 (Tiwari et al., 2023). Besides, the utilities in the energy space, there is need to focus more on emission reduction for each of the scopes. The shifting away from the reliance on fossil fuels, including Scope 1, 2 and 3 emissions and making substantial investments towards decarbonizing many operational aspects of activities in this industry are the need of the hour (Ali et al., 2019). The energy sector can effectively pursue the objective of net-zero emissions and in combating climate change challenges with strategies that are aligned with the Sustainable Development Goals (SDGs) and through leveraging of the advancements in RES and nuclear powers (Ulpiani et al., 2023).

In fact, it is broad technological solutions and strategies that can enable a net zero emissions transition in the energy system, as discussed in detail in existing literature (Su et al., 2022). Low-carbon innovations, electrification and low-carbon fuels are some critical enablers of a much wider ambition for sector decarbonization (Nguyen et al., 2024). In addition, carbon capture, utilization and storage (CCUS) technologies adoption in the oil and gas sector would point to the fact that they could reduce emissions drastically while at the same time improve their oil production capabilities (Botelho et al., 2021). Finally, electrification in the power sector is an area of focus as utilities make aggressive net-zero targets by 2050, focusing on ways to reduce emissions from different sectors (Evli et al., 2022). The adoption of RES, such as solar and wind power, becomes of great importance in the endeavour of reducing GHG emissions and striking the set targets of net zero emissions (Otsuki et al., 2023). The sector will successfully be brought into a state of net zero emission through the integration of a combination of the multifaceted strategies. Some potential solutions to achieve net zero emissions are utilization of open data that can foster interoperability with the energy system and use of low carbon energy sources. The literature also brings the way to effectively mitigate long-term expenses associated with raising the demand for electricity by the use of policy and regulatory interventions (Jing et al., 2022).

Curbing energy and non-energy-related GHG emissions by transitioning to a circular economy is necessary to achieve net-zero emissions by 2050. This drags, in the integrated view of changes in society, energy availability and global dynamics toward net-zero emissions, mainly in the energy sector, where present literature focuses on decarbonization strategies for specific

sectors. The analysis supports emissions reduction to be achieved in the maritime sector through energy efficiency improvements, biofuels and blue ammonia, showing the technical feasibility of attaining net-zero targets with minimal cost implications (Rusmanis et al., 2023). Moreover, the calculation of embodied carbon in tall structures and contributing design parameters can positively signal a way forward in the transition to sustainability for building industry, showing net-zero energy buildings (Ahmed et al., 2022). Trade association working on comprehensive strategies for the attainment of net-zero emissions for the sector, therefore, must seek to integrate them with insights across the sectors and consider the broader societal and energy dynamics (Safari et al., 2018).

## 2. 2. DECARBONIZATION IN ENERGY SECTOR

Decarbonization of energy, therefore, becomes a critical goal in the global trend toward sustainable energy systems. As such, the objective shall reduce GHG emissions and consequently guard against climate change challenges (Kurniawan et al., 2024; Sahoo et al., 2025). It is a complex process that involves a change in sources of energy towards renewable ones, popularizing electric vehicles, implementing smart grids and meters and, slowly but surely, weaning ourselves off fossil fuels (Rajabloo et al., 2022). Decentralized generation will help in this transition by providing greater levels of efficiency, flexibility and cost-effectiveness. This is especially possible because of its potential to create energy near the point of consumption, which cuts down on transmission and distribution losses (Dalpaz et al., 2020). Of greater importance, perhaps, are restructuring of the energy market and introducing a competitive landscape as things that stand out. This can attract investments toward modernizing infrastructure and improving power supply reliability (Plazas-Niño et al., 2022). Basically, energy sector decarbonization is itself a complex process that requires a multilevel approach to technological innovation, policy readjustment and international cooperation to achieve SDGs in the long run (Asif, 2022).

Decarbonization of the energy sector and achieving Net Zero Energy Buildings (NZEBs) are two important steps in this contest against climate change, reducing GHG emissions (Jaysawal et al., 2022). The transition to NZEBs requires the innovative technologies that include intelligent building automation systems, energy-efficient lighting solutions, Heating, Ventilation and Air Conditioning (HVAC) systems and Building Integrated Photovoltaic (BIPV) systems (Biyyik et al., 2017). At the same time, utilities feel mounting pressure to decarbonize themselves, with many others already pledging to achieve net-zero by 2050. This translates to deep cuts in emissions from far-ranging scopes (Golombek et al., 2022; Seck et al., 2022). It is after all finally strategic designing of buildings for achieving higher energy performance criteria and incorporation of renewable energy sources that become key strategies, as observed in the case study of a building in a composite climate zone (Luderer et al., 2019). On the other hand, the achievement of such goals is likely to involve recycling existing buildings. This could therefore overshoot the capacities of building owners in the absence of Governmental support through subsidies and grants (Papadis and Tsatsaronis, 2020). Thereby, an integrative approach driven by technology, policy and finance becomes a prerequisite at this stage (Le Treut et al., 2021).

Even though the position has changed in terms of decarbonization technologies, there are still major gaps evident in the literature. First, the energy transition is currently studied in isolation, either in terms of the equipment or systems to accomplish it, like NZEB automation (Attia et al., 2022; Ahmed et al., 2022), or a single policy mechanism, which refuses to acknowledge the fact of the intricate relationship between both technological, regulatory, and social enablers. Second, although the importance of Government subsidies and renewable investments is not a new concept (Dekeyrel and Fessler, 2024), the interactions between these enablers have been studied without considering how such schemes interact with one another to achieve desired

outcomes. The enablers of causal relationship between the different stakeholders such as Government, utilities and consumers are not well captured, and the policy makers will not have a clear picture of whether these enablers are cause or effect (Bumharter et al., 2023).

Moreover, the available literature usually focuses on theoretical frameworks or descriptive case studies, and there are no adequate data-driven methodologies that can serve in order to prioritize these enablers in the real world. This study fills these important gaps by providing three separate scientific presentations:

1. **Holistic Enabler Identification:** This is opposed to single-sector research because this study is synthesized (18 enablers in policy, technology and market dimensions) which were narrowed on 13 potential enablers to net zero transition in energy sector via. experts' validation as summarized in Table 2.
2. **Methodological Novelty:** It is going on further than a mere descriptive analysis by using the Trapezoidal Fuzzy DEMATEL method. This methodology effectively addresses the subjectivity of human judgment while visualizing causal relationships between driving enablers and outcomes.
3. **Practical Strategic Framework:** The mapping of these interdependencies offers the stakeholders a scientifically-founded roadmap on how the top-impact interventions can be prioritized, instead of the stakeholders focusing on the thing that has to be done, the study offers how these enablers can be arranged in a manner that meets the targets of net zero.

There exists a vast and complex research gap concerning understanding enablers for the achievement of transition to net-zero emission in the energy sector, more so within decarbonization. While there is some progress in strategies and technologies for reaching net-zero objectives, several critical areas are still inadequately explored (Pinkse et al., 2023). While Government policies and investments in renewable energy have been recognized as important, there is a lack of thorough analysis on the specific enablers facilitating the transition to net zero (Dekeyrel and Fessler, 2024). The significance of subsidies and tax incentives is acknowledged. However the intricate interactions among stakeholders and their distinct contributions to decarbonization endeavours are not extensively documented. The existing literature often concentrates on theoretical frameworks without case studies or practical implementations that illustrate how these methodologies can be utilized to evaluate the efficacy of various enablers in real-world contexts. Based on the literature search, initially, a total of 18 enablers were distinguished. Then it was later scale down to 13 based on the expert suggestions and are presented in Table 2. The utilization of MCDM techniques, such as the Trapezoidal Fuzzy DEMATEL method, for evaluating and prioritizing these enablers can be seen as a potential solution.

Table 2. Enablers to net zero transition in energy sector

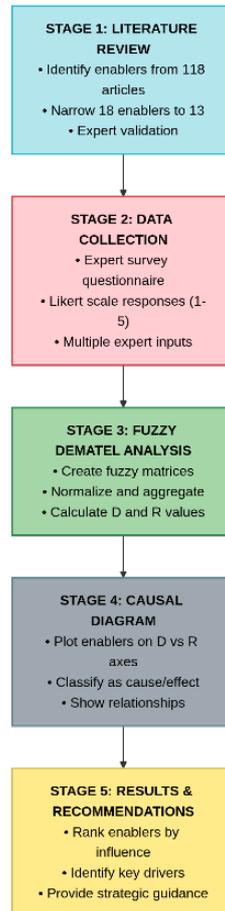
Code	Enablers	Description	References
EN1	Energy-as-a-Service Models	Encouraging business models that provide energy services rather than selling energy as a commodity, focusing on efficiency and sustainability.	Kat et al., 2024; Browning et al., 2023; Kannan et al., 2022; Bistline and Blanford, 2021; Pye et al., 2021.
EN2	Heat Recovery Systems in Industrial Processes	Installing heat recovery systems in industrial settings to capture and reuse waste heat for power generation or other processes.	Muhumuza and Eames, 2022; Kim, 2021; Loni et al., 2021; Pili et al., 2020.
EN3	Biogas Production from Agricultural Waste	Implementing biogas plants that convert agricultural waste, such as crop residues and manure, into biogas for energy use and organic fertilizers.	Bastola and Hiloidhari, 2024; Liu et al., 2023; Kabeyi and Olanrewaju, 2022; Babu et al., 2022; Brémond et al., 2021; Kapoor et al., 2020.
EN4	Battery Reuse and Recycling	Creating systems for the collection, refurbishment and recycling of batteries used in energy storage to minimize waste and recover critical minerals.	Scheller et al., 2023; Bhatt et al., 2022; Skeete et al., 2020; Cusenza et al., 2019.
EN5	Decentralized Energy Systems	Encouraging development of localized energy systems, likewise microgrids, to reduce transmission losses and improve resilience.	Angelidis et al., 2023; Wu et al., 2022; Heendeniya et al., 2020; Kim et al., 2019.
EN6	Smart Metering and Demand Response Programs	Implementing smart metering technology combined with demand response programs to optimize energy use and reduce peak demand.	Javed et al., 2023; Avordeh et al., 2022; Kampelis, 2021; Carmichael et al., 2021; Kiliccote et al., 2019.
EN7	Circular Design for Energy Infrastructure	Designing energy infrastructure components, like transformers and inverters, with modularity and recyclability in mind. The function of third-party providers of logistical services.	Moghayedi et al., 2024; Edwards et al., 2024; Mignacca et al., 2020; Invernizzi et al., 2020.
EN8	Smart Grid Technology	Implementing smart grids to efficiently manage energy distribution and consumption, reducing waste and improving reliability.	Kabeyi and Olanrewaju, 2022; Kourgiouzou et al., 2021; Tuballa and Abundo, 2016.
EN9	Carbon Pricing Mechanism	Implementing carbon pricing to make fossil fuels economically less attractive and promote investment in renewable energy.	Tan et al., 2023; Leroutier, 2022; Arimura et al., 2021; Cox and Edwards, 2019; Narassimhan et al., 2017.
EN10	Blockchain for Energy Trading	Using blockchain technology to create decentralized energy markets that enable peer-to-peer trading of renewable energy, increasing grid flexibility and efficiency.	Parhamfar et al., 2024; Wongthongtham et al., 2021; Mika and Goudz, 2021; Wang and Su, 2020; Ahl et al., 2020.
EN11	Circular Procurement Policies	Adopting procurement policies that prioritize products and services characterized by elevated recycled content and energy efficiency within the energy sector is crucial.	Sajid et al., 2024; Das and Ghosh, 2023; Husgafvel et al., 2022; Bataille et al., 2021.
EN12	Urban Mining for Critical Metals	Establishing urban mining operations to extract critical metals, such as lithium and cobalt, from electronic waste for use in energy storage technologies.	Dou et al., 2023; Okorie et al., 2023; Janardhanan et al., 2023.
EN13	Waste-to-Energy Conversion	Utilizing waste materials to generate energy, reducing landfill waste and providing an alternative energy source.	Tsai et al., 2023; Kurniawan et al., 2023; López-Sosa et al., 2022; Quicker et al., 2020; Goldsmith et al., 2017.

Source: The Author

### 3. RESEARCH DESIGN AND METHODOLOGY

This study uses a multi-stage approach to assess the intricate combinations of components underlying the net zero transition systematically. The study based on the combination of the knowledge of experts and the Trapezoidal Fuzzy DEMATEL approach is able to not only explain the cause-effect relationships of human decision-making in the energy industry, but also the ambiguity of the human decision-making process.

Figure 1. Five-stage research methodology



Source: The Author

Figure 1 represents the five steps of research. The research commenced with a literature review of 118 articles that revealed 18 potential enablers which were proved and reduced to 13 with the help of experts panel. The expert questionnaires were used to obtain data with Likert scale ratings. The prominence and causal metrics were then computed using trapezoidal Fuzzy DEMATEL analysis. These measurements put enablers on a causal diagram to classify and prioritize them.

#### 3. 1. DATA COLLECTION AND RATIONALE FOR EXPERT SELECTION

A purposive sampling design was used to choose the experts with extensive interest in the energy sector and the sustainability transitions, to confirm the reliability and validity of the evaluation. Since the implementation of Net Zero is a multi-dimensional problem with regulatory and technical and operational aspects, the selected panel has been designed as a multi-dimensional cross-section of stakeholders. The list of the selected experts summarized in Appendix A was divided into three different groups (1) Policymakers (Government officials in Ministries of New and Renewable Energy/Industry) to also provide some regulatory perspective; (2) Industry

Practitioners (General Managers, Total Quality Managers) in order to have a view on operational feasibility and circularity; and (3) Academia (Researchers) to ensure a theoretical rigor. The enablers were sent out to 39 experts through email in June 2024. Thirteen valid responses were obtained (estimated response rate of 33 percent). Though the sample size is smaller than that of consumer surveys, it is statistically adequate and powerful to MCDM research that is founded on the quality and depth of the expert vision as opposed to the statistical magnitude. The influence of the subject matter of the linguistic tests that should be administered is the high average experience level of the respondents (10-28 years), as the linguistic tests given will be based on intelligent professional judgment and not guesswork.

### 3. 2. TRAPEZOIDAL FUZZY DEMATEL METHODOLOGY

The application of DEMATEL approach in lieu of other MCDM methods (including AHP or TOPSIS) can also be explained by the peculiarities of the research issue. Meeting Net Zero emissions is not some sort of ranking game, it is a systems-level issue with complicated interrelationships between one enabler (e.g. government policy) being a trigger to another (e.g. the uptake of technologies). Conventional techniques such as AHP presuppose criteria independence, which cannot be made in complex energy systems. DEMATEL is suited unparalleled to this study as it represents the causality of relationships which enables the researcher to differentiate between the enablers that work (causes) and the enablers worked upon (effects).

Moreover, the human reason of such abstract notions as policy effectiveness or sustainability is subjective and unclear in nature. To overcome this uncertainty, this study incorporates Trapezoidal Fuzzy Numbers (TrFNs) into the conventional DEMATEL model (Wu and Lee, 2007; Appasamy, 2026). TrFNs represent the uncertainty and lack of crispness of expert linguistic judgments, unlike crisp numbers, and thus give a more realistic picture of the real-world decision-making situation (Basuri et al., 2026; Lo et al., 2025). This methodological decision provides that the consequent prioritization of enablers is strong, managing the general uncertainty of the energy transformation space.

## 4. RESULT AND INTERPRETATION

Wu and Lee, (2007) presented fuzzy DEMATEL as an extension of traditional DEMATEL that integrates Fuzzy Set Theory (FST). This enhancement improves upon conventional DEMATEL by incorporating human ambiguity throughout the multiple data collection phases from experts. Various types of fuzzy numbers are accessible within fuzzy theory. In this investigation, Trapezoidal Fuzzy DEMATEL was utilized, as proposed by (Hiete et al., 2012). The linguistic scale for the TrFN has also been delineated by Hiete et al., (2012), as illustrated in Table 3. A number of contemporary studies within the literature have employed trapezoidal fuzzy DEMATEL to address numerous intricate management dilemmas (Biswas et al., 2024; Xu et al., 2024; Gökalp and Eti, 2025). Therefore, the Trapezoidal Fuzzy DEMATEL methodology is adopted in this study.

Table 3. Linguistic scale considered for the analysis

Linguistic terms	Trapezoidal fuzzy numbers
No influence (No)	(0, 0, 0, 0)
Very low influence (VL)	(0, 0, 0.05, 0.2)
Low influence (L)	(0.05, 0.2, 0.3, 0.45)
Medium influence (M)	(0.3, 0.45, 0.55, 0.7)
High influence (H)	(0.55, 0.7, 0.8, 0.95)
Very high influence (VH)	(0.8, 0.95, 1, 1)

The following steps constitute the Trapezoidal Fuzzy DEMATEL, as described by the (Hiete et al., 2013):

*Step 1: Prepare average direct relation matrix*

In this phase, individual experts were requested to submit their evaluations regarding the interrelationships among enablers utilizing linguistic expressions. The TrFN were subsequently assigned accordingly and the data from all matrices were integrated through the aggregation method. Following this, de-fuzzification was executed by converting Fuzzy Data into Crisp Scores (CFCS) methodology, which was developed by Opricovic and Tzeng, (2003) and subsequently refined for TrFN by (Hiete et al., 2012).

Let,  $\tilde{A}_{ij}^n = (a_{ij}^n, b_{ij}^n, c_{ij}^n, d_{ij}^n)$  and influence matrix  $\tilde{A}^n$  is defined as

$$\tilde{A}^n = \begin{bmatrix} 0 & \tilde{A}_{12}^n & \tilde{A}_{13}^n & \dots & \tilde{A}_{1m}^n \\ \tilde{A}_{21}^n & 0 & \tilde{A}_{23}^n & \dots & \tilde{A}_{2m}^n \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \tilde{A}_{m1}^n & \tilde{A}_{m2}^n & \tilde{A}_{m3}^n & \dots & 0 \end{bmatrix}, n = 1, 2, 3, \dots, h \quad (1)$$

where,  $m$  is the number of enablers and  $h$  is the number of experts

The step-wise procedure of the CFCS method for TrFN is described as:

Normalization

$$x d_{ij}^n = (d_{ij}^n - \min a_{ij}^n) / \Delta_{min}^{max} \quad (2)$$

$$x c_{ij}^n = (c_{ij}^n - \min a_{ij}^n) / \Delta_{min}^{max} \quad (3)$$

$$x b_{ij}^n = (b_{ij}^n - \min a_{ij}^n) / \Delta_{min}^{max} \quad (4)$$

$$x a_{ij}^n = (a_{ij}^n - \min a_{ij}^n) / \Delta_{min}^{max} \quad (5)$$

where,  $\Delta_{min}^{max} = \max d_{ij}^n - \min a_{ij}^n$

Determine the right-side and left side normalized values:

$$x c s_{ij}^n = \frac{x c_{ij}^n}{(1 + x a_{ij}^n - x c_{ij}^n)} \quad (6)$$

$$x a s_{ij}^n = \frac{x b_{ij}^n}{(1 + x b_{ij}^n - x a_{ij}^n)} \quad (7)$$

Determine the total normalized crisp values:

$$x_{ij}^n = [x a s_{ij}^n (1 - x a s_{ij}^n) + x c s_{ij}^n \times x c s_{ij}^n] / (1 - x a s_{ij}^n + x c s_{ij}^n) \quad (8)$$

Determine the crisp values:

$$z_{ij}^n = \min a_{ij}^n + x_{ij}^n \times \Delta_{min}^{max} \quad (9)$$

Relate the crisp values:

$$z_{ij} = \frac{1}{h} (z_{ij}^1 + z_{ij}^2 + \dots + z_{ij}^h) \quad (10)$$

As demonstrated in equation (11), the collective direct-influence fuzzy matrix was derived by assigning linguistic variables to each identified enabler, as delineated in Table 4.

$$Z = [z_{ij}] \quad (11)$$

Table 4. Group direct-influence fuzzy matrix

Code	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13
EN1	(0,0,0,0)	(0.55, 0.7, 0.8, 0.95)	(0.027, 0.108, 0.185, 0.335)	(0.05, 0.2, 0.3, 0.45)	(0.446, 0.573, 0.642, 0.723)	(0.3, 0.45, 0.55, 0.7)	(0, 0, 0.05, 0.2)	(0.55, 0.7, 0.8, 0.95)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0.8, 0.95, 1, 1)
EN2	(0.3, 0.45, 0.55, 0.7)	(0, 0, 0, 0)	(0.3, 0.45, 0.55, 0.7)	(0.05, 0.2, 0.3, 0.45)	(0.55, 0.7, 0.8, 0.95)	(0.012, 0.046, 0.069, 0.104)	(0.55, 0.7, 0.8, 0.95)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)
EN3	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0, 0, 0, 0)	(0.3, 0.45, 0.55, 0.7)	(0.3, 0.45, 0.55, 0.7)	(0.242, 0.392, 0.492, 0.642)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.454, 0.604, 0.677, 0.746)	(0.05, 0.2, 0.3, 0.45)	(0.665, 0.815, 0.892, 0.973)	(0.8, 0.95, 1, 1)	(0.3, 0.45, 0.55, 0.7)
EN4	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0.05, 0.2, 0.3, 0.45)	(0, 0, 0, 0)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.254, 0.323, 0.396, 0.546)	(0.55, 0.7, 0.8, 0.95)	(0.296, 0.377, 0.454, 0.604)	(0, 0, 0.05, 0.2)	(0.3, 0.45, 0.55, 0.7)
EN5	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.454, 0.604, 0.677)	(0.05, 0.2, 0.3, 0.45)	(0, 0, 0, 0)	(0.8, 0.95, 1, 1)	(0.05, 0.2, 0.3, 0.45)	(0.038, 0.154, 0.231, 0.346)	(0.55, 0.7, 0.8, 0.95)	(0.55, 0.7, 0.8, 0.95)	(0.185, 0.335, 0.435, 0.585)	(0.281, 0.431, 0.531, 0.681)	(0.55, 0.7, 0.8, 0.95)
EN6	(0.25, 0.308, 0.338, 0.373)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0.3, 0.45, 0.55, 0.7)	(0.05, 0.2, 0.3, 0.45)	(0, 0, 0, 0)	(0, 0, 0.05, 0.2)	(0.108, 0.258, 0.358, 0.508)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.281, 0.431, 0.531, 0.681)	(0.319, 0.469, 0.569, 0.719)	(0.05, 0.2, 0.3, 0.45)
EN7	(0.377, 0.527, 0.619, 0.746)	(0.55, 0.7, 0.8, 0.95)	(0.454, 0.604, 0.677)	(0.3, 0.45, 0.55, 0.7)	(0.3, 0.45, 0.55, 0.7)	(0.8, 0.95, 1, 1)	(0, 0, 0, 0)	(0.3, 0.45, 0.55, 0.7)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.8, 0.95, 1, 1)
EN8	(0.55, 0.7, 0.8, 0.95)	(0.8, 0.95, 1, 1)	(0.338, 0.488, 0.588, 0.738)	(0.473, 0.623, 0.723, 0.873)	(0.3, 0.45, 0.55, 0.7)	(0.55, 0.7, 0.8, 0.95)	(0.8, 0.95, 1, 1)	(0, 0, 0, 0)	(0.05, 0.2, 0.3, 0.45)	(0.05, 0.2, 0.3, 0.45)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.55, 0.7, 0.8, 0.95)
EN9	(0.55, 0.7, 0.8, 0.95)	(0.473, 0.623, 0.723, 0.873)	(0.646, 0.796, 0.862, 0.908)	(0.723, 0.873, 0.931, 0.954)	(0.627, 0.777, 0.862, 0.965)	(0.723, 0.873, 0.938, 0.985)	(0.55, 0.7, 0.8, 0.95)	(0.554, 0.658, 0.692, 0.692)	(0, 0, 0, 0)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0.05, 0.2, 0.3, 0.45)
EN10	(0.123, 0.146, 0.154, 0.154)	(0.165, 0.315, 0.408, 0.535)	(0.473, 0.623, 0.723, 0.873)	(0.204, 0.354, 0.454, 0.604)	(0.627, 0.777, 0.862, 0.965)	(0.381, 0.485, 0.554, 0.658)	(0.377, 0.527, 0.627, 0.777)	(0.55, 0.7, 0.8, 0.95)	(0.55, 0.7, 0.8, 0.95)	(0, 0, 0, 0)	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)
EN11	(0.338, 0.488, 0.588, 0.738)	(0.127, 0.277, 0.377, 0.527)	(0.588, 0.738, 0.831, 0.958)	(0.762, 0.912, 0.969, 0.992)	(0.723, 0.873, 0.938, 0.985)	(0.627, 0.777, 0.862, 0.965)	(0.55, 0.7, 0.8, 0.95)	(0.246, 0.292, 0.308, 0.308)	(0.8, 0.95, 1, 1)	(0.8, 0.95, 1, 1)	(0, 0, 0, 0)	(0.05, 0.2, 0.3, 0.45)	(0, 0, 0.05, 0.2)
EN12	(0.55, 0.7, 0.8, 0.95)	(0.05, 0.2, 0.3, 0.45)	(0.465, 0.592, 0.685, 0.835)	(0.435, 0.585, 0.685, 0.835)	(0.723, 0.873, 0.938, 0.985)	(0.169, 0.215, 0.246, 0.292)	(0.473, 0.623, 0.723, 0.873)	(0.55, 0.7, 0.8, 0.95)	(0, 0, 0.05, 0.2)	(0.05, 0.2, 0.3, 0.45)	(0.3, 0.45, 0.55, 0.7)	(0, 0, 0, 0)	(0.05, 0.2, 0.3, 0.45)
EN13	(0.665, 0.815, 0.892, 0.973)	(0, 0, 0.05, 0.2)	(0, 0, 0.05, 0.2)	(0.55, 0.7, 0.8, 0.95)	(0.8, 0.95, 1, 1)	(0.8, 0.95, 1, 1)	(0.55, 0.7, 0.8, 0.95)	(0.3, 0.45, 0.55, 0.7)	(0.55, 0.7, 0.8, 0.95)	(0.3, 0.45, 0.55, 0.7)	(0.55, 0.7, 0.8, 0.95)	(0.3, 0.45, 0.55, 0.7)	(0, 0, 0, 0)

Source: The Author

*Step 2: Normalization of Direct Relation Matrix*

The normalized direct-influence fuzzy matrix was obtained through the application of equation (12), with the resultant data presented in Table 5.

$$X = \lambda * Z, \tag{12}$$

where,

$$\lambda = \min \left[ \frac{1}{\max_{1 \leq i \leq m} \sum_{j=1}^m |z_{ij}|} ; \frac{1}{\max_{1 \leq j \leq m} \sum_{i=1}^m |z_{ij}|} \right]$$

Table 5. Normalized direct-influence fuzzy matrix

Code	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13
EN1	(0, 0, 0, 0)	(0.058, 0.074, 0.085, 0.1)	(0.003, 0.011, 0.02, 0.035)	(0.005, 0.021, 0.032, 0.048)	(0.047, 0.061, 0.068, 0.076)	(0.032, 0.048, 0.058, 0.074)	(0, 0, 0.005, 0.021)	(0.058, 0.074, 0.085, 0.1)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0.085, 0.1, 0.106, 0.106)
EN2	(0.032, 0.048, 0.058, 0.074)	(0, 0, 0, 0)	(0.032, 0.048, 0.058, 0.074)	(0.005, 0.021, 0.032, 0.048)	(0.058, 0.074, 0.085, 0.1)	(0.001, 0.005, 0.007, 0.011)	(0.058, 0.074, 0.085, 0.1)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)
EN3	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0, 0, 0, 0)	(0.032, 0.048, 0.058, 0.074)	(0.032, 0.048, 0.058, 0.074)	(0.026, 0.041, 0.052, 0.068)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.048, 0.064, 0.072, 0.079)	(0.005, 0.021, 0.032, 0.048)	(0.07, 0.086, 0.094, 0.103)	(0.085, 0.1, 0.106, 0.106)	(0.032, 0.048, 0.058, 0.074)
EN4	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0.005, 0.021, 0.032, 0.048)	(0, 0, 0, 0)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.027, 0.034, 0.042, 0.058)	(0.058, 0.074, 0.085, 0.1)	(0.031, 0.04, 0.048, 0.064)	(0, 0, 0.005, 0.021)	(0.032, 0.048, 0.058, 0.074)
EN5	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.004, 0.016, 0.024, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0, 0, 0, 0)	(0.085, 0.1, 0.106, 0.106)	(0.005, 0.021, 0.032, 0.048)	(0.004, 0.016, 0.024, 0.037)	(0.058, 0.074, 0.085, 0.1)	(0.058, 0.074, 0.085, 0.1)	(0.02, 0.035, 0.046, 0.062)	(0.03, 0.046, 0.056, 0.072)	(0.058, 0.074, 0.085, 0.1)
EN6	(0.026, 0.033, 0.036, 0.039)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0.032, 0.048, 0.058, 0.074)	(0.005, 0.021, 0.032, 0.048)	(0, 0, 0, 0)	(0, 0, 0.005, 0.021)	(0.011, 0.027, 0.038, 0.054)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.03, 0.046, 0.056, 0.072)	(0.034, 0.05, 0.06, 0.076)	(0.005, 0.021, 0.032, 0.048)
EN7	(0.04, 0.056, 0.065, 0.079)	(0.058, 0.074, 0.085, 0.1)	(0.032, 0.048, 0.058, 0.074)	(0.032, 0.048, 0.058, 0.074)	(0.032, 0.048, 0.058, 0.074)	(0.085, 0.1, 0.106, 0.106)	(0, 0, 0, 0)	(0.032, 0.048, 0.058, 0.074)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.085, 0.1, 0.106, 0.106)
EN8	(0.058, 0.074, 0.085, 0.1)	(0.085, 0.1, 0.106, 0.106)	(0.036, 0.052, 0.062, 0.078)	(0.05, 0.066, 0.076, 0.092)	(0.032, 0.048, 0.058, 0.074)	(0.058, 0.074, 0.085, 0.1)	(0.085, 0.1, 0.106, 0.106)	(0, 0, 0, 0)	(0.005, 0.021, 0.032, 0.048)	(0.005, 0.021, 0.032, 0.048)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.058, 0.074, 0.085, 0.1)
EN9	(0.058, 0.074, 0.085, 0.1)	(0.05, 0.066, 0.076, 0.092)	(0.068, 0.084, 0.091, 0.096)	(0.076, 0.092, 0.098, 0.101)	(0.066, 0.082, 0.091, 0.102)	(0.076, 0.092, 0.099, 0.104)	(0.058, 0.074, 0.085, 0.1)	(0.059, 0.07, 0.073, 0.073)	(0, 0, 0, 0)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0.005, 0.021, 0.032, 0.048)
EN10	(0.013, 0.015, 0.016, 0.016)	(0.017, 0.033, 0.043, 0.057)	(0.05, 0.066, 0.076, 0.092)	(0.022, 0.037, 0.048, 0.064)	(0.066, 0.082, 0.091, 0.102)	(0.04, 0.051, 0.059, 0.07)	(0.04, 0.056, 0.066, 0.082)	(0.058, 0.074, 0.085, 0.1)	(0.058, 0.074, 0.085, 0.1)	(0, 0, 0, 0)	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)
EN11	(0.036, 0.052, 0.062, 0.078)	(0.013, 0.029, 0.04, 0.056)	(0.062, 0.078, 0.088, 0.101)	(0.08, 0.096, 0.102, 0.105)	(0.076, 0.092, 0.099, 0.104)	(0.066, 0.082, 0.091, 0.102)	(0.058, 0.074, 0.085, 0.1)	(0.026, 0.031, 0.033, 0.033)	(0.085, 0.1, 0.106, 0.106)	(0.085, 0.1, 0.106, 0.106)	(0, 0, 0, 0)	(0.005, 0.021, 0.032, 0.048)	(0, 0, 0.005, 0.021)
EN12	(0.058, 0.074, 0.085, 0.1)	(0.005, 0.021, 0.032, 0.048)	(0.049, 0.063, 0.072, 0.088)	(0.046, 0.062, 0.072, 0.088)	(0.076, 0.092, 0.099, 0.104)	(0.018, 0.023, 0.026, 0.031)	(0.05, 0.066, 0.076, 0.092)	(0.058, 0.074, 0.085, 0.1)	(0, 0, 0.005, 0.021)	(0.005, 0.021, 0.032, 0.048)	(0.032, 0.048, 0.058, 0.074)	(0, 0, 0, 0)	(0.005, 0.021, 0.032, 0.048)
EN13	(0.07, 0.086, 0.094, 0.103)	(0, 0, 0.005, 0.021)	(0, 0, 0.005, 0.021)	(0.058, 0.074, 0.085, 0.1)	(0.085, 0.1, 0.106, 0.106)	(0.085, 0.1, 0.106, 0.106)	(0.058, 0.074, 0.085, 0.1)	(0.032, 0.048, 0.058, 0.074)	(0.058, 0.074, 0.085, 0.1)	(0.032, 0.048, 0.058, 0.074)	(0.058, 0.074, 0.085, 0.1)	(0.032, 0.048, 0.058, 0.074)	(0, 0, 0, 0)

Source: The Author

#### 4. 1. DETERMINATION OF TOTAL RELATION MATRIX

$$T = X(I - X)^{-1}, \tag{13}$$

In this context, **I** represents the identity matrix, while **X** denotes the normalized direct-influence fuzzy matrix.

The fuzzy total relation matrix and the defuzzified total relation matrix are exhibited in Table 6 and Table 7. In the defuzzified total relation matrix, as indicated in Table 7, the summation of rows (D) and columns (R) is calculated as follows:

$$T = [ t_{ij} ] m \times m, i, j = 1, 2, \dots, m, \tag{14}$$

$$D = [ \sum_{j=1}^m t_{ij} ] m \times 1 = [ t_i ] m \times 1 \tag{15}$$

$$R = [ \sum_{i=1}^m t_{ij} ] 1 \times m = [ t_j ] 1 \times m \tag{16}$$

Table 6. Fuzzy total relation matrix

Code	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13
EN1	(0.03, 0.07, 0.123, 0.325)	(0.074, 0.12, 0.175, 0.367)	(0.018, 0.054, 0.099, 0.263)	(0.03, 0.087, 0.152, 0.376)	(0.077, 0.134, 0.197, 0.408)	(0.065, 0.127, 0.195, 0.418)	(0.028, 0.068, 0.128, 0.354)	(0.078, 0.127, 0.183, 0.373)	(0.078, 0.133, 0.197, 0.422)	(0.023, 0.076, 0.136, 0.347)	(0.024, 0.074, 0.132, 0.334)	(0.043, 0.086, 0.135, 0.308)	(0.101, 0.15, 0.202, 0.382)
EN2	(0.049, 0.1, 0.158, 0.36)	(0.016, 0.045, 0.087, 0.251)	(0.039, 0.077, 0.12, 0.271)	(0.02, 0.071, 0.132, 0.341)	(0.072, 0.125, 0.186, 0.389)	(0.027, 0.073, 0.131, 0.33)	(0.072, 0.121, 0.179, 0.388)	(0.067, 0.111, 0.163, 0.339)	(0.023, 0.075, 0.136, 0.347)	(0.016, 0.063, 0.12, 0.316)	(0.018, 0.064, 0.118, 0.306)	(0.015, 0.055, 0.101, 0.262)	(0.026, 0.073, 0.127, 0.308)
EN3	(0.031, 0.088, 0.152, 0.366)	(0.044, 0.093, 0.149, 0.339)	(0.018, 0.046, 0.084, 0.228)	(0.057, 0.114, 0.179, 0.399)	(0.061, 0.122, 0.188, 0.403)	(0.056, 0.119, 0.189, 0.41)	(0.031, 0.087, 0.152, 0.375)	(0.026, 0.076, 0.133, 0.321)	(0.069, 0.125, 0.187, 0.403)	(0.026, 0.079, 0.14, 0.347)	(0.083, 0.131, 0.187, 0.379)	(0.093, 0.135, 0.179, 0.335)	(0.046, 0.097, 0.156, 0.35)
EN4	(0.021, 0.066, 0.118, 0.303)	(0.012, 0.037, 0.075, 0.226)	(0.016, 0.05, 0.089, 0.227)	(0.017, 0.048, 0.092, 0.27)	(0.024, 0.071, 0.126, 0.313)	(0.055, 0.107, 0.165, 0.359)	(0.072, 0.115, 0.167, 0.359)	(0.018, 0.058, 0.104, 0.267)	(0.046, 0.084, 0.136, 0.33)	(0.069, 0.111, 0.16, 0.339)	(0.043, 0.079, 0.125, 0.298)	(0.007, 0.029, 0.067, 0.216)	(0.044, 0.085, 0.133, 0.299)
EN5	(0.081, 0.134, 0.194, 0.403)	(0.021, 0.069, 0.123, 0.311)	(0.015, 0.042, 0.078, 0.222)	(0.029, 0.085, 0.149, 0.366)	(0.029, 0.073, 0.128, 0.326)	(0.113, 0.173, 0.235, 0.437)	(0.027, 0.08, 0.143, 0.364)	(0.026, 0.073, 0.126, 0.309)	(0.08, 0.134, 0.197, 0.416)	(0.073, 0.124, 0.183, 0.386)	(0.037, 0.085, 0.142, 0.337)	(0.042, 0.083, 0.131, 0.298)	(0.073, 0.122, 0.177, 0.365)
EN6	(0.035, 0.067, 0.108, 0.261)	(0.012, 0.047, 0.088, 0.232)	(0.007, 0.026, 0.053, 0.162)	(0.041, 0.082, 0.13, 0.298)	(0.017, 0.062, 0.112, 0.278)	(0.012, 0.043, 0.085, 0.242)	(0.011, 0.038, 0.081, 0.253)	(0.02, 0.058, 0.1, 0.244)	(0.015, 0.056, 0.104, 0.274)	(0.014, 0.053, 0.098, 0.256)	(0.035, 0.071, 0.114, 0.265)	(0.037, 0.068, 0.105, 0.234)	(0.013, 0.05, 0.093, 0.241)
EN7	(0.062, 0.111, 0.164, 0.338)	(0.07, 0.112, 0.159, 0.317)	(0.012, 0.035, 0.067, 0.189)	(0.053, 0.104, 0.16, 0.343)	(0.026, 0.066, 0.114, 0.28)	(0.11, 0.165, 0.218, 0.384)	(0.022, 0.056, 0.101, 0.273)	(0.02, 0.052, 0.092, 0.236)	(0.076, 0.126, 0.182, 0.367)	(0.021, 0.069, 0.122, 0.295)	(0.021, 0.066, 0.116, 0.282)	(0.017, 0.055, 0.098, 0.24)	(0.098, 0.142, 0.186, 0.33)
EN8	(0.087, 0.15, 0.221, 0.463)	(0.104, 0.157, 0.214, 0.414)	(0.051, 0.097, 0.149, 0.331)	(0.077, 0.141, 0.215, 0.466)	(0.064, 0.132, 0.207, 0.452)	(0.098, 0.169, 0.247, 0.497)	(0.112, 0.172, 0.238, 0.477)	(0.023, 0.064, 0.119, 0.318)	(0.039, 0.104, 0.179, 0.433)	(0.028, 0.088, 0.157, 0.394)	(0.078, 0.134, 0.2, 0.427)	(0.022, 0.072, 0.129, 0.325)	(0.085, 0.143, 0.207, 0.424)
EN9	(0.086, 0.147, 0.216, 0.443)	(0.074, 0.128, 0.189, 0.391)	(0.083, 0.129, 0.176, 0.336)	(0.101, 0.164, 0.231, 0.455)	(0.095, 0.161, 0.232, 0.459)	(0.116, 0.187, 0.259, 0.485)	(0.086, 0.146, 0.215, 0.453)	(0.08, 0.131, 0.187, 0.374)	(0.033, 0.083, 0.146, 0.373)	(0.078, 0.137, 0.204, 0.427)	(0.032, 0.091, 0.155, 0.37)	(0.02, 0.054, 0.1, 0.271)	(0.037, 0.096, 0.159, 0.365)
EN10	(0.04, 0.083, 0.137, 0.333)	(0.039, 0.088, 0.142, 0.327)	(0.067, 0.109, 0.155, 0.311)	(0.048, 0.105, 0.169, 0.386)	(0.092, 0.15, 0.212, 0.42)	(0.077, 0.135, 0.2, 0.412)	(0.065, 0.119, 0.182, 0.401)	(0.075, 0.123, 0.177, 0.359)	(0.084, 0.139, 0.202, 0.42)	(0.022, 0.06, 0.11, 0.299)	(0.077, 0.126, 0.183, 0.378)	(0.02, 0.063, 0.112, 0.28)	(0.023, 0.06, 0.107, 0.284)

**Net Zero Transition Towards Decarbonization in Context of Energy Sector**

Code	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13
EN11	(0.067, 0.128, 0.196, 0.42)	(0.039, 0.094, 0.155, 0.355)	(0.082, 0.129, 0.178, 0.341)	(0.11, 0.172, 0.239, 0.457)	(0.109, 0.174, 0.242, 0.458)	(0.112, 0.182, 0.254, 0.479)	(0.088, 0.148, 0.217, 0.45)	(0.051, 0.097, 0.151, 0.334)	(0.118, 0.18, 0.246, 0.465)	(0.11, 0.168, 0.228, 0.43)	(0.027, 0.069, 0.123, 0.318)	(0.024, 0.073, 0.127, 0.308)	(0.03, 0.073, 0.132, 0.335)
EN12	(0.078, 0.128, 0.186, 0.384)	(0.024, 0.069, 0.12, 0.296)	(0.057, 0.091, 0.133, 0.282)	(0.062, 0.112, 0.171, 0.377)	(0.094, 0.146, 0.202, 0.393)	(0.048, 0.095, 0.152, 0.348)	(0.067, 0.116, 0.174, 0.381)	(0.07, 0.115, 0.167, 0.342)	(0.024, 0.06, 0.115, 0.324)	(0.02, 0.067, 0.123, 0.316)	(0.017, 0.049, 0.093, 0.266)	(0.014, 0.039, 0.075, 0.22)	(0.032, 0.08, 0.134, 0.313)
EN13	(0.102, 0.163, 0.23, 0.46)	(0.025, 0.064, 0.122, 0.335)	(0.02, 0.051, 0.098, 0.277)	(0.088, 0.151, 0.223, 0.469)	(0.117, 0.181, 0.248, 0.474)	(0.13, 0.199, 0.27, 0.5)	(0.087, 0.145, 0.216, 0.465)	(0.056, 0.111, 0.173, 0.382)	(0.092, 0.154, 0.225, 0.474)	(0.059, 0.118, 0.185, 0.416)	(0.079, 0.133, 0.197, 0.419)	(0.047, 0.094, 0.149, 0.339)	(0.031, 0.073, 0.127, 0.326)

Source: The Author

Table 7. De-fuzzified total relation matrix

Code	EN1	EN2	EN3	EN4	EN5	EN6	EN7	EN8	EN9	EN10	EN11	EN12	EN13	D
EN1	0.146226	0.196491	0.118751	0.170919	0.215602	0.211864	0.151424	0.203412	0.217531	0.155577	0.151603	0.155252	0.223373	2.318026
EN2	0.178257	0.109231	0.139967	0.150925	0.205142	0.150394	0.201403	0.183345	0.155522	0.138845	0.136993	0.119654	0.145096	2.014775
EN3	0.169888	0.168318	0.104536	0.19757	0.204876	0.204412	0.170983	0.1507	0.207358	0.158796	0.207966	0.201491	0.174279	2.321174
EN4	0.137945	0.096656	0.10736	0.115654	0.14437	0.184078	0.190614	0.122903	0.15934	0.182794	0.147697	0.087449	0.153088	1.829946
EN5	0.214716	0.14201	0.099345	0.167533	0.149139	0.252906	0.162629	0.145051	0.217761	0.203276	0.161379	0.15087	0.197521	2.264133
EN6	0.129858	0.106253	0.071946	0.150391	0.129351	0.10511	0.103329	0.11767	0.123183	0.116547	0.134044	0.12444	0.110803	1.522926
EN7	0.182777	0.178939	0.086294	0.177776	0.133427	0.23539	0.122841	0.111109	0.201253	0.138737	0.133461	0.114998	0.205708	2.02271
EN8	0.23906	0.235143	0.16945	0.232733	0.222474	0.26063	0.258723	0.140362	0.196629	0.175621	0.220057	0.147998	0.226175	2.725056
EN9	0.233581	0.20774	0.19622	0.248825	0.247715	0.272208	0.234468	0.206423	0.16747	0.222386	0.172848	0.121296	0.175802	2.706982
EN10	0.158815	0.16133	0.175211	0.187875	0.230698	0.217475	0.202551	0.19692	0.222555	0.132241	0.203357	0.130537	0.12862	2.348185
EN11	0.213327	0.172459	0.197642	0.255814	0.257613	0.267445	0.235322	0.170768	0.263635	0.247094	0.144044	0.14487	0.151693	2.721725
EN12	0.206498	0.138759	0.154427	0.192074	0.222366	0.172169	0.195921	0.187223	0.138406	0.142006	0.115686	0.096813	0.151974	2.114321
EN13	0.249032	0.144182	0.12007	0.24155	0.265479	0.284876	0.23617	0.191885	0.24451	0.204309	0.21769	0.169233	0.149066	2.718053
R	2.459978	2.057511	1.741221	2.489639	2.628252	2.818958	2.466377	2.127771	2.515154	2.21823	2.146825	1.764899	2.193197	

Source: The Author

Later, D and R values were added and subtracted to attain the values of prominence (D+R) and influence (D-R) as shown in Table 8.

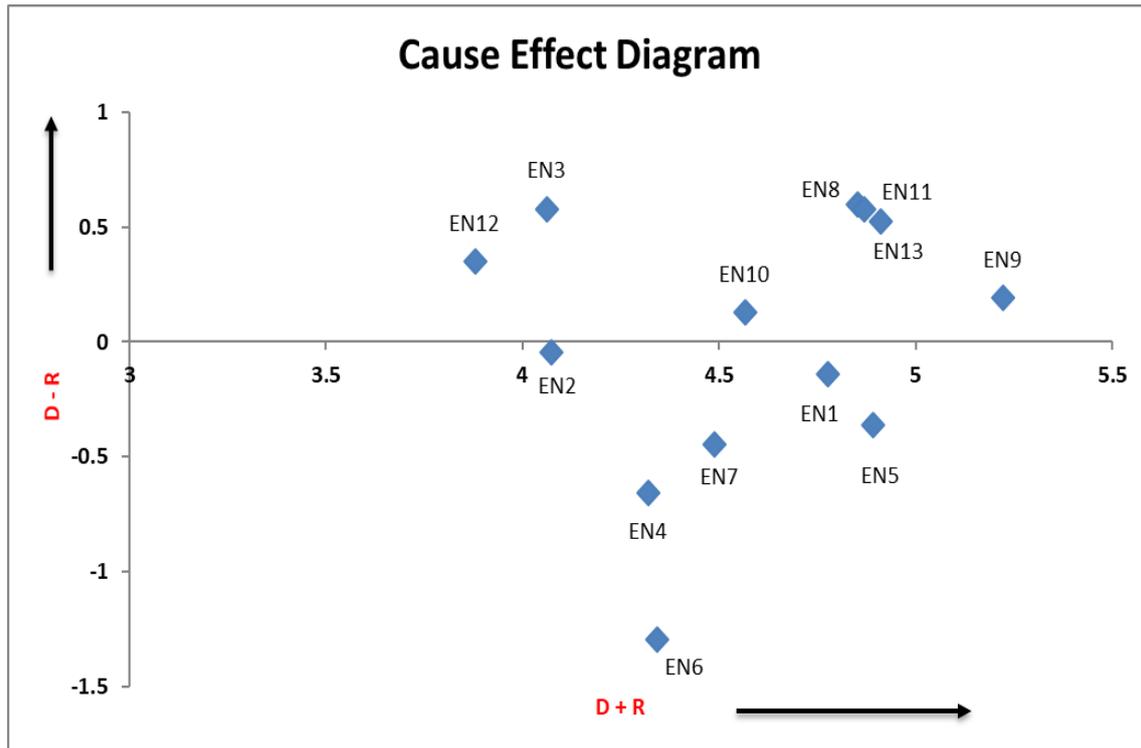
Table 8. The score for each enabler

Code	Enablers	D	R	D+R	D-R	Rank	Cause/Effect
EN1	Energy-as-a-Service Models	2.318026	2.459978	4.778004	-0.14195	6	Effect
EN2	Heat Recovery Systems in Industrial Processes	2.014775	2.057511	4.072286	-0.04274	11	Effect
EN3	Biogas Production from Agricultural Waste	2.321174	1.741221	4.062394	0.579953	12	Cause
EN4	Battery Reuse and Recycling	1.829946	2.489639	4.319585	-0.65969	10	Effect
EN5	Decentralized Energy Systems	2.264133	2.628252	4.892385	-0.36412	3	Effect
EN6	Smart Metering and Demand Response Programs	1.522926	2.818958	4.341884	-1.29603	9	Effect
EN7	Circular Design for Energy Infrastructure	2.02271	2.466377	4.489087	-0.44367	8	Effect
EN8	Smart Grid Technology	2.725056	2.127771	4.852827	0.597284	5	Cause
EN9	Carbon Pricing Mechanism	2.706982	2.515154	5.222136	0.191828	1	Cause
EN10	Blockchain for Energy Trading	2.348185	2.21823	4.566415	0.129955	7	Cause
EN11	Circular Procurement Policies	2.721725	2.146825	4.868551	0.5749	4	Cause
EN12	Urban Mining for Critical Metals	2.114321	1.764899	3.87922	0.349422	13	Cause
EN13	Waste-to-Energy Conversion	2.718053	2.193197	4.91125	0.524855	2	Cause

Source: The Author

The cause-and-effect diagram for the enablers is highlighted in Figure 2.

Figure 2. cause-and-effect diagram for the enablers



Source: The Author

## 4. 2. ANALYTICAL INTERPRETATION OF RESULTS

The results of the quantitative analysis (Table 8) and the Cause-Effect diagram (Figure 2) show that the energy transition has a clear hierarchical organization. The enablers are grouped into a Cause group (positive D-R) and an Effect group (negative D-R), which gives a roadmap on the implementation.

### 4. 2. 1. THE STRATEGIC TRIGGERS: THE CAUSE GROUP.

The analysis has discovered seven enablers of the cause necessitating the first priority that should initiate the transition.

- Carbon Pricing Mechanism (EN9) becomes the most prevalent driver (Rank 1). This insight suggests that economic incentives are the chief trigger; in the absence of an economic price on carbon, technological remedies have no business appropriate market signal to scale.
- The next important infrastructure and regulatory enablers are Waste-to-Energy Conversion (EN13), Circular Procurement Policies (EN11), and Smart Grid Technology (EN8). The high positive D-R values for EN13 (0.52) and EN8 (0.59), along with EN11 (0.57), indicate that policymakers cannot wait for consumer adoption they must proactively invest in smart grid infrastructure and implement procurement regulations to establish enabling conditions

### 4. 2. 2. THE OPERATIONAL OUTCOMES: THE EFFECT GROUP.

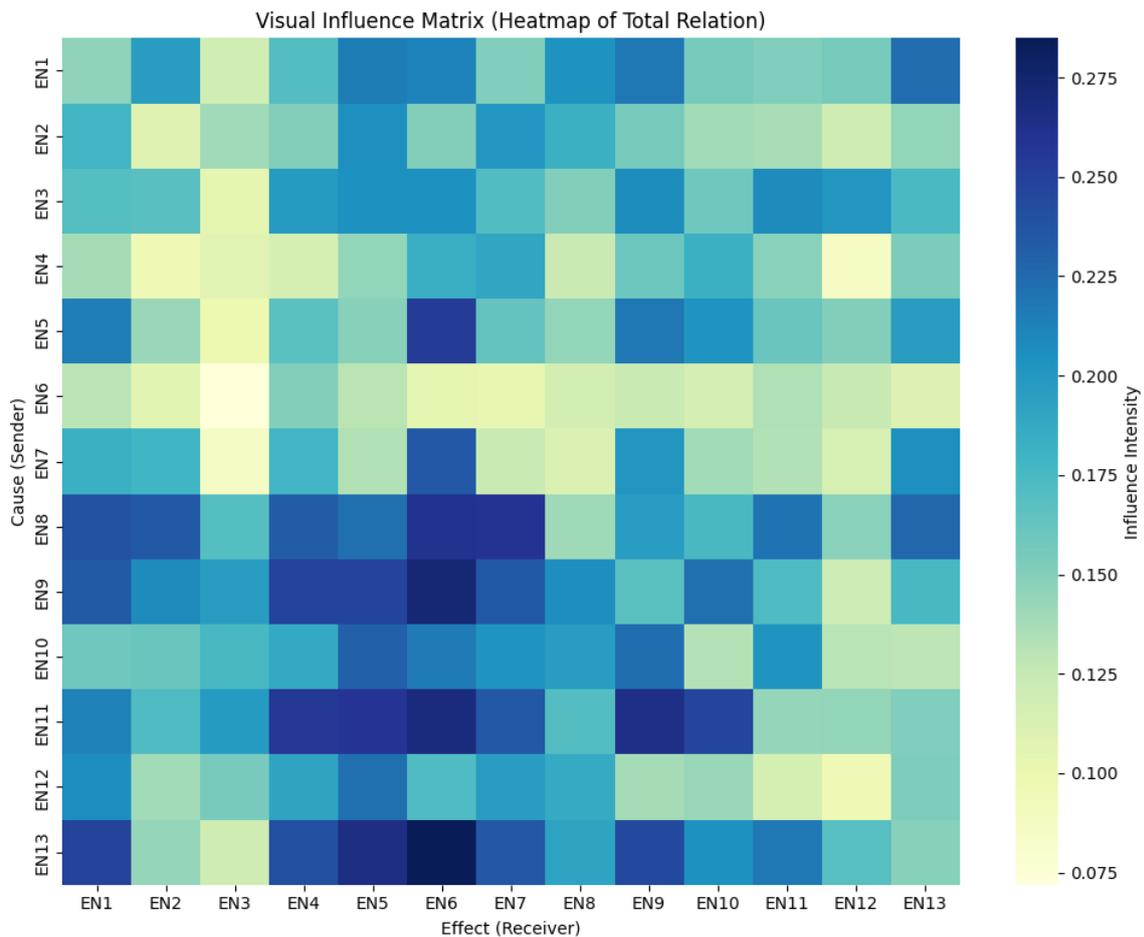
The effect group comprises seven dependent enablers that require antecedent implementation of Cause enablers.

- Decentralized Energy Systems (EN5) emerges as the most interconnected outcome

(Rank 3 prominence,  $D+R = 4.89$ ). Although central to the circular energy ecosystem (high  $D+R$ ), its negative  $D-R$  value ( $-0.36$ ) indicates that decentralization cannot be mandated directly; it develops organically when prerequisite regulatory frameworks particularly Circular Procurement Policies (EN11,  $D-R = +0.57$ ) establish market conditions for adoption.

- Similarly, Smart Metering and Demand Response Programs (EN6) exhibits the strongest dependency signature ( $D-R = -1.30$ ), indicating it is highly sensitive to prior enablers. Mass meter deployment cannot serve as an initial intervention; instead, it naturally follows Smart Grid Technology (EN8) infrastructure development, which provides the technical backbone for demand response capabilities.

Figure 3. Heat Map



Source: The Author

In order to solve the issue of the complexity of the relationships, the de-fuzzified total relation matrix (Table 7) is represented through a color-coded interaction matrix (Figure 3). The enablers are shown with a more or less intensity, which is emphasized by this visual matrix. Blacker shades of cell refer to greater direct impact. As can be seen, Carbon Pricing Mechanism (EN9) and Smart Grid Technology (EN8) were statistically significant and, as expected, were predominantly comparable in terms of high-intensity interaction with many rows (dark blue cells) which is a visual confirmation of their influence on the system as systemic drivers. On the other hand, the columns that refer to Smart Metering and Demand Response Programs (EN6) and Decentralized Energy Systems (EN5) are mostly dark which implies that they are strongly affected by the other enablers.

## 5. DISCUSSION

This study (Table 8 and Figure 2) shows that the change in energy state is mediated by an order of causes instead of a homogeneous body of enablers. In particular, Carbon Pricing Mechanism (EN9) and Waste-to-Energy Conversion (EN13) are the potential causal enablers. This observation is consistent with recent econometric work which asserts that carbon pricing mechanism is not simply a regulatory mechanism but the underlying tipping point that allows all other green technologies to scale (Ren et al., 2024). Whereas previous literature tends to place the concept of renewable technology adoption as a change agent, our structural analysis leads to the conclusion that it is an outcome, contingent on the economic messages that carbon pricing mechanism convey (Chantzis et al., 2023). This difference adds to the existing literature by explaining the policy intervention chronology i.e. economic incentives should precede technological requirements.

As the most impactful enabler, carbon pricing mechanism serves as a cause that drives the adoption of cleaner technologies by assigning a cost to carbon emissions (Haite et al., 2023). It is considered as means of an economic incentive, whereby companies as well as consumers will be pushed and pull enablers toward a low-carbon substitute and, therefore, changing energy behaviours and investments toward sustainable practice (Becattini et al., 2022). This carbon pricing mechanism is more effective in reducing GHG emissions and evidence suggests that carbon pricing mechanisms are the most efficient tool in increasing renewable energy development (Lilliestam et al., 2020; Liu et al., 2018). Notably, examples representative of such causes are waste-to-energy technologies, which act not only in energy renewal but also in the management of waste. By converting waste into energy, these systems thus act to reduce landfill usage and lower methane emissions, crucially contributing to climate change mitigation. In practice, it reflects approaches that are currently followed toward principles of the circular economy with an accent on resources' recovery and sustainability (Rusmanis et al., 2023). Energy decentralization systems, such as microgrids and localized renewable energy generation, are some of the impacts in the energy transition. Such systems enhance resilience in energy and also empower communities in the management of resources cost-effectively. They help in the easy integration of renewable sources from solar and wind into the energy mix by lessening dependency currently existing on centralized fossil fuel-based power generation (Sommarberg and Loikkanen, 2021). It is one of the driving forces that would push the sustainable practices in supply chains: circular procurement policies. Indeed, they incentivize not only the adoption of renewable materials and energy-efficient technologies but also the design of products and services under circular economy principles. As a result, environmental impact is lessened and innovation in the design of sustainable products is fostered (Ren et al., 2024; Sher, 2024). The very technology of smart grids just adheres to making energy distribution systems more efficient and reliable in carrying out their function of service delivery (Aziz et al., 2024). It enables better management of supply and demand toward integrating renewable energy through advanced communication and automation technologies for flexibility and responsiveness in the energy system (Ullah et al., 2021; Eissa, 2019). Models like Energy-as-a-Service are ways that the transition in the energy sector will be making the switch from a focus on energy consumption to a focus on energy services. The business model promotes energy efficiency and adoption of renewables by the consumer through an offered tailor-made solution without burdens in ownership (Liu et al., 2022). Therefore, this business model adaptation is crucial for the realization of sustainable energy behaviour.

Decentralized energy trading among consumers will be a trigger for blockchain technology (Esamat et al., 2021). In such a view, peer-to-peer will increase the quality of transparency and trust in the without-border application of blockchain technology in energy markets for maximal participation in renewable energy generation and consumption (Wu et al., 2022). This innovation may significantly change the dynamics in traditional energy markets. Circular design for energy

infrastructure are effects that support the sustainability of used assets by expanding their life and rendering them reusable and recyclable. Smart metering and demand response programs are enabling effects for customers in overseeing their power consumption (Pye et al., 2020). Their functionality is based on reducing resource extraction and the generation of waste, hence aligns with the circular economy (Su and Urban, 2021). Smart metering and demand response programs improve the efficiency of energy and grid stability through real-time data and providing incentives to end-users to minimize their energy consumption in peak periods (Chantzis et al., 2023). Specifically, the recycling and reuse of electric car batteries are a case in point that will address the challenges of resource depletion and environmental issues as far as the manufacturer of these batteries are concerned (Nurdiawati and Agrawal, 2022). These efforts help to bring up a more sustainable energy ecosystem by recovering useful materials and extending the useful life of batteries (Atia et al., 2019). One such example effect is the higher efficiency in energy of heat recovery systems in industrial processes (Zuberi et al., 2018). It is able to have high levels of energy savings with its overall consumed emissions reduced through the capture and recycling of waste heat, hence reducing the overall level of energy consumption by such systems in energy-intensive industries (Oh et al., 2024). This cause transforms biogas production from agricultural waste, which results in the generation of not only lifelong sustainable sources of energy but also in waste management that diminishes GHG emissions through the decomposition of organic waste (Akyürek, 2023; Materazzi and Foscolo, 2019). This cause lessens the environmental impact of heavy metal mining by recovering metals from electronic waste and other material wastes. The latter, related to urban mining for critical metals, supports circular economy realization and would decrease our dependence on finite resources by securing such critical materials for technologies under the renewable domain (Kurniawan et al., 2024).

## 5. 1. THE ROLE OF CIRCULAR ECONOMY IN ENERGY SYSTEMS

The rise of Waste-to-Energy Conversions (EN13) and Circular Procurement Policies (EN11) on our causal list upholds the digital movement in Renewable and Sustainable Energy Reviews that the principles of a circular economy is an intrinsic component of energy resilience (Materazzi and Foscolo, 2019). In contrast to less technologically advanced linear models covered in the past literature, recent research highlights that waste recovery is no longer merely an environmental compliance imperative, but an energy security strategy (Oh et al., 2024). It builds upon our findings regarding Circular Procurement Policies as a root cause (EN11), whereas Ullah et al., (2021) perceived it more as an operational result. This implies that supply chain rules are more influential as sources of systemic change than what is known in the literature.

## 5. 2. DECENTRALIZATION AND GRID RESILIENCE

The alignment of our finding that Smart Grid Technology (EN8) can be viewed as a key enabler in research conducted by Ahmad et al., (2022), which suggest that smart grids are the foundational platform of any renewable integration, is no coincidence. But we distinctly tabulate Smart Metering and Demand Response Programs (EN6) and Decentralized Energy Systems (EN5) as effects (Rank 6 and 3 in prominence, but negative D-R). The DEMATEL findings suggest that effective decentralization is a result of adequate pricing policies and grid modernization, rather than a precondition. The observation fills a significant gap in the literature on the question of why microgrid pilot initiatives fail to scale regularly without prior policy provisions (Aziz et al., 2024).

Enablers such as carbon pricing mechanism and decentralized energy systems, among many other sustainability policies and technologies, have so far continued to occupy central spaces dealing with the increase in the share of renewable energy sources in the energy production structure. Carbon pricing mechanism and decentralized energy systems are the key enablers

among the other sustainability policies and technologies that help to increase the share of renewable energy sources in the energy structure of the economy (Klemeš et al., 2023). Understanding such relationships is critical to the design of strategies for supporting a sustainable energy future that has been indicated recently in the literature focusing on energy behavior and acceptance of policy (Hromada et al., 2025). It is only when these enablers are incorporated into planning and decision-making of energy that the goals set at the global level for climate can actually be reached, in addition to having realized a resilient energy future (Ritchie, 2021).

## 6. IMPLICATIONS FROM THE STUDY

The study shows that evidence-based policy making, policy coherence, innovative business models, stakeholder collaboration, and policy evaluation are the primary driving enablers in the implementation of sustainable energy transitions. Using the methods above improves the change at and quickly upturns the transitional change toward sustainable energy systems with sustained concern for social equity concerns. Public awareness and participation fosters the culture of sustainability. Challenges presented by energy transition can only be effectively dealt with, if there is a well-coordinated approach between policymakers, society and academia. A sustainable energy future for stakeholders will be built by including research findings in policy development, promoting public engagement and including interdisciplinary collaboration (Liu et al., 2022). According to their claim, this will help realize the climate goals, the resilience of the energy system's equity and at the same time add benefits to society. The assertion repeated the fact that not only would the implementation of these goals push for progress toward climate goals, but it will definitely enhance the resilience of the energy infrastructure and provide equity toward the final benefit of society. It is necessary to ensure that these considerations be effectively integrated through a continuous commitment and joint effort from all stakeholders be involved.

### 6. 1. POLICY IMPLICATIONS

Policymakers are called upon to take evidence-based pathways to critical influential enablers, including carbon pricing mechanism and decentralized energy systems. In particular, policymakers need to use research-based empirical data and insights in guiding policy deliberations and choices, ensuring policies are scientifically based, not politically motivated or founded on assumptions. This alignment can strengthen the credibility and effectiveness of energy policies. Further, encourage closer coordination between Government agencies, private sectors and academes in the development of a more coherent approach to sustainable energy applications. Also, there is a need to develop policies that facilitate innovative business and technology models such as energy-as-a-service models or blockchain-related energy trade. This can be realized through the progressive development of financial incentives and pilot programs that can enable their adoption and in effect, drive this transition to renewable energy (Demartini et al., 2023).

### 6. 2. SOCIETAL IMPLICATIONS

The societal implications highlight the significance of stakeholder interest and education in fostering a sustainability culture. This refers to design and implement educational programs to make the public more aware on the benefits of sustainability practices and technologies. This may equip citizens and their communities with more effective choices for their demand for energy as well as further involving them in promoting renewable energy projects. Further to introduce mechanisms that enable citizens to have effective access to engage in decision-making about energy policy to communicate their views and preferences. Also, it should be made clear that policies would consider the social equity dimension of accessibility to energy resources at affordable prices and, in cases where energy transitions have been considered, they would be fair for all sections of the society.

## 7. CONCLUSION

This study gives a detailed discussion of the key enablers that influence the move towards a net zero transition in energy sector. The findings substantiate that the shift in energy is non-linear and dynamic and is activated by a diversified combination of enablers instead of just one. The results show that government policy, technological innovation, corporate strategy, and circular economy framework in the systematic interventions should operate as a combined organization to achieve net-zero energy system transformation. More precisely, the study emphasizes that knowledge-based policymaking, along with decentralized energy systems and procurement that is circular, is the most significant trigger of increasing the energy system resilience and sustainability. These findings have important implications to policy makers and industry players. To energy managers, the DEMATEL causal structure reveals a sequential dependency pattern. Phase 1 should prioritize policy and economic enabler Carbon Pricing Mechanism (EN9, D-R = +0.19) and Circular Procurement Policies (EN11, D-R = +0.57) which establish foundational market signals. Phase 2 must focus on infrastructure enabler Smart Grid Technology (EN8, D-R = +0.59) and Waste-to-Energy Conversion (EN13, D-R = +0.52) which build the technical backbone required for downstream systems. Phase 3 involves deploying operational technologies Smart Metering and Demand Response Programs (EN6, D-R = -1.30) and Energy-as-a-Service Models (EN1, D-R = -0.14) which demonstrate the highest dependency (negative D-R values) and cannot achieve acceptable return on investment without prior phases. This will avoid a frequent trap of investing in Effect technologies (such as smart meters) without first having an Infrastructure (such as smart grids) in place that can support them. To policymakers, the research indicates the need to go beyond the individual regulations to coherent, evidence-based models to incorporate carbon pricing mechanism with social equity implications. The necessity to develop collaborative governance which would close the divide between the public agencies and the private sectors is critical. The findings imply that moving to new types of business models like energy-as-a-service or blockchain-made trading will be necessary to stay financially viable in this transition to the industry. Firms are advised to match their corporate strategies to the idea of the circular economy to utilize the opportunities in the market.

In spite of these insights, this study has its limitations which should be accepted. First, the study analysed a set of enablers, which could be not sufficient to reflect the entire richness of future energy situations in which new disruptive aspects might arise. Second, the conclusions are based on quantitative analysis to a large degree; statistically solid but this method may underestimate subtle qualitative enablers such as cultural resistance or unofficial social processes playing a major role in determining the transition rate. And lastly, the overall significance of the identified enablers might differ in many geographical and socio-economic settings, and it is not possible to infer the findings to all regions of the world.

Further studies ought to seek to support these results in a wider context. Researchers are urged to embrace longitudinal designs to monitor how these enablers interact and change over time and this offers a better understanding of the temporal dynamics of the transition. Moreover, qualitative methods, including stakeholder interviews and case studies, would provide more information on the barriers and facilitators of the sustainable practice of energy in particular. It would also be interesting to diversify the geographical areas of investigation especially those in developing economies to come up with more knowledge about the transitions of energy around the world.

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## Appendix A

Sl. no.	Designation	Experts	Experience (years)	Field
1	Total quality manager	2	10	Circularity expert
2	General Manager	1	15	Recycling certification and sustainability
3	Government officials	2	10	Ministry of New and Renewable Energy
4	Researchers	3	25	Researcher domain belonging to Renewable energy and decarbonization
5	Government officials	2	16	Ministry of commerce and industry
6	Managers	3	28	Composite units and recycling business