# A Grey-DEMATEL Approach to Prioritize Challenges for Decarbonization of Energy Sector

Anil K Sharma, Manoj K Srivastava
Management Development Institute-Gurgaon
Corresponding author: Anil K Sharma, Email: efpm22anilkumar_s@mdi.ac.in

The paper identifies and ranks the challenges for decarbonization of the energy sector in India using the Grey-DEMATEL technique of MCDM. The research aims to understand why decarbonization is slow and prioritize the challenges that need to be addressed first. This paper contributes to the domain of decarbonization of the energy sector in India by identifying and ranking the challenges through the Grey-DEMATEL technique of MCDM. The paper addresses why decarbonization of the energy sector is very slow and which challenges are to be addressed first. The paper provides a methodology for identifying and ranking the challenges, which can be useful for policymakers and stakeholders in the energy sector.

**Keywords**: Grey-DEMATEL, decarbonization, energy sector, MCDM

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# 1 Introduction

The Indian power sector is one of the most diversified in the world. In electricity generation, India is in third place while in consumption, it is the second-largest worldwide. Total All India Installed Electricity Generating Capacity as of August 31, 2022 is 405773.22 MW comprising of Thermal 236065.42 MW, Hydro 46850.17 MW, Nuclear 6780.00 MW and 116077.64 MW from renewable energy sources (Central Electricity Authority, CEA) The growth in the population and per capita usage increase will further lead to rise in demand for electricity. As per the national infrastructure pipeline for 2019-25, energy sector projects accounted for the highest share of this demand, which further poses challenges for decarbonization plans.

The historic Paris Agreement of 2015 [1] on climate change has been adopted by 196 countries to reduce global warming and build resilience to climate change. Its overall goal is to limit warming to no more than 1.5 °C. Currently, the Earth is already about 1.1°C warmer than it was in the late 1800s, and emissions continue to rise.

Humans have triggered climate change, which is responsible for global warming, which is a massive threat to the planet Earth. To limit global warming to 1.5 °C, it needs global net human-caused carbon dioxide emissions ($CO_2$) to reduce by around 45% from 2010 levels by 2030 and thus reach net zero by around 2050 [2]. Also, any remaining emissions in the atmosphere will have to be well-adjusted by taking out $CO_2$ from the atmosphere. The electricity sector emitted 12.3 Gt $CO_2$ in 2020 (36% of all energy-related emissions), which is more than any other sector. Coal remains the largest single source of electricity worldwide and by far the largest source of electricity sector emissions: it contributes just over one-third of electricity supply but is responsible for nearly three-quarters of electricity sector $CO_2$ emissions. and therefore holds the key to preventing the worst effects of climate change [3].

Due to the predicted population growth, energy consumption is going to increase drastically by 2050. As per this anticipated rise, a great deal of focus is being put on smart technologies to meet this demand; however, decarbonization should be a fundamental component of the solution provided [4]. Decarbonization and net zero commitments are linked to national priorities; these priorities can be related to energy for all and sustainable development. Thus, every country has its own considerations depending on its limits, constraints, and capabilities for accelerating decarbonization, it therefore has its own set of technology priorities and policies [5].

The achievement of decarbonization can be facilitated by the widespread implementation of sophisticated low-carbon technologies, alongside the adoption of strategies that promote greater investments in low-carbon infrastructure and a reduction in investments in fossil fuel-based technologies within the power and transport sectors. Hence, it is imperative to acquire a comprehensive comprehension of the sectoral transition paths across all climate targets to effectively synchronize inter-sectoral endeavors and allocate resources in a manner that optimizes cost-efficiency [6]. To reduce the effect of climate change, energy sector decarbonization is possible by means of wide-ranging new actions in the energy sector. The electricity market being complex and having a dynamic environment, requires manifold views and an all-round approach [7].

The contribution of renewable energy has increased as a primary energy source, this has been made possible due to the focus on climate change and worldwide efforts on the carbon dioxide emissions reduction pledge. However, in the future, all countries must also extensively focus on the decarbonization of the energy sector [8]. Wind and solar energy technologies will definitely have a vital role to play in eliminating energy generated by coal and also in decarbonizing the power sector in the future [9].
In this paper, the challenges for decarbonizing the energy sector have been identified through a review of selected articles and reports from prominent consulting companies. Further, these challenges have been ranked and causal relationships drawn based on outcome of the Grey-DEMATEL technique of MCDM. The research questions being answered by this paper are:

RQ1: Why is the decarbonization of the energy sector very slow?
RO1: To find out the challenges for the decarbonization of the energy sector.

RQ2: Which challenges are to be addressed first?
RO2: To prioritize the challenges for decarbonization of the energy sector

## 2 Research Methodology

A combination of literature review and interviews with industry experts of the domain were conducted to finalize the Challenges for Decarbonization of the Energy Sector (CDES). This was done in two steps. In the first step, research papers and reports from the consultancies working in the area were reviewed to list the probable challenges. In the second step, these challenges were sent to industry experts for their review and suggestions. After their comments, the list of final challenges was drafted as mentioned in Table 2.

A methodology based on the Grey-Decision Making Trial and Evaluation Laboratory (DEMATEL), a hybrid multiple-criteria decision-making (MCDM) technique, has been used to envisage the complex causal relationships among the identified challenges. These challenges are ranked as per prominence, and identifying cause and effect as per the net effect number.

### 2.1 Grey-systems Theory

Grey-systems theory provides support in business situations that involve a lack of certainty and some involve some element of randomness. In business situations involving human judgment, some probabilistic component is essentially considered. Grey-systems theory is useful in these situations and can produce far better and more rigorous models of a phenomenon. A grey number $\otimes x$ is defined as an interval with known upper and lower bounds but having unknown distribution information for x [10] as shown in Table 1. The grey-systems theory, when coupled with the DEMATEL method, helps to conduct a rigorous analysis of the data collected from respondents in linguistic terms. It captures the essence of judgments and minimizes the loss of information. The response is collected as an influence score (0-4) and converted in to grey number as explained under Section 2.4, Grey DEMATEL Procedure.

**Table 1.** Linguistic response with corresponding influence score and Grey numbers

| Linguistic response | Influence score | Grey number |
|---|---|---|
| No influence (N) | 0 | [0,0] |
| Ver low influence (VL) | 1 | [0,1] |
| Low influence(L) | 2 | [1,2] |
| High influence (H) | 3 | [2,3] |
| Very high influence (VH) | 4 | [3,4] |

### 2.2 DEMATEL Approach

The DEMATEL methodology was created by the Battle Memorial Institute of Geneva over the period from 1972 to 1976. The fundamental principle underlying this approach was to employ quantitative techniques to capture intricate human judgments and cultivate a more streamlined comprehension of the phenomenon. According to [11], the assertion is made that a comprehensive understanding of any given notion can be achieved by examining its constituent factors and organizing them into a hierarchical framework that interconnects all the factors. In order to construct the present model, the relevant data concerning the interconnectedness of the elements is gathered from domain experts and subjected to sophisticated mathematical methodologies for analysis and interpretation. The interrelationships essentially encompass the impact that each variable exerts on every other variable. This approach heavily relies on the utilization of directed graphs, also known as diagraphs, to visually represent the causal relationships among the variables associated with a particular phenomena. The DEMATEL approach has seen recent developments, which involve the incorporation of grey numbers to effectively capture the intricate human judgement by considering the inter-relationships among many parameters.

## 2.3 Rationale for Selecting Grey – DEMATEL Approach

The objective of this study was to determine the hierarchical position of the CDES and establish its causal relationship. In order to achieve this purpose, data pertaining to the interdependencies of difficulties was gathered utilizing grey numbers and afterwards analyzed through the employment of the grey-based DEMATEL approach. The data was obtained from a sample of four executives who hold positions in reputable organizations within the energy industry, encompassing power generating and original equipment manufacturers (OEMs) in India. The DEMATEL technique, which is based on grey theory, effectively incorporates linguistic variables and a grey aggregation method, so mitigating the potential for imprecise and ambiguous judgments.

The DEMATEL approach combined with Fuzzy, grey, ISM etc. has been extensively used by researchers for ranking and prioritizing decision variables and tackling challenges. Grey DEMATEL has been used by [12] to develop third-party logistics provider selection criteria, by [13] to Model critical success factors for sustainability initiatives in supply chains in the Indian context, by [14] to Model enablers of supply chain quality risk management, and by [15] to model supply chain sustainability drivers for the FMCG sector.

## 2.4 Grey DEMATEL Procedure

Step 1: Compute the average grey direct-relation matrix: The linguistic responses of each expert were collected through a survey, thereby recording the influence of CDES i on CDES j. The responses were converted into associated grey scales using the labels. Grey scales are specified by an upper range and a lower range of values.

This step resulted in 4 grey relation matrices. These 4 matrices are then aggregated to create an average grey relation matrix.

Step 2 Compute the crisp direct- relation matrix from grey relation matrix: The three-step procedure of the modified CFCS method suggested by [16] for converting grey numbers into crisp numbers has been followed.

Step 3: Compute the normalized crisp direct-relation matrix (R): The normalized crisp relation matrix is computed by multiplying the average relation matrix with Normalising factor.

Step 4: Computing the total crisp relation matrix: The total-relation matrix, T is calculated as follows:

$$T = R \times (I - R)^{-1} \quad (1)$$

where I is the identity matrix and $(I - R)^{-1}$ is the inverse of the matrix resulting from the subtraction of identity matrix, I and matrix R.
Additionally, the threshold value $\theta$ can be computed based on the mean ($\mu$) and standard deviation ($\sigma$) of the values from the total-relation matrix $T$ [17]. However, for this study, the threshold value $\theta$ has been restricted to only mean ($\mu$) to have diagraph with more relations. Diagraph is drawn is per Step 6

Step 5: Obtaining causal parameters: In this step, the sums of rows and columns of the Total Relation Matrix T are obtained.

The sums of the row values determine the sum of influence given by a criteria or factor and denoted as D. The sums of column values decide the sum of influence received by a factor denoted as R. Next, the overall prominence, (R+D) and net effect (or relation), (R-D) of each of the factors are obtained.

Step 6: Plotting a diagraph: A diagraph is plotted through a dataset consisting of (R + D, R − D). Before plotting the diagraph, a threshold value $\theta$ from Step 4 is used to filter out negligible effects in the total relation, the T matrix. All values greater than $\theta = \mu$ (mean) are used to draw the diagraph.

## 2.5 Challenges for Decarbonization of Energy Sector

The various challenges identified after literature review has been listed down in below table.

**Table 2.** Challenges for Decarbonization of energy sector

| Challenges | | Description | References |
|---|---|---|---|
| C1 | High initial Investment cost of new technologies | High investment cost of new technologies, High Investments required in energy conversion systems | [8]<br>[18]<br>[3] |
| C2 | Technological challenges | Low energy conversion efficiency of renewable resources Harnessing technology which is having no carbon emission (Immature new technologies like Hydrogen, NH3, energy storage etc.) | [18]<br>[19]<br>[20] |
| C3 | Government policies and regulations | Lack of relevant regulations and standards, Balance of Regulation and responsibility, Policy, and government targets | [18]<br>[20]<br>[19] |
| C4 | Operational Challenges | Building resilient supply chains for clean energy,<br>Collaboration with suppliers and customers<br>Expanding and upgrading transmission and distribution networks. Energy mix-Fossil and renewable energy mix is a challenge Retrofitting challenges | [21] |
| C5 | Social Challenges | Ensuring power supply reliability Harmonizing the renewables industry's relationship with land and the community. Customer, employee, and community demands. Need to provide Reliable and affordable energy to all | [21]<br>[19]<br>[8] |
| C6 | lack of management willingness | Resistance Mindset of management towards decarbonization | [22] |

## 2.6 Challenge Matrix for Response from Industry Experts.

The CDES are put in the form of a matrix for getting responses (an influence Score) from industry experts. Instructions to fill out the score are mentioned under notes; additionally, each expert was contacted personally to explain the context and clarify their queries so that they could give correct response.

**Table 3.** Challenges matrix for response from experts

| How important is one challenge to another (Bx to By) | | High initial Investment cost of new technologies | Technological challenges | Government policies and regulations | Operational Challenges | Social Challenges | lack of management willingness |
|---|---|---|---|---|---|---|---|
| | | C1 | C2 | C3 | C4 | C5 | C6 |
| High initial Investment cost of new technologies | C1 | | **a** | **b** | **c** | **d** | **e** |
| Technological challenges | C2 | | | | | | |
| Government policies and regulations | C3 | | | | | | |
| Operational Challenges | C4 | | | | | | |
| Social Challenges | C5 | | | | | | |
| lack of management willingness | C6 | | **z** | | | | |

Instructions to Fill

1. We Need to assign numbers 0-4 for all blue cells, while Black cells should not be filled as these will have number zero.
2. a,b,c,d….shall be a number from 0-4 which you have to fill in depending on how important C1 is to C2, C1 is to C3 and C1 is to C4 and so on. see below for examples for further clarity:

"a" will be a number that you will assign from 0-4 depending on your view of how important C1 (High initial Investment cost of new technologies) is for C2 (Technological challenges) and so on.

"z" will be a number that you will assign from 0-4 depending on your view of how important C6 (lack of management willingness) is for C2 (Technological challenges) and so on.

# 3 Outcome of Study/Results and Discussion

The grey-based DEMATEL approach was utilized to uncover causal relations among the identified CDES. Industry experts rated the prominence and relation effect of each of the eight CDES (C1–C6) based on pairwise comparison data. Every expert evaluated each challenge's influence on every other challenge, resulting in a direct-relation matrix. Table 4 shows the final total relation matrix with threshold analysis (highlighted values are above threshold).

obtained using steps 1–4 of the Grey DEMATEL for all entities. The threshold value has been calculated as the mean (1.203) to sort out several relationships with a value higher than θ.

**Table 4.** Final total direct relation matrix based on DEMATEL calculation steps

| | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| C1 | 1.246 | 1.425 | 1.861 | 1.227 | 1.226 | 1.104 |
| C2 | 1.316 | 1.110 | 1.673 | 1.181 | 1.098 | 0.945 |
| C3 | 1.288 | 1.192 | 1.448 | 1.065 | 1.164 | 1.041 |
| C4 | 1.189 | 1.197 | 1.553 | 0.923 | 0.992 | 0.970 |
| C5 | 1.085 | 1.173 | 1.542 | 1.039 | 0.903 | 0.958 |
| C6 | 1.270 | 1.192 | 1.621 | 1.098 | 1.099 | 0.878 |

Based on the sum of rows and sum of columns (denoted by D & R respectively) of the total relation matrix the (D + R) and (D – R) scores were calculated. The (D+R) score, called "prominence", depicts the degree of influence of an CDES on others, while the (D–R) score, called 'relation', indicates the net effect that an CDES attributes to the other drivers examined [23]. Examined CDES with positive (D–R) scores were classified in the cause group; and those with negative scores were categorized as effects.

The larger the absolute value of (D+R), the more impactful the challenge for decarbonization. Table 5 shows the prominence and net effect values. The data set in Table 5 is plotted to create diagraph (Figure 1) showing the causal effect among the CDES. Only relationships meeting or exceeding the threshold value are plotted. The arrows in the figure represent the association between the two drivers.

**Table 5.** Prominence and net effect values based on DEMATEL calculation steps

| | D | R | Prominence (D + R) | Rank | Net effect (D - R) | Cause/ Effect |
|---|---|---|---|---|---|---|
| C1 | 8.09 | 7.394 | 15.484 | 2 | 0.696 | 2 |
| C2 | 7.322 | 7.289 | 14.611 | 3 | 0.033 | 5 |
| C3 | 7.198 | 9.698 | 16.896 | 1 | -2.5 | 6 |
| C4 | 6.824 | 6.534 | 13.358 | 4 | 0.29 | 3 |
| C5 | 6.701 | 6.482 | 13.183 | 5 | 0.219 | 4 |
| C6 | 7.158 | 5.897 | 13.055 | 6 | 1.261 | 1 |

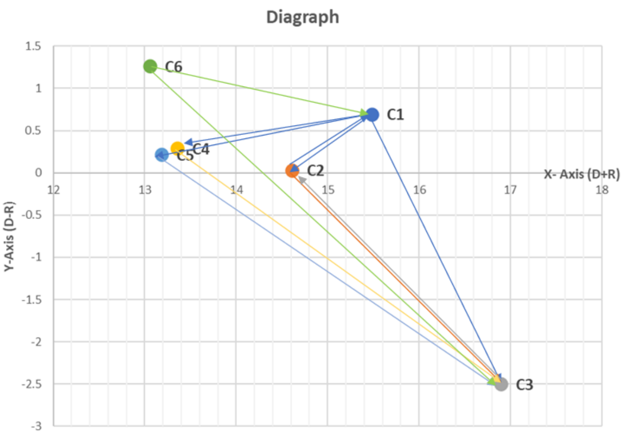


**Fig. 1.** Diagraph (Author's owner creation basis DEMATEL process calculation)

# 4 Discussion

## 4.1 Key Causal CDES

Among the entire CDES, "lack of management willingness (C6)" have the maximum D – R score of 1.261, but has the lowest power to affect other CDES by D+R value (13.055). This makes it apparent that management willingness plays a key role in decarbonization initiatives, especially when government policies are very strong.

The second influencing CDES as per the D – R scores of 0.696 is the "High initial Investment cost of new technologies (C1)", This can be attributed to the fact that most of the new technologies available in the market have low RoI therefore an influencing challenge.

"Operational Challenges (C4)", with D – R score of 0.20 is ranked third, and having rank 4 as prominence with D+R score of 13.358, a firm's operational challenges are also falling among the key causal challenges since many operations challenges are associated with regards to new technologies like retrofitting with existing technologies and in terms of low efficiency as well.

## 4.2 Key Effect CDES

Based on the analysis (D–R scores), the CDES are classified into the effect or impact group of CDES. As per the analysis, the only CDES that is in effect is "Government policies and regulations (C3)". This CDES has rank 1 as per the prominence (D+R score) of 16.896, which indicates that all the challenges are having an effect on C3 which also has the highest rank and thus is the most important challenge to be tackled.

# 5 Conclusion and Implication

Based on the analysis and discussion of the results obtained by applying grey DEMATEL steps, it can be concluded that "lack of management willingness (C6)" , "High initial Investment cost of new technologies (C1)", and "Operational Challenges (C4)" are the key top three causal CDES. The industry practitioners should focus mainly on these key causal barriers to achieve significant decarbonization in the energy sector. Further, since the analysis points out towards "Government policies and regulations (C3)" as the key effect CDES with the highest rank, so the policy makers and regulating bodies should focus on making and enforcing policies favoring decarbonization, which should also eliminate the key causal barriers.

The implication for industry practices is that the findings of the study will give direction to the government and environmentalists to lay down the path forward to achieve the decarbonization target by removing the barriers highlighted in this study. The study results will help industry people, particularly companies in countries with emerging economies that have significant initiatives, by eliminating the barriers highlighted. The managers can plan to take action on the top barriers to contribute towards decarbonization, net zero emission, and ultimately fighting climate change (CC).

# 6 Limitations and Future Direction for Research

This study has been conducted by collecting responses from two senior executives of two different energy sector companies. Although the grey theory given by [10] has been applied in order to deal with a lack of certainties and subjectivity, it is possible that there could still be some degree of judgment error because of variations in the amount of expertise, familiarity, and perception of the industry experts.

Future research may also investigate the potential of using industry 4.0 techniques like artificial intelligence, as well as other cutting-edge digital technologies like IoT and cloud computing, the metaverse, and digital twins, to track and manage the various players in energy and other carbon-intensive industries from the perspective of decarbonization.

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