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# Challenges in the Adaptation of Biomass Energy in India: A Multi-Criteria Decision-Making Approach Using DEMATEL

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**Abstract:** As a rapidly developing nation, India faces an urgent need to diversify its energy portfolio to ensure long-term sustainability and energy security. Biomass energy, as a renewable and sustainable resource, has the potential to play a crucial role in achieving these objectives. Its integration into the national energy framework, however, is hindered by multiple challenges, including technological limitations, socio-economic constraints, and environmental concerns. Despite its advantages—such as reducing greenhouse gas emissions, promoting economic growth, managing waste, and preserving biodiversity—several barriers must be systematically analyzed to facilitate its widespread adoption. In this study, a structured approach is employed to identify and evaluate the key challenges associated with biomass energy adaptation in India. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology is applied to determine the relative importance of these challenges, offering insights into the most critical criteria that require focused intervention. The findings of this study are expected to provide a strategic foundation for policymakers and stakeholders in formulating effective policies and technological solutions to enhance the viability of biomass energy in India's energy transition.

**Keywords:** Biomass energy; Renewable energy; Crisp value; Decision-Making Trial and Evaluation Laboratory (DEMATEL); Energy transition; Sustainability; Multi-criteria analysis

## 1 Introduction

Energy resources play a vital role in the overall development of each country. Especially in a country like India, one cannot deny the huge impact of energy resources on its economy as well as on the development of society. From an early age, fossil fuels and coal are used as the primary energy resources, but there are some drawbacks to using these, such as greenhouse gas emissions, limited stock, air pollution, etc. So, to address the energy demand, alternative renewable energy resources are needed. In India, a sufficient amount of agricultural residue, organic waste, and natural resources are available that can be used for biomass energy production. Thus, by promoting the use of biomass energy, it is possible to make a cleaner and eco-friendly atmosphere. Despite having various benefits of using biomass energy, there are some difficulties in using biomass energy on a large scale. Lack of modern technologies, poor transportation systems, lack of funds, limited knowledge of people, etc., are some of the challenges of accepting biomass energy as an alternative resource. By adopting proper steps to overcome the challenges, biomass energy will become a reliable and sustainable energy resource for our country.

### 1.1 Biomass Energy

Biomass energy is one of the main renewable energy resources. Using organic wastes like crop residue, forestry waste, animal manure, etc., biomass energy is produced. Biomass energy helps to create a cleaner ecosystem as it reduces greenhouse gas emissions and utilizes organic waste. Biomass energy can be generated through various processes, namely fermentation, anaerobic digestion, and combustion, and transformed in the form of biodiesel, bioethanol, and biogas. Biomass energy is very much effective for the development of rural areas, as it can be used for cooking, heating, producing electricity, etc. There is much research work focusing on biomass energy. In 2023, Tshikovhi and Motaung [1] worked on their paper about Technologies and Innovations for Biomass Energy Production. Kumar et al. [2] provide a review on biomass energy resources, potential, conversion, and policy in India. Wang et al. [3] in their work concentrated on biomass energy production and its impacts on the ecological footprint. Abbasi and Abbasi [4] focuses on the environmental impacts associated with the production and utilization of biomass energy. Antar et al. [5] in their research give an overview of world biomass production and utilization for generating a sustainable bio-economy. Kabeyi and Olanrewaju [6] in their study discussed the production of biogas and its use for sustainable power generation. Banerjee [7] discussed different resources of biomass, different technical ways for bioenergy conversion, and other challenges related to biofuel production. Kumar et al. [8] in their paper focus on techniques used for the conversion of agricultural residues in the form of biomass energy. Negi et al. [9] in their work concentrated on the situation of biomass availability in India and its potential to generate bioenergy.

### 1.2 MCDM Method for Decision Making

Multi-Criteria Decision-Making (MCDM) is a powerful technique used for tackling complex decision-making problems where multiple conflicting criteria are present. There are various types of MCDM methods; some of them are used to find the criteria weight, some for ranking alternatives, and some are used to find the relationship among the criteria related to that problem. Depending on the nature of the problem, we can choose which method will be applicable to fulfill the purpose. The MCDM method is applied in various fields, including teacher selection [10], site selection for renewable energy [11], the healthcare supplier selection problem [12], sustainable transportation systems analysis [13], selection of pesticides in agriculture [14], student performance evaluation [15], site selection for restaurant [16], etc.

In this paper, we use the decision-making method named Decision-Making Trial and Evaluation Laboratory (DEMATEL). This is a MCDM procedure, and it helps to determine the cause-and-effect relationships. This methodology can be used to solve various complicated issues, analyze the criteria, and boost their effectiveness. In the backdrop of biomass energy adaptation, DEMATEL facilitates identifying key obstacles, such as high initial costs, limitations of technology, supply chain inefficiencies, policy difficulties, infrastructure requirements, public acceptance, etc. By mapping these interconnected elements, decision-makers (DMs) might strengthen policy frameworks, prioritize required solutions, and optimize resource allocation. The wide variation in biomass energy availability and conversion efficiency further complicates adaptation. Collaboration with stakeholder efficiency and financial incentives is significant for removing these obstacles. In the final phase, DEMATEL contributes to creating strategic pathways for the successful integration of biomass energy. Here, we explain some works on DEMATEL in an ambiguous environment. It already applied to determine the crucial criteria for the solar power plan project [17], analyze emergency facilities and urban fire [18], lay out the methodology of DEMATEL under a bipolar unpredictable environment [19], identify the obstacles to the execution of circularity in the aluminum industry [20], and so on.

### 1.3 Advantages of Using Biomass Energy Resources

Regarding using alternative sources of renewable energy, biomass energy acts as a great option. There are multiple advantages of using biomass energy:

**(i) Renewable and sustainable energy resource:** Biomass energy is obtained by using organic materials like wood, agricultural residues, bio-waste, seaweed and algae, etc., and further converted to produce heat, electricity, bio-fuel, etc. The materials from which biomass energy is generated can be restored through natural growth cycles, and by managing this process sustainably, we can get a continuous energy source.

**(ii) Carbon neutral energy source:** Carbon neutral means a cycle where the amount of carbon dioxide ($CO_2$) released during energy production is nearly equal to the quantity of $CO_2$ absorbed by plants during their growth. So, biomass energy acts as a carbon-neutral energy source.

**(iii) Reducing of waste materials:** In the process of biomass energy production, energy is generated from agricultural residues, forestry waste materials, food scraps, used papers, organic waste generated during paper manufacturing, food processing etc. Thus, biomass energy helps to manage waste by converting the waste material into environmentally friendly, secure energy resources.

**(iv) Economic growth:** The process of biomass energy production required manpower. So, it creates job opportunities for a huge number of people. Usage of biomass energy in agriculture and household work also reduces the expenditure of each family to use energy. Thus, in rural areas, biomass energy production helps to promote sustainable economic growth.

**(v) Versatile applications:** Biomass energy can be produced through various processes, and it generates heat, electricity, bio-diesel, bio-ethanol, biogas, etc. So, biomass energy has a vast application area.

**(vi) Reducing greenhouse gas emissions:** Biomass energy can act as an alternative resource of energy instead of fossil fuels like coal, petroleum, natural gas, etc., which also reduces greenhouse gas emissions, hence it helps to maintain ecological balance.

### 1.4 Structure of the Work

The structure of this research is presented here. The introduction of finding the most important criteria for adaptation challenges of biomass energy in India is thoroughly discussed in Section 1. Advantages of using biomass energy resources are explained in Section 1.3, and Section 1.4 displays the present status of producing the international biomass energy and the biomass energy in India, respectively. The literature survey of the biomass energy and its applications is presented in Section 2. The criteria selection procedure and a short discussion on it are covered in Section 3. Therefore, the decision-making technique, namely the DEMATEL methodology, is analyzed in Section 4. Then, the model formulation and data collection process of the proposed study are explained in Section 5. Further, the numerical illustration and results are discussed in Section 6. Finally, the conclusion and future research scope are mentioned elaborately in Section 7.

## 2 Literature Studies

Literature on biomass energy and its application in India is thoroughly discussed in this section.

### 2.1 Present Status of Producing International Biomass Energy

International biomass energy is the phrase that explains the widespread use of organic resources, such as crop contaminants, wood, and animal waste, to produce renewable energy. To mitigate the carbon emissions and diminish reliance on fossil fuels, many countries make an investment in biomass biofuels, biogas, and power plants. The European Union, the United States, and China lead the way for the generation of biomass energy. Additionally, the developing countries utilize it for cooking and heating. Anaerobic digestion and gasification are examples of advanced technologies that enhance efficiency and sustainability. Whatever the benefits, concerns about deforestation and competition with food production still remain challenges. We describe some recent international biomass energy-related research papers and their applications in Table 1.

**Table 1.** Some applications of international biomass energy

| Authors | Year | Contribution Area |
|---|---|---|
| Banja et al. [21] | 2019 | A discussion of biomass energy in the EU countries |
| Pata et al. [22] | 2023 | Improving the quality of environment in the United States with biomass energy consumption and load capacity factor |
| Alfonso et al. [23] | 2009 | Optimization, evaluation, management and utilization of biomass energy and its resources |
| Wang et al. [24] | 2024 | Current development status and its future prospects of biomass energy in China |
| Wang et al. [25] | 2024 | Reflections on the sustainability of biomass energy in Chinese policy scenarios |

### 2.2 Present Status of Producing Biomass Energy in India

In India, biomass energy is a significant green energy source produced from organic materials, such as agricultural waste, animal manure, and forest remnants. It has a vital role in meeting the rural energy importance, minimizing dependence on fossil fuels, and developing waste-to-energy solutions. India has enormous biomass sources with an estimated annual potential of 500 million metric tons of biomass. Various techniques, i.e., biogas plants, biomass gasifiers, and advanced combustion systems, are extensively used. Biomass energy defends rural employment, energy safety, and climate change mitigation. Moreover, challenges include inefficient conversion procedures, resource competition, and logistics. Government initiatives like the National Bio-Energy Mission aim to raise biomass utilization sustainably. In this paper, we work on the biomass energy in India. Now, we discuss some recent research work on biomass energy and related applications in Table 2.

**Table 2.** Some applications of biomass energy in India

| Authors | Year | Contribution Area |
|---|---|---|
| Seth et al. [26] | 2015 | India's demand for Biomass Energy |
| Karmakar et al. [27] | 2021 | A review on Biomass Energy Potential in India |
| Prakash and Lal [28] | 2023 | A comprehensive evaluation of biomass energy in India for agricultural and household usage |
| Chauhan and Singh [29] | 2023 | A brief discussion about biomass to bioenergy in India |
| Damian et al. [30] | 2024 | A comprehensive analysis of biomass pyrolysis as a key strategy for achieving India's sustainable energy objectives in hydrogen production |
| Mondal et al. [31] | 2024 | A comprehensive approach for integrating renewable energy and environmental sustainability |
| Kumar and Vyas [32] | 2024 | Investigating various aspects of biomass utilization, biogasification for sustainable energy production |
| Yadav et al. [33] | 2024 | Current status of Technology and future prospect of Biojet Fuel production |
| Ali et al. [34] | 2024 | Application of Biomass for green and sustainable energy |
| Toplicean and Datcu [35] | 2024 | Bioeconomy in Agricultural Sector |
| Nguyen and Toan [36] | 2024 | In the framework of trade growth, application on generating biomass energy from agricultural waste |
| Aduba et al. [37] | 2024 | Application on utilising biomass waste-to-energy for electricity production |
| Juneja [38] | 2024 | Biomass waste transformation technology for its utilisation and energy production in India |

### 2.3 Literature on MCDM Methodology

This section discussed the brief literature review on the MCDM methodology. There are several MCDM-based optimization techniques that are applied in different real-world problems. Biswas et al. [39] used MCDM methods to choose canteen location in a university campus. Further, Adhikari et al. [40] used two MCDM methodologies namely AHP and TOPSIS to identify the best environment for women considering different factors. Momena et al. [41] analysis the prediagnosis of disease based on symptoms using MCDM-based optimization techniques in an uncertain environment. Pamučar et al. [42] applied MCDM based optimization techniques AHP and BWM to evaluate the criteria weights. Momena et al. [43] rank the supply chain companies using CRITIC, Multi-Objective Optimization by Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA)-based MCDM methodologies. Adhikari et al. [44] determine the most suitable states in India based on women's empowerment and Gazi et al. [45] evaluate the location for a sustainable hospital in Saudi Arabia based on Entropy and Vlsekriterijumska Optimizacija I KOmpromisno Resenje (VIKOR) techniques in an uncertain environment. Alzahrani et al. [46] applied the Analytical Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and COPRAS methodologies to identify the most suitable location for a women's university in West Bengal, India, in the neutrosophic field. Mandal et al. [47] applied the MCDM-based AHP-TOPSIS methodology to select the PhD supervisor in an interval-valued intuitionistic fuzzy environment.

Yang and Tzeng [48] applied DEMATEL methodology for choosing the best vendor based on different criteria. Biswas et al. [49] evaluate the efficiency of the different criteria to adopting the circular economic model using the DEMATEL methodology.

## 3 Criteria Selection

Biomass energy is an important renewable energy resource. There are many challenges in the process of biomass energy production. Here, we consider five such challenges as criteria, namely, Technology and Infrastructure ($C_1$), Economic Viability ($C_2$), Competition ($C_3$), Resource Availability ($C_4$) and Environmental Impact ($C_5$). Figure 1 represents the graphical diagram of the criteria for biomass energy production in India, and the denoted criteria are explained in detail below:

### 3.1 Technology and Infrastructure $(C_1)$

Technology and Infrastructure are critical factors in biomass energy production [1]. Advanced technologies enhance biomass conversion processes, enable modern storage solutions, support low-emission processing methods, and minimize environmental impact. They also help to include biomass energy into the existing energy framework [50]. Strong infrastructure is also very important in addressing the challenges related to biomass energy. By a strong infrastructure [51, 52], we mean advanced transportation facilities, supply chain networks, processing facilities, etc., which provide a reliable and environmentally friendly energy resource. But without proper Technology and Infrastructure, the process of biomass energy production becomes inefficient, expensive, and not sustainable for the environment.

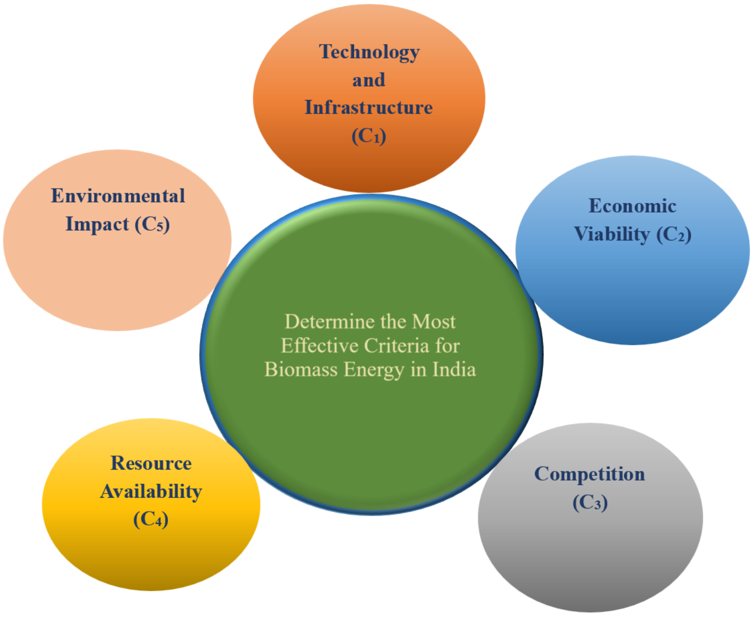


**Figure 1.** Criteria for biomass energy production

### 3.2 Economic Viability $(C_2)$

Economic Viability is a very important criterion for biomass energy production [53]. Economic Viability describes how much the production and expansion of biomass energy is affordable and practical. It is very difficult to start a biomass energy production project without financial support [54, 55], due to high costs for infrastructure, technology, and raw materials. Whether these projects can make a profit depends on various factors like ongoing expenses, bioenergy demand, and competition with other energy resources that are cheaper than biomass energy, etc. Economic Viability can attract the investments for biomass energy [37, 38]. It also boosts the rural economies with lower reliance on fossil fuels. Its viability in the energy market is developed by cost-effective technologies and government incentives. How much investors are attracted by a biomass energy project and how a project can compete in the energy market are determined by Economic Viability [56].

### 3.3 Competition $(C_3)$

Competition [57] is crucial for producing biomass energy because it encourages innovative ideas, betterment of efficiency, and cost reduction. This makes biomass energy [58] more appealing compared to other renewable energy, namely solar energy, wind energy, hydro energy, etc. Tough Competition also initiates challenges for biomass energy [59, 60]. So, it is important to make visible the economic affordability and environmental advantages of using biomass energy over other alternative resources. There are also some factors, such as land availability, energy crops, biomass feasibility, etc., which affect the success of biomass energy.

### 3.4 Resource Availability $(C_4)$

In the process of biomass production, Resource Availability acts as a significant benchmark [2, 9]. It is significant to guarantee a consistent and sustainable fuel supply. Biomass energy [30, 31] is produced by using organic waste materials, energy crops, etc. On the other hand, availability of these products also depends on the agricultural practices, regional climate, etc. Hence, for continuous energy generation, a consistent and adequate supply of these resources plays a vital role. Abundant agriculture and forestry can minimize waste and increase the security of energy. The appropriate use of these resources supports rural lives and fosters the growth of clean energy. There is a pivotal role of the transportation system as poor transportation causes operational risk, limited resource access, and increasing expenses. Thus, for maximizing the efficiency of biomass energy [61, 62], it is at first crucial to ensure a steady, local, and sustainable supply chain.

### 3.5 Environmental Impact $(C_5)$

Environmental Impact is a major criterion for the production of biomass energy [3, 63]. The acceptance of biomass energy among people as an alternative energy resource is dependent on its sustainable nature and positive impact on biodiversity. Biomass energy production helps manage waste materials in a scientific way and provides us with a comparatively healthy environment [4]. People's desire to earn more money from biomass energy production may encourage unsustainable practices such as over-harvesting, deforestation, and changes in land use, which can lead to soil degradation and damage our ecosystem and biodiversity [64]. During the process of burning biomass, some pollutants like nitrogen oxides, fine particles, etc., are released, which become a reason for poor air quality. Thus, biomass energy can help to maintain a cleaner and healthier environment by adopting sustainable practices.

## 4 DEMATEL Methodology

In this section, we will describe the DEMATEL method in a crisp environment. This method is used to assess the dependencies and influences among criteria. This method helps DMs to identify the main criterion driving the system and their interdependencies. The DEMATEL method is used in various fields. Abdel-Basset et al. [65] used the DEMATEL method for developing supplier selection criteria. In 2022, the DEMATEL method is used by Khorshidi et al. [17] for solar power plant location selection. For selecting the best vendor, the DEMATEL method is used by Yang and Tzeng [48].

In our study, we consider $\alpha$ number of criteria. We consider the opinion of $\beta$ number of DMs who provide their decision in linguistic terms. Our purpose is to find the most effective criteria among these $\alpha$ criteria. The hierarchical structural procedure of the DEMATEL methodology is presented in Figure 2. Further, the mathematical steps of the DEMATEL method are given as follows:

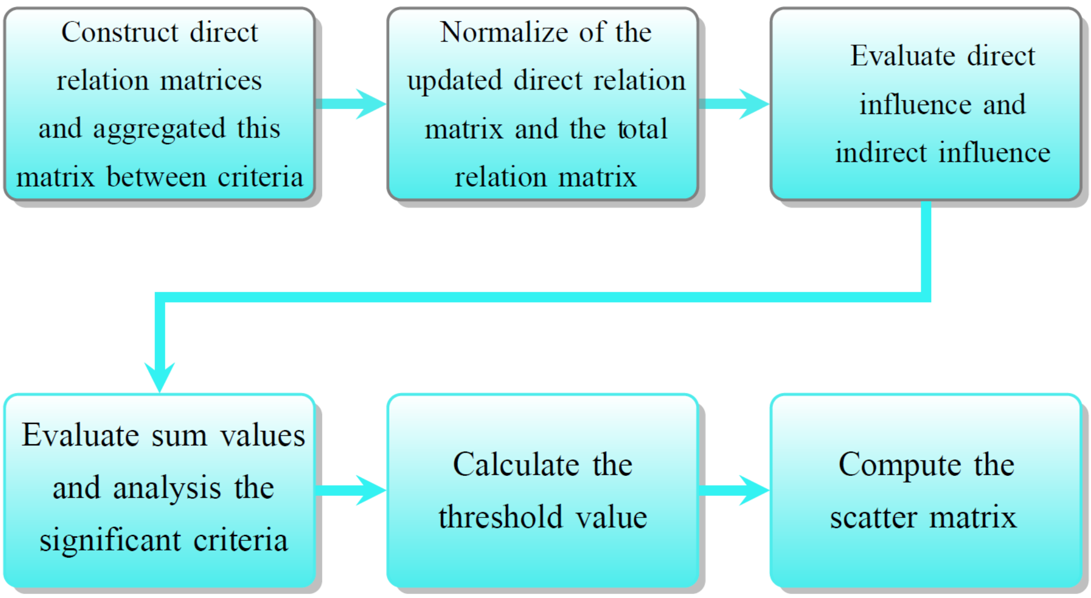


**Figure 2.** Structural framework of DEMATEL process

**Table 3.** Linguistic term with crisp value for direct relation matrix $(M_\xi)$

| Linguistic Term | Crisp Value |
|---|---|
| No Influence (NI) | 0 |
| Fairly Influence (FI) | 1 |
| Average Influence (AI) | 3 |
| Very Influence (VI) | 5 |
| Strongly Influence (SI) | 7 |
| Extremely Influence (EI) | 9 |

**Step 1: Construction of the direct relation matrix $(M_\xi)$:**

At first, the direct relation matrix $M_\xi$ where $\xi = 1, 2, \ldots, \beta$ is constructed by DMs based on the proposed linguistic variables. DMs assign a linguistic term using six linguistic variables ranging from Absolutely Influence (AI) to No Influence (NI), which are described in Table 3. The $\xi^{th}$ DM give the score $(m_{\kappa_1\kappa_2})_\xi$, where the notation $m_{\kappa_1\kappa_2}$ represents the extent to which the $\xi^{th}$ DM consider criteria $\kappa_1$ influences criteria $\kappa_2$. In the process of decision-making, zero (no influence) is assigned to the diagonal components and the $M_\xi$ evaluation can be represented as follows:

$$M_\xi = \begin{bmatrix} (m_{11})_\xi & (m_{12})_\xi & \ldots & (m_{1\kappa_2})_\xi & \ldots & (m_{1\alpha})_\xi \\ (m_{21})_\xi & (m_{22})_\xi & \ldots & (m_{2\kappa_2})_\xi & \ldots & (m_{2\alpha})_\xi \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (m_{\kappa_1 1})_\xi & (m_{\kappa_1 2})_\xi & \ldots & (m_{\kappa_1\kappa_2})_\xi & \ldots & (m_{\kappa_1\alpha})_\xi \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ (m_{\alpha 1})_\xi & (m_{\alpha 2})_\xi & \ldots & (m_{\alpha\kappa_2})_\xi & \ldots & (m_{\alpha\alpha})_\xi \end{bmatrix}_{\alpha\times\alpha} \tag{1}$$

i.e.,

$$M_\xi = \left[(m_{\kappa_1\kappa_2})_\xi\right]_{\alpha\times\alpha} \tag{2}$$

where,

the comparison matrices $(M_\xi)$ are of order $\alpha \times \alpha$ in crisp environment.

**Step 2: Aggregated direct relation matrix formation $(M_{\mathscr{A}})$:**

To aggregate $\beta$ number of direct relation matrices $(M_\xi)$, $\xi = 1, 2, \ldots, \beta$ into one aggregated direct relation matrix we use the formula,

$$m_{\kappa_1\kappa_2} = \left(\prod_{\xi=1}^{\beta} (m_{\kappa_1\kappa_2})_\xi\right)^{\frac{1}{\beta}} \tag{3}$$

The form of the aggregated direct relation matrix $(M_{\mathscr{A}})$ is:

$$\begin{aligned} M_{\mathscr{A}} &= [m_{\kappa_1\kappa_2}]_{\alpha\times\alpha} \\ &= \begin{bmatrix} m_{11} & m_{12} & \ldots & m_{1\kappa_2} & \ldots & m_{1\alpha} \\ m_{21} & m_{22} & \ldots & m_{2\kappa_2} & \ldots & m_{2\alpha} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{\kappa_1 1} & m_{\kappa_1 2} & \ldots & m_{\kappa_1\kappa_2} & \ldots & m_{\kappa_1\alpha} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ m_{\alpha 1} & m_{\alpha 2} & \ldots & m_{\alpha\kappa_2} & \ldots & m_{\alpha\alpha} \end{bmatrix}_{\alpha\times\alpha} \end{aligned} \tag{4}$$

where,

$m_{\kappa_1\kappa_2}$ is the aggregated ratting of the $\kappa_2$th criteria based on the $\kappa_1$th criteria with $\kappa_1, \kappa_2 = 1, 2, \ldots, \alpha$.

**Step 3: Normalization of the updated direct relation matrix $(M_{\mathscr{N}})$:**

The normalized direct relation matrix is denoted by $(M_{\mathscr{N}})$ and defined as

$$M_{\mathscr{N}} = \left[(m_{\kappa_1\kappa_2})_{\mathscr{N}}\right]_{\alpha\times\alpha} = \left[\frac{m_{\kappa_1\kappa_2}}{\sum_{\kappa_2=1}^{\alpha} m_{\kappa_1\kappa_2}}\right]_{\alpha\times\alpha} \tag{5}$$

**Step 4: Construction of the total relation matrix $(M_{\mathscr{T}})$:**

The total relation matrix $(M_{\mathscr{T}})$ is obtained from the normalized direct relation matrix $(M_{\mathscr{N}})$ and it is represented as,

$$\begin{aligned} M_{\mathscr{T}} &= M_{\mathscr{N}} (I_\alpha - M_{\mathscr{N}})^{-1} \\ &= \lim_{n\to\infty} \left\langle M_{\mathscr{N}} + (M_{\mathscr{N}})^2 + (M_{\mathscr{N}})^3 + \cdots + (M_{\mathscr{N}})^n \right\rangle \\ &= \left[\nu_{\kappa_1\kappa_2}\right]_{\alpha\times\alpha} \end{aligned} \tag{6}$$

where,

$I_\alpha$ is an $\alpha \times \alpha$ order identity matrix and $\nu_{\kappa_1\kappa_2}$ is the ${\kappa_1\kappa_2}^{th}$ entry of the total relation matrix $(M_{\mathscr{T}})$.

**Step 5: Evaluating direct influence $(D_\kappa)$ and indirect influence $(I_\kappa)$ for the criteria:**

The direct influence $(D_\kappa)$ is evaluated by adding $\kappa^{th}$ column of the total relation matrix $(M_{\mathscr{T}})$ such that

$$\mathcal{D}_\kappa = \mathcal{D}_{\kappa_1} = \sum_{\kappa_2=1}^{\alpha} \nu_{\kappa_1\kappa_2} \tag{7}$$

where,

$\kappa = \kappa_1 = 1, 2, \ldots, \alpha$ and the indirect influence $(\mathcal{I}_\kappa)$ is evaluated by adding $\kappa^{th}$ row of the total relation matrix $(M_{\mathscr{T}})$ such that

$$\mathcal{I}_\kappa = \mathcal{I}_{\kappa_2} = \sum_{\kappa_1=1}^{\alpha} \nu_{\kappa_1\kappa_2} \tag{8}$$

where,

$\kappa = \kappa_2 = 1, 2, \ldots, \alpha$.

The vertical axis $(\mathcal{D}_\kappa - \mathcal{I}_\kappa)$ denotes "relation," and the horizontal axis $(\mathcal{D}_\kappa + \mathcal{I}_\kappa)$ denotes "prominence" which represents the relative significance of the criterion. From the value of $(\mathcal{D}_\kappa - \mathcal{I}_\kappa)$ one can decide whether a criterion belongs to the cause group or to the effect group.

**Step 6: Evaluate sum values and analysis the significant criteria for construction of a causal diagram:**

Causal diagrams become very helpful for decision-making problems. The prominence value $(\mathcal{P}_\kappa)$ of criterion $\kappa$ lies in the horizontal axis and is evaluated as

$$\mathcal{P}_\kappa = \mathcal{D}_\kappa + \mathcal{I}_\kappa = \sum_{\kappa_2=1}^{\alpha} \nu_{\kappa_1\kappa_2} + \sum_{\kappa_1=1}^{\alpha} \nu_{\kappa_1\kappa_2} \tag{9}$$

and the relative value $(\mathcal{R}_\kappa)$ of criterion $\kappa$ lies in the vertical axis and is calculated as

$$\mathcal{R}_\kappa = \mathcal{D}_\kappa - \mathcal{I}_\kappa = \sum_{\kappa_2=1}^{\alpha} \nu_{\kappa_1\kappa_2} - \sum_{\kappa_1=1}^{\alpha} \nu_{\kappa_1\kappa_2} \tag{10}$$

where,

$\mathcal{D}_\kappa$ and $\mathcal{I}_\kappa$ are determined in previous steps and $\kappa = 1, 2, \ldots, \alpha$.

First, the $(\mathcal{P}_\kappa, \mathcal{R}_\kappa) = (\mathcal{D}_\kappa + \mathcal{I}_\kappa, \mathcal{D}_\kappa - \mathcal{I}_\kappa)$ data set is plotted to form the graph. The "Prominence" is characterized by the horizontal axis $\mathcal{P}_\kappa = \mathcal{D}_\kappa + \mathcal{I}_\kappa$ and "Relation" is represented by the vertical axis $\mathcal{R}_\kappa = \mathcal{D}_\kappa - \mathcal{I}_\kappa$, respectively.

Prominence value $(\mathcal{P}_\kappa)$ discloses the degree of the relation of every criterion with the remaining criteria. Hence, it represents the importance of the criteria. So, if a criterion has acquired higher value of $(P_\kappa)$ that means the criterion is more related to the other criteria and conversely, criteria with lower $(\mathcal{P}_\kappa)$ values indicate a weaker relationship with other criteria. On the other hand, the relative value $(\mathcal{R}_\kappa)$ represents the type of relationship among the criteria. If the relative value $(\mathcal{R}_\kappa)$ is positive, then the criterion often belongs to the cause group that is the $\kappa^{th}$ criterion influences other criteria. simultaneously, if $\mathcal{R}_\kappa$ value is negative, then the criterion is included in the effect group that is the $\kappa^{th}$ criterion is influenced by the other criteria.

**Step 7: Calculation of threshold value $(\nu^t)$:**

The threshold value $(\nu^t)$ is calculated from the total relation matrix $(M_{\mathscr{T}})$ by using the following formula,

$$\nu^t = \frac{\sum_{\kappa_1=1}^{\alpha} \sum_{\kappa_2=1}^{\alpha} (\mu_{\kappa_1\kappa_2})}{\alpha^2} \tag{11}$$

where,

$\kappa_1, \kappa_2 = 1, 2, \ldots, \alpha$.

**Step 8: Computing scatter matrix $(S_{\mathscr{T}})$:**

The scatter matrix $(S_{\mathscr{T}})$ is calculated from the total relation matrix $(M_{\mathscr{T}})$ and the threshold value $(\nu^t)$ as follows:

$$\kappa_1{\kappa_2}^{th} \text{ entry} = \begin{cases} 1 \text{ (i.e., entry is relatable)} & ; \text{if } \nu^t_{\kappa_1\kappa_2} \geq \nu_{\kappa_1\kappa_2} \\ 0 \text{ (i.e., entry is not relatable)} & ; \text{if } \nu^t_{\kappa_1\kappa_2} < \nu_{\kappa_1\kappa_2} \end{cases} \tag{12}$$

where,

$\kappa_1, \kappa_2 = 1, 2, \ldots, \alpha$. Therefore, the $\kappa_1{\kappa_2}^{th}$ entry is relatable implying that the ${\kappa_1}^{th}$ criterion is relatable with the ${\kappa_2}^{th}$ criterion; otherwise, it is not relatable. One may draw the scatter matrix diagram to visualize the scatter matrix $(S_{\mathscr{T}})$.

## 5 Model Formulation and Data Collection

In this section, we highlight the model formulation and data collection of the adaptation challenges problem of biomass energy in India.

### 5.1 Model Formulation

After a deep study on biomass energy production in India, a total of 5 criteria were identified for this research. A few direct relation matrices $(M_\xi)$ of order $5 \times 5$ are formulated in linguistic terms by the DMs and shown in Table 4. Further, all data are translated to crisp numbers using Table 3. The graphical structure of this study is presented in Figure 3. We have applied the MCDM technique, namely the DEMATEL method for further numerical evaluation.

Three DMs are given the required data based on their skills and expertise in this paper. All the DMs are given their data with linguistic terms. Here, the data are collected from three decision experts namely,

**DM 1:** A senior government officer works under the ministry of renewable energy.

**DM 2:** A professor working in a biomass energy research center with more than 10 years of experience.

**DM 3:** A social worker who works on renewable energy development and environmental issues with 15 years of experience.

Here, in coordination with local agencies, businesses, and research institutions, a senior government official in the ministry can facilitate biomass energy data to gather information on the availability of resources, the implications of policy, and the adoption of technology. Besides, a professor in a biomass energy research center can collect required data through field studies, utilizing experiments and surveys while collaborating with government agencies and industry for real-time resource and technological assessments. And a social worker in renewable energy development can gather biomass energy data through stakeholder interviews, resident surveys, and grassroots evaluations of the availability of resources and local adoption challenges. They all conducted various surveys, monitored energy production trends, and analyzed accurate data using satellites and various tools. For these reasons, the three DMs selected are well suited for this research work.

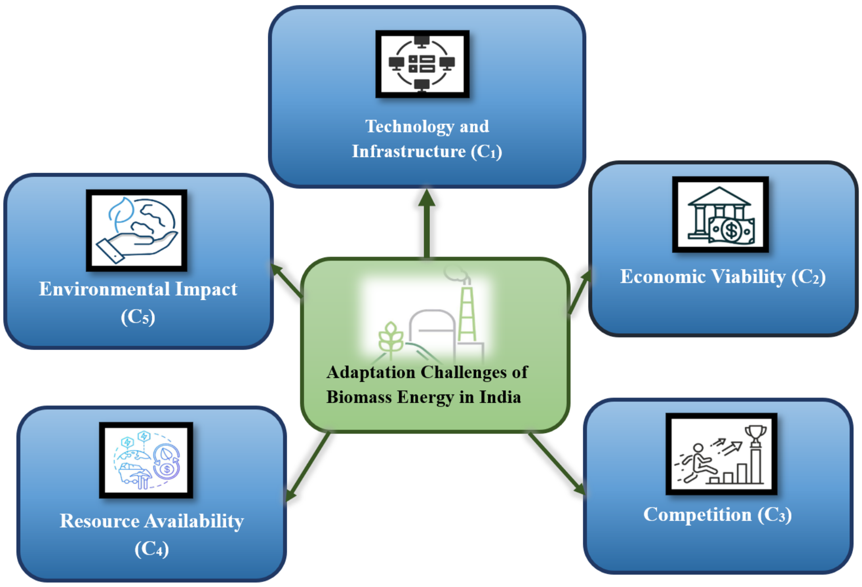


**Figure 3.** The hierarchical structure of the considered model

### 5.2 Data Collection

This section demonstrates the data sources and data collection used in this paper. First of all, required data are collected by three DMs in linguistic terms that we apply in the direct relation matrices $(M_\xi)$ with the help of Table 3, and then it is comprised in Table 4. Then, the direct relation matrices $(M_\xi)$ were decoded into crisp numbers with the help of Table 3 and appeared for the DEMATEL technique with Section 4.

## 6 Numerical Illustration

In this section, we will discuss the numerical results and further analyze the results. All mathematical calculations are carried out by using the DEMATEL method, which is described in Section 4. For numerical evaluation, we will use the data collected from DMs in the form of the direct relation matrix $M_\xi$ in Table 4. Further, we convert the data of the direct relation matrix $M_{\xi}$ from a linguistic term to a crisp number by using Table 3. The aggregated direct relation matrix $(M_{\mathscr{A}})$ is obtained by using Eq. (3). We apply Eq. (5) for constructing the normalized direct relation matrix $(M_{\mathscr{N}})$, which is shown in Table 5. The total relation matrix $(M_{\mathscr{T}})$ is evaluated in Table 6 by using Eq. (6). Further, we calculate the direct influence $(\mathcal{D}_{\kappa})$, indirect influence $(\mathcal{I}_{\kappa})$, prominence value $(\mathcal{P}_{\kappa})$ and relative value $(\mathcal{R}_{\kappa})$ by using Eqs. (7)–(10), respectively and represent the results in Table 7.

**Table 4.** Direct relation matrix $(M_{\xi})$ given by DMs

| | **Criteria vs Criteria** | **Technology and Infrastructure** $(C_1)$ | **Economic Viability** $(C_2)$ | **Competition** $(C_3)$ | **Resource Availability** $(C_4)$ | **Environmental Impact** $(C_5)$ |
|---|---|---|---|---|---|---|
| **DM 1** | Technology and Infrastructure $(C_1)$ | NI | SI | SI | FI | VI |
| | Economic Viability $(C_2)$ | SI | NI | AI | AI | FI |
| | Competition $(C_3)$ | SI | VI | NI | SI | FI |
| | Resource Availability $(C_4)$ | VI | SI | SI | NI | EI |
| | Environmental Impact $(C_5)$ | EI | AI | FI | EI | NI |
| **DM 2** | Technology and Infrastructure $(C_1)$ | NI | EI | SI | AI | SI |
| | Economic Viability $(C_2)$ | SI | NI | FI | VI | FI |
| | Competition $(C_3)$ | VI | SI | NI | SI | FI |
| | Resource Availability $(C_4)$ | AI | AI | VI | NI | SI |
| | Environmental Impact $(C_5)$ | SI | FI | AI | EI | NI |
| **DM 3** | Technology and Infrastructure $(C_1)$ | NI | SI | EI | AI | VI |
| | Economic Viability $(C_2)$ | EI | NI | AI | FI | AI |
| | Competition $(C_3)$ | VI | AI | NI | VI | AI |
| | Resource Availability $(C_4)$ | AI | VI | VI | NI | EI |
| | Environmental Impact $(C_5)$ | SI | AI | FI | VI | NI |

**Table 5.** Normalized direct relation matrix $(M_{\mathscr{N}})$

| **Criteria vs Criteria** | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| Technology and Infrastructure $(C_1)$ | 0 | 0.40 | 0.42 | 0.11 | 0.33 |
| Economic Viability $(C_2)$ | 0.31 | 0 | 0.11 | 0.14 | 0.09 |
| Competition $(C_3)$ | 0.23 | 0.25 | 0 | 0.34 | 0.09 |
| Resource Availability $(C_4)$ | 0.15 | 0.25 | 0.31 | 0 | 0.49 |
| Environmental Impact $(C_5)$ | 0.31 | 0.11 | 0.08 | 0.41 | 0 |

**Table 6.** Total relation matrix $(M_{\mathscr{T}})$

| Criteria vs Criteria | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| Technology and Infrastructure $(C_1)$ | 15.08 | 15.33 | 14.33 | 15.09 | 15.37 |
| Economic Viability $(C_2)$ | 9.59 | 9.35 | 8.83 | 9.39 | 9.49 |
| Competition $(C_3)$ | 12.34 | 12.34 | 11.34 | 12.34 | 12.34 |
| Resource Availability $(C_4)$ | 15.00 | 15.00 | 14.05 | 14.80 | 15.31 |
| Environmental Impact $(C_5)$ | 13.14 | 12.98 | 12.13 | 13.13 | 13.04 |

**Table 7.** Direct influence $(\mathcal{D}_\kappa)$, indirect influence $(\mathcal{I}_\kappa)$, prominence $(\mathcal{P}_\kappa)$ and relative $(\mathcal{R}_\kappa)$ values of different criteria

| Criteria | $\mathcal{D}_\kappa = \sum_{\kappa_2=1}^{\alpha} \nu_{\kappa_1\kappa_2}$ | $\mathcal{I}_\kappa = \sum_{\kappa_1=1}^{\alpha} \nu_{\kappa_1\kappa_2}$ | $\mathcal{P}_\kappa = \mathcal{D}_\kappa + \mathcal{I}_\kappa$ | $\mathcal{R}_\kappa = \mathcal{D}_\kappa - \mathcal{I}_\kappa$ |
|---|---|---|---|---|
| Technology and Infrastructure $(C_1)$ | 75.20 | 65.15 | 140.35 | 10.05 |
| Economic Viability $(C_2)$ | 46.66 | 65.00 | 111.66 | -18.33 |
| Competition $(C_3)$ | 60.71 | 60.68 | 121.39 | 0.03 |
| Resource Availability $(C_4)$ | 74.16 | 64.76 | 138.92 | 9.40 |
| Environmental Impact $(C_5)$ | 64.42 | 65.56 | 129.98 | -1.14 |

Prominence value $(P_k)$ represents the importance of each criterion to others. From Table 7, we can see that Technology and Infrastructure $(C_1)$ got the highest prominence value. So, it is the most important criterion as it has the maximum relation with other criteria. Depending on the prominence value we get that Resource Availability $(C_4)$, Environmental Impact $(C_5)$ and Competition $(C_3)$ has the second, third and fourth highest relation with other criteria respectively. Economic Viability $(C_2)$ has the lowest relation with other criteria.

From Table 7, we also got the relative value $(R_k)$ which displayed the type of relation among criterion. Here, the criteria Technology and Infrastructure $(C_1)$, Resource Availability $(C_4)$ and Competition $(C_3)$ got positive $(+ve)$ relative values, so they belong to the cause group. Again, we got negative $(-ve)$ relative values of criteria Economic Viability $(C_2)$ and Environmental Impact $(C_5)$, so, they belong to the effect group.

The causal diagram for the proposed model, which was used to identify the most efficient criteria for biomass energy production, is shown in Figure 4.

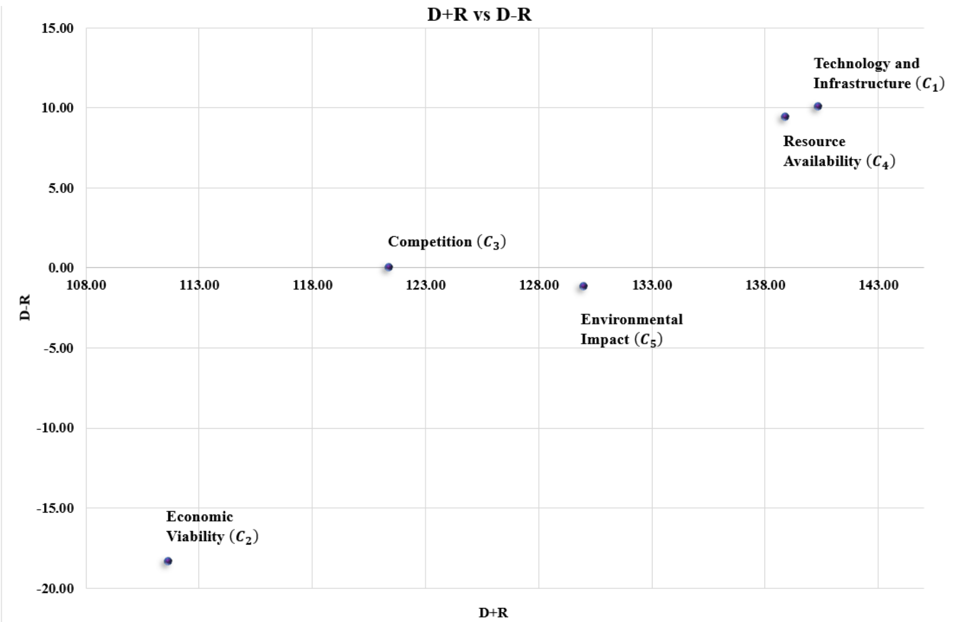


**Figure 4.** Causal diagram for each criterion based on $\mathcal{P}_\kappa$ and $\mathcal{R}_\kappa$ values

**Remark 1.** Based on numerical calculation and a casual diagram, it is clear that Technology and Infrastructure $(C_1)$ is the most important criteria and Resource Availability ( $C_4$ ) is the second most important criteria. The criteria Technology and Infrastructure $(C_1)$, Resource Availability $(C_4)$ and Competition $(C_3)$ serve as cause or dispatcher criteria. The criteria Economic Viability $(C_2)$ and Environmental Impact $(C_5)$ belong to the effect group.

Using Eq. (11), we got the threshold value $(v^t)$ as 12.8459. Using the total relation matrix $(M_{\mathscr{T}})$ and the threshold value $(v^t)$, we got the scatter matrix $(S_{\mathscr{T}})$, which is given in Table 8.

Using the scatter matrix in Table 8, we draw the scatter diagram, which is shown in Figure 5. From this scatter diagram, we have a clear view of the interrelation among all the criteria.

**Remark 2.** From Table 8 and Figure 5, we conclude that the criteria Technology and Infrastructure ( $C_1$ ) and Resource Availability $(C_2)$ are retable 1 with all other criteria, i.e., $(C_1)$ , $(C_2)$ , $(C_3)$ , $(C_4)$ and $(C_5)$, the criteria Economic Viability $(C_2)$ and Competition $(C_3)$ are not retable 0 with other criteria and the criteria Environmental Impact $(C_5)$ is retable 1 with criteria $(C_1)$ , $(C_2)$ , $(C_4)$ and $(C_5)$, respectively.

**Table 8.** Scatter matrix $(S_{\mathscr{T}})$ of the suggested DEMATEL methodology

| **Criteria vs Criteria** | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| Technology and Infrastructure $(C_1)$ | 1 | 1 | 1 | 1 | 1 |
| Economic Viability $(C_2)$ | 0 | 0 | 0 | 0 | 0 |
| Competition $(C_3)$ | 0 | 0 | 0 | 0 | 0 |
| Resource Availability $(C_4)$ | 1 | 1 | 1 | 1 | 1 |
| Environmental Impact $(C_5)$ | 1 | 1 | 0 | 1 | 1 |

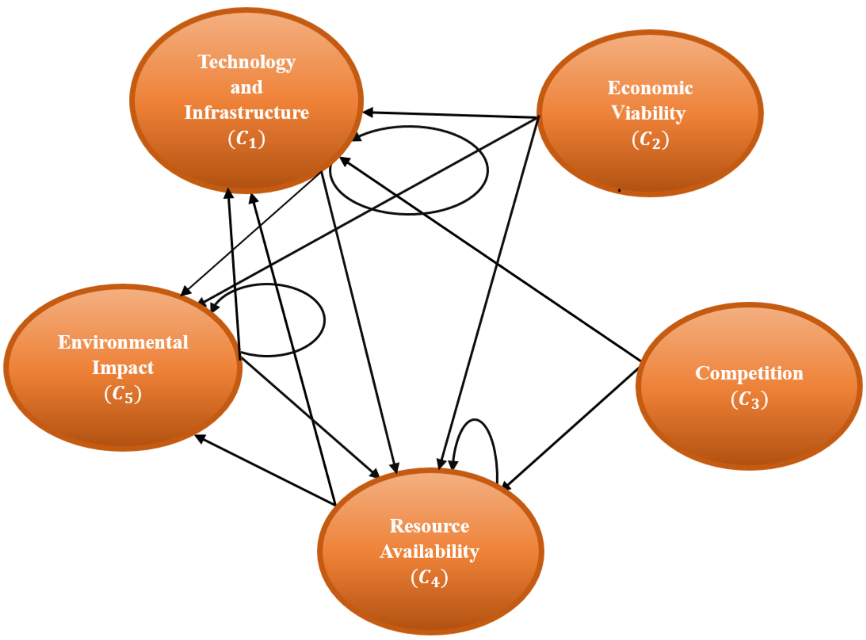


**Figure 5.** Scatter matrix $(S_{\tau})$ diagram for the proposed model

## 7 Conclusion

Energy is one of the main pillars of every progressive country. In a country like India, to meet the huge energy demand, it is essential to find alternative renewable energy resources. Due to the availability of biomass energy resources, biomass energy may become one of the best alternatives for energy production in the future.

In this paper, we have constructed a model by using the DEMATEL method to investigate the challenges of biomass energy production. Here we have considered the total of five criteria related to biomass energy production. The opinions of three DMs have been taken in the linguistic term, and further, we convert them into crisp numbers. Further, we have performed the numerical calculations. From the numerical calculation, we have found that Technology and Infrastructure $(C_1)$ is the most important criterion, and Resource Availability $(C_4)$ and Environmental Impact $(C_5)$ are the second and third most important criteria. So, for addressing the challenges related to biomass energy production, we have to pay attention to these criteria. Policy concepts for biomass energy in India entail offering biomass supply chains, implementing stringent sustainability criteria, and integrating biomass with existing renewable energy policies. Real-world applications include expanding waste-toenergy projects, promoting biomass-related rural electrification, and assisting industries in implementing biomass pellets and briquettes. Increasing financial support and research efforts may stimulate efficiency and innovation in the application of biomass energy. By taking these actions, India will achieve energy security while lowering environmental impact. So, the adaptation challenges of biomass energy in India can be identified through targeted support of policy, enhanced technology, and the engagement of community, facilitating the path for a sustainable and inclusive energy transition.

There are many passages for further research. In this paper, we consider only five criteria, whereas some criteria like energy conversion efficiency, water usage, community acceptance, feedstock quality, social acceptance, energy conversion efficiency, etc. could be included. In this paper, we discussed small sample sizes, but in the future, we may expand our data. Also, we can process the problem by using other decision-making methods in addition to DEMATEL and showing the differences between DEMATEL and them. Here, we used crisp numbers, but fuzzy numbers or neutrosophic numbers could be applied to include the uncertainty in the data. Here, we considered the opinions of three DMs. Considering the opinions of more DMs, we could get more reliable results. Further, this model can be adapted to various other sectors.

## Author Contributions

All authors have read and agreed to the published version of the manuscript.

## Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

## Data Availability

The data used to support the research findings are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare no conflict of interest.

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