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Technology Selection and Evaluation Criteria in Microalgae Biofuels Production Using DEMATEL and OPA Methods

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Abstract

Attention to the energy extraction from the Biofuel has been increased due to the environmental pollution. Researchers have paid a lot of attention to microalgae as a renewable source for biofuel production. There are different technologies to produce microalgae biofuels including direct combustion, pyrolysis, gasification and anaerobic digestion. Identification of technology evaluation criteria to pick up the appropriate technology leads to lower costs, higher efficiency, less environmental pollution, and higher level of social welfare. This research is focused on the identification and ranking the technologies evaluation criteria and selecting the appropriate technology for producing microalgae biofuel using the DEMATEL and OPA methods. Initially, the criteria were identified based on expert opinions and previous studies and using the Delphi method in three stages. Then, using the DEMATEL method, the relationships, effects, and influences of the criteria were examined. Ultimately, the criteria weights were determined by the OPA method. The results indicated, profitability risk, environmental and social compatibility, employment creation, and increase in environmental pollution criteria were the most important ones. The technology gasification considered as the most important technology. This is because it provides more coverage for sustainability criteria. The use of this technology helps to reduce costs and pollution and increase welfare and service levels.

Keywords: Selecting, Technologies, Microalgae, Biofuel, DEMATEL, OPA

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1. Introduction

Considering the production of environmental fuels in the world, there are different active countries in this area. The share of each country in producing environmental fuels is shown in Figure 1. Germany (48%), European countries (30%), the United States (15%), and Brazil, China, India, Canada, and Malaysia (75%).

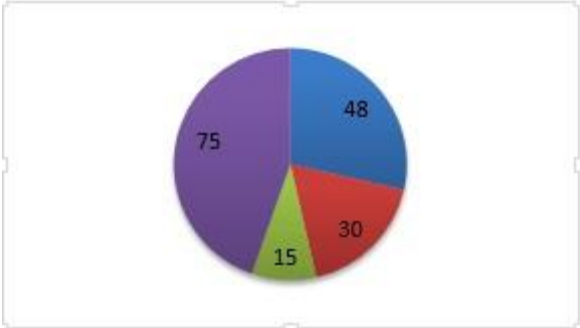

Figure1: The share of each country in producing environmental fuels

Todays estimation shows that by 2030, energy demand will increase by about 53%. Hence, although oil, natural gas, and coal are abundant in nature, over-consumption has led to significant depletion of these resources (Bertel & Roux, 2008). By causing pollution, fossil fuels have led to global warming and environmental imbalance. In general, biofuels are recognized as potential alternatives to fossil fuels (Feng & Ryu, 2015). Biofuels can be obtained from existing biological sources (Guillen & Puigjaner, 2007). Microalgae are a renewable source for biofuel production. Due to their growth in salt water and wastewater, carbon dioxide absorption, and fat storage, microalgae have received much attention. Due to the importance of renewable energies and their widespread applications and the need for representing appropriate methods for the highest level of productivity in manufacturing and distribution, it is a must to represent a scientific method considering all aspects and factors affecting the issue to yield the maximum use of these new sources of energy.

Reviewing past papers, (Del Río, & Mir-Artigues, 2018), (Hua, & Hu, 2016),(Moriarty & Honnery, 2021), (Wicker, et al., 2021), (Welfle, Thornley, & Röder, 2020),(Karthigadevi, et al., 2021),(Moglia, Cook, & McGregor, 2017),(Rogge & Reichardt, 2016),(Jimenez, Franco, & Dyner, 2016),(Mignon & Bergek, 2016),(Naeini, et al., 2020), (Keihani, 2024), (Alizadeh, et al., 2020), (Chobar et al. 2022), (Durmaz & Bilgen, 2020), (Noorazar et al. 2024) and(Lee & Huh, 2017) addressed analytical and comparative aspects, exploring various perspectives. In the papers by (Balin, 2020), (Roudaki, et al., 2024), (Kumar et al., 2017), (Touti and Chobar, 2020), (Mastrocinque, et al., 2020), (Ganji et al. 2024) and (Shao et al., 2020), the focus has been on decision-making aspects. However, none of these papers has mentioned the importance and use of appropriate technology, the criteria aiding in selecting the appropriate technology, and the role of that technology in improving quality and productivity. The present research covers all these aspects.

According to the research in the literature, one prominent drawback of algae supply chain models is the lack of attention to the evaluation criteria for new technologies and picking up an appropriate technology in the whole chain which leads to the ignorance of costs, efficiency, social welfare and environmental pollution. To surmount this obstacle, different novel

technologies and evaluation criteria in the production of microalgae are investigated. Therefore, this study aims to answer the following research questions:

1) What are the most effective factors and criteria influencing technology in the biofuels industry?

2) What is the weight and priority of each of the factors affecting the technology using DEMATEL and OPA technique in the biofuels industry?

3) What is the most important and influential technology in terms of sustainability in the biofuel industry?

research is focused on the identification and ranking the technologies evaluation criteria and picking up an appropriate technology in microalgae biofuels production using the DEMATEL and OPA methods. Accordingly, in this research, due to the latest studies and also viewpoints of experts, the criteria of technologies in the biofuels industry will be identified comprehensively. Then, the criteria will be finalized using three Delphi stage. In the DEMATEL method, cause and effect relationships between the criteria will be investigated. Ranking the criteria will be obtained using the OPA method.

2. Theoretical Background

This paper uses a combined technique and consequently the methods used in this research will be described in what follows.

2.1. Delphi Method

One of the ways of polling and reaching consensus is the Delphi method (Shah, Solangi, & Ikram, 2019) (Singh and Sarkar 2020) (Miller et al., 2020). This technique is simple and highly reliable in which experts are polled on the subject and an attempt is made to reach an appropriate consensus. Delphi technique and questionnaire design were used to evaluate the criteria by the experts in this study.To analyze the questionnaires designed using Delphi method in all three stages, minimum percentage allowed (APMO) method is used which is calculated using the equation(1). (Cottam, Roe, & Challacombe, 2004) , von der Gracht (2008).

$$\text{APMO} = \frac{\text{The total number in agreement} + \text{The maximum number in disagreement}}{\sum Total} \quad (1)$$

Accordingly, suppose that the minimum percentage of the average majority of opinions is equal to 70%, so this 70% means that any parameter that receives 70% of the opinions of experts, enters the next round of analysis, otherwise out of the next round and is eliminated. (Strand, Carson, Navrud, Ortiz-Bobea, & Vincent, 2017). As mentioned, the statistical population in this study includes 10 managers and experts, who were selected. Table 2 shows the statistical characteristics of the individuals who have specialized and worked in this field.

Table 1. characteristics of the population filling the questionnaire

Gender		Education			Work experience in building industry(years)		Age (years)			
Male	**Female**	**Bachlor's degree**	**Master's degree**	**Phd**	**10-5**	**>10**	**40 - 30**	**50 - 40**	**60 - 50**	**>61**
10	0	0	7	3	4	6	2	4	4	0
100%	0%	0%	70%	30%	40%	60%	20%	40%	40%	0%

2.2. DEMATEL(Decision Making Trial and Evaluation Laboratory) Method

DEMATEL specifies the interdependence and influence of the criteria on each other (Han & Deng, 2018), (Hasheminezhad, Hadadi, & Shirmohammadi, 2021). This method takes priority over other methods due to clarity and transparency in reflecting the mutual relationships between a wide set of components, enabling experts to better express their ideas regarding the direction and intensity and mutual impacts of factors. In this method, a broad set of criteria are classified, putting decision maker in a better position to understand relationships. The specifications of the experts are presented in Table 2. Reader are refered to (Quezada, López-Ospina, Palominos, & Oddershede, 2018)for more information, below are the steps taken to conduct DEMATEL:

1) Determining the effective criteria and placing them at the vertices of a diagram.
2) Determining the relation between criteria by comparing them in pairs.
3) Assessing the matrices obtained from the previous step and determining the presence or absence of the final correlation between the two criteria by a majority vote of the experts and the direct relationship matrix (mean) M is formed.
4) Drawing a direct correlation diagram.
5) Normalizing the M matrix is calculated by the equation (2).

$$N = \alpha \times M \qquad \alpha = \frac{1}{\mathrm{Max} \sum_{j=1}^{n} a_{ij}} \tag{2}$$

6) The total matrix is obtained using equation (3).

$$S = \frac{N}{I - N} \tag{3}$$

7) Drawing the causal diagram. The following principles are represented for this purpose:
D represents the sum of columns and R stands for the sum of rows of the total matrix.
R>D⇒R-D>0⇒ cause (Impacting).
R<D⇒R-D<0 effect (being impacted).
(R + D, R-D).
8) Identifying the hierarchy or possible structure of the criteria.
9) Drawing a network relationship map (NRM).

2.3. OPA(Ordinary Priority Approach) Method

This is a novel method where experts, criteria and alternatives are prioritized and weighted accordingly.This method no longer uses pairwise comparisons and averaging, and experts' opinions are aggregated using a mathematical model. Reader are refered to(Ataei, Mahmoudi, Feylizadeh, & Li, 2020) for more information. The specifications of the experts are presented in Table 2.

The advantages of OPA method are as follows:

- Obviation of the need for pairwise comparisons and data normalization.
- Experts only comment on the issues on which they have complete mastery.

Below are the steps taken to perform OPA:

Step 1: Evaluation of academic and professional records of experts.

Step 2: Evaluation of criteria, alternatives, and prioritization of alternatives in criteria by experts.

Step 3: Peresenting and solving a model.

r_k= (k=1….,m) : Prioritizing alternative k .

r_j= (j=1….,n) : Prioritizing criterion j.

r_i= (i=1….,p) : Prioritizing expert i.

W_{ijk} : The weight of alternative k in criterion j by expert i.

When the model is solved, weights are determined from Equations 4, 5, and 6, respectively.

$$W_k = \sum_{i=1}^{p}\sum_{j=1}^{n} W_{ijk} \quad \forall k \tag{4}$$

$$W_j = \sum_{i=1}^{p}\sum_{k=1}^{m} W_{ijk} \quad \forall j \tag{5}$$

$$W_i = \sum_{j=1}^{n}\sum_{k=1}^{m} W_{ijk} \quad \forall i \tag{6}$$

3.Research Methodology

Below are the steps of the suggested method:

- Evaluation the technologies criteria by expert opinions, interviews and previous studies.
- Remove the less important criteria using three Delphi steps and APMO.
- Investigate cause and effect relation in each category using DEMATEL method.
- Prioritizing important criteria and selecting the appropriate technology using OPA method. The proposed steps are presented in Fig 2.

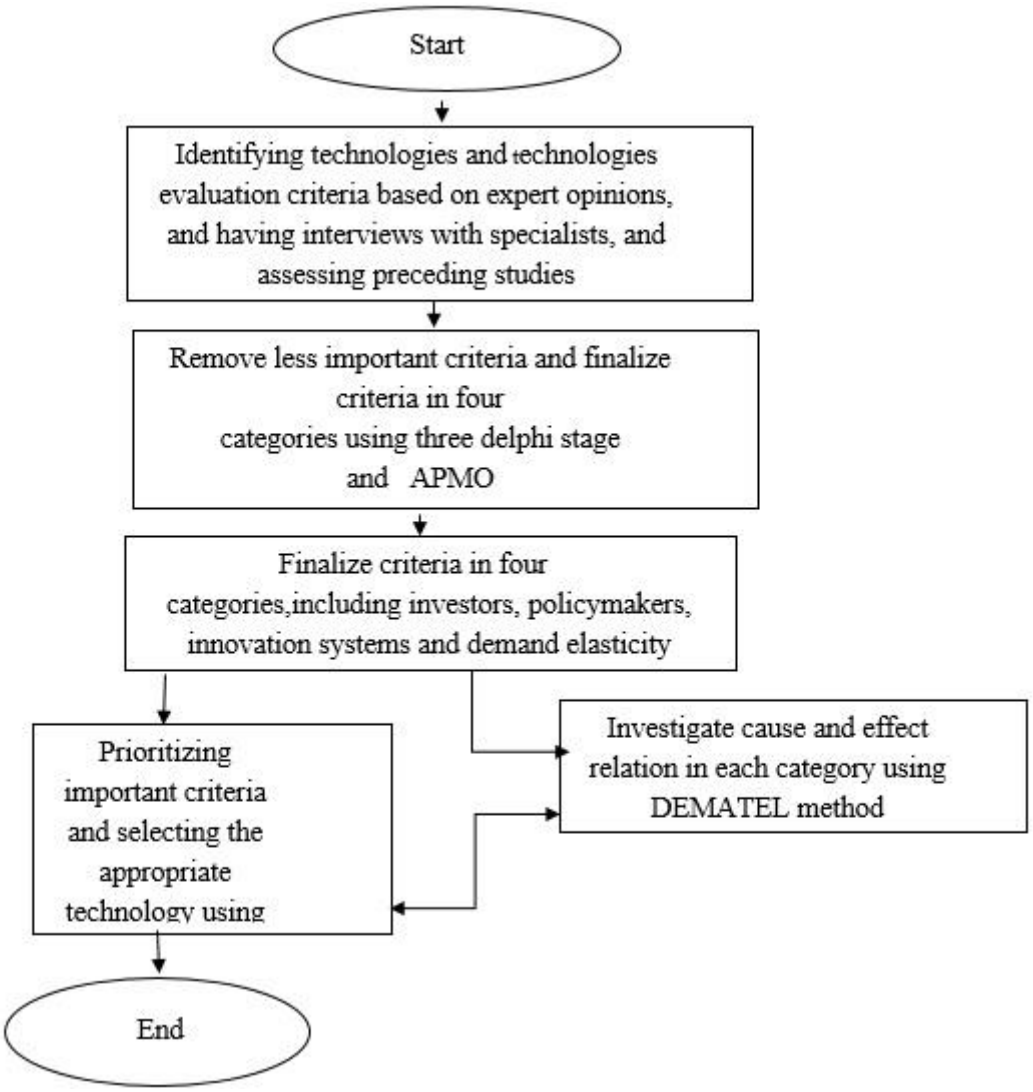

Figure2: Method steps

4. Results and Discussion

In this study, 100 criteria impacting technologies, taking into account preceding studies and expert opinions, identified. Using the Delphi method in three stages, 21 final criteria were identified. In each Delphi step, experts gave yes / no answers to each criterion. The percentage of yes and no answers was calculated, then the minimum acceptable percentage was obtained from equation (1). Every criterion with a minimum acceptable percentage of 70 and above was introduced into the next Delphi stage. Thus, 21 criteria were finalized in three Delphi steps. Table 2 displays the final criteria in four categories. The statistical characteristics of the experts are shown in table 1.

Table2: Final criteria derived from the three Delphi steps

index	criterion
Effective criteria from investment point of view	
I1	High costs of investment projects(Rinne, 2003; Suh & Park, 2009)
I2	The uncertainty of the price of alternative fuels of energy supply(Kim et al., 2009)
I3	Compete with Renewable Energy Technologies(Wath, Vaidya, Dutt, & Chakrabarti, 2010)
I4	Risk of profitability and economic feasibility(Geum, Kim, Son, & Park, 2013)
I5	Barriers to market entry(Wath et al., 2010)
I6	Access to financial resources(Jeong & Yoon, 2015)
I7	Market development policies(Mignon & Bergek, 2016)
I8	Dependence on geographical conditions(Aleina, Viola, Fusaro, & Saccoccia, 2016)
Effective criteria from policy-making's point of view	
P1	Pricing of fossil fuels**(Del Río et al., 2018)**
P2	Climate Change(Chen, Mazlack, Minai, & Lu, 2015)
P3	Economic prosperity(Rinne, 2003)
P4	Sanction(Amer & Daim, 2010)
P5	Environmental and social compatibility(Martin & Daim, 2012)
Effective criteria from innovation system point of view	
IN1	Inability to explain real expectations(Haddad & Maldonado, 2017)
IN2	Conflicting laws between different sections**(Moglia et al., 2017)**
IN3	Inappropriate market structure(Abdi & Kishore, 2010)
IN4	Economical potential(Del Río et al., 2018)
IN5	Employment creation(Pfeiffer & Mulder, 2013)
Effective criteria from demand Elasticity point of view	
EN1	Environmental treaties(Martin & Daim, 2012)
EN2	Increase in environmental pollution(Rivero & Daim, 2017)
EN3	Country's economic growth(Rinne, 2003)

After completing the three stages of the Delphi method, 21 criteria remained in four categories. Using the DEMATEL method, the relationship between criteria and their influence in four categories investment, policy-making, demand Elasticity and innovation was examined.

We used DEMATEL method for 8 criteria in the investment category. We reached table3.

.

Table 3: Relationships between investment criteria

	I1	I2	I3	I4	I5	I6	I7	I8
I1	1	0	1	1	0	0	0	1
I2	0	1	0	0	1	1	1	0
I3	0	0	1	0	0	1	1	0
I4	1	0	0	1	0	0	0	1
I5	0	1	0	0	1	1	1	0
I6	1	0	0	0	0	1	0	1
I7	1	0	0	1	0	0	1	1
I8	1	0	0	0	1	0	0	1

Table 3 displays the communications and impacting and being impacted of criteria on each other. In this table, 1 in the criteria section means these criteria are related to and affect each other. For instance, criterion I1 (high costs of investment projects) and criterion I3 (competition with renewable energy technologies) are related. Because in today's competitive market in the energy industry, technology and its use play a leading role in the world of competition. Also, in order to use and apply these technologies, it needs an investment in the projects of this industry to cover the high costs for the creation and use of these technologies. Due to the high costs of investment projects this industry has a much higher efficiency in comparison with investing in fossil fuels.

Table 4 shows that ,according to the final 8 criteria of the investment category, the criteria of uncertainty of the price of alternative energy fuels(3.31) , competing with renewable energy technologies(0.23) and market development policies (1.25) are the main causes of the research .

Table 4: Cause-effect results of the final criteria of the investment category

criterion	index	R	C	R+C	R-C	Cause/Effect
High costs of investment projects	I1	-1.15	-0.28	-1.43	-0.87	Effect
The uncertainty of the price of alternative fuels of energy supply	I2	1.77	-1.54	0.23	3.31	Cause
Compete with Renewable Energy Technologies	I3	-0.73	-0.96	-1.68	0.23	Cause
Risk of profitability and economic feasibility	I4	-0.65	0.25	-0.41	-0.90	Effect
Barriers to market entry	I5	-0.27	0.72	0.45	-0.99	Effect
access to financial resources	I6	-0.55	1.03	0.47	-1.58	Effect
Market development policies	I7	0.72	-0.53	0.19	1.25	Cause
Dependence on geographical conditions	I8	-0.18	0.27	0.09	-0.45	Effect

It is observable that the criterion of barriers to market entry and access to financial resources has higher importance than other criteria. Figure 3 displays the importance, impacting and being impacted of the criteria. Figure 3 also reveals that among the criteria of the investing category, the uncertainty of the price of alternative fuels for energy supply and

market development policies have the most influential. Furthermore, the presence of reciprocating arrows among the 3 criteria out of 8 criteria is a clear indication of the existence of simultaneous and reciprocal impacting and being impacted of the technology selection criteria and the proper use of the DEMATEL method in this research.

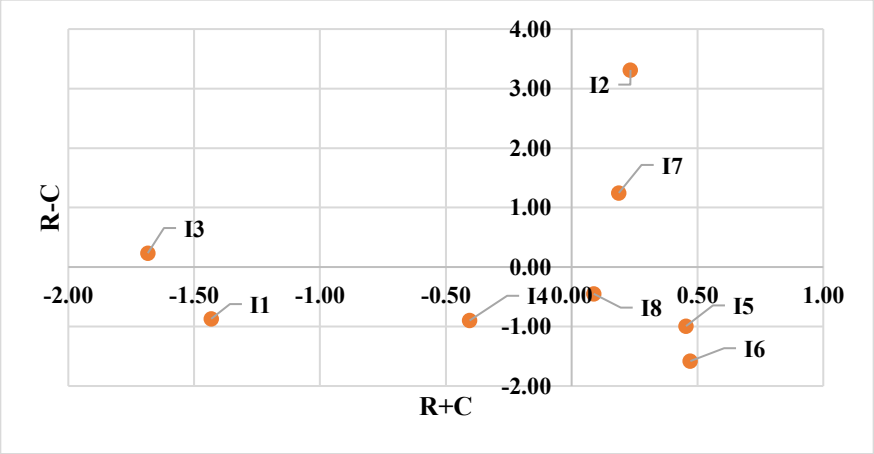

Figure 3. Relationship, importance, impacting and being impacted of investment criteria

We used DEMATEL method for 5 criteria in the policy making category. Referring to the results obtained from table 5, the criteria in this section are significantly linked to each other.

Table 5: Relationships between Policy making criteria

	P1	P2	P3	P4	P5
P1	1	0	1	1	0
P2	0	1	0	0	1
P3	1	1	1	0	0
P4	0	0	0	1	0
P5	0	0	1	1	1

For instance, fossil fuel pricing is linked to the criteria of economic prosperity and sanctions. This is because there are a number of criteria involved in setting pricing policies for fossil fuels, the most important of which are economic prosperity and sanctions. When economic prosperity in a society is declining and also the ways of communication with the outside world to reform and restore economic prosperity to society are limited, the need to use the capacities of biofuels increases. Table 6 shows that among the policy criteria, changes in environmental and social compatibility (0.28), economic prosperity (0.17) and sanction (0.15) (foreign laws and regulations) have the most influential.

Table 6: Cause-effect results of the final criteria of policy making category

criterion	index	R	C	R+C	R-C	Cause/Effect
Pricing of fossil fuels	P1	-1.15	-0.77	-1.92	-0.38	Effect
Climate Change	P2	-0.76	-0.53	-1.29	-0.23	Effect
Economic prosperity	P3	-0.72	-0.89	-1.62	0.17	Cause
Sanction	P4	-0.90	-1.05	-1.95	0.15	Cause
Environmental and social compatibility	P5	-0.63	-0.92	-1.55	0.28	Cause

Figure 4 shows that among the policy criteria, changes in environmental and social compatibility, economic prosperityand sanction (foreign laws and regulations) have the most influential and criteria p1 and p2 are the most affected and important ones.

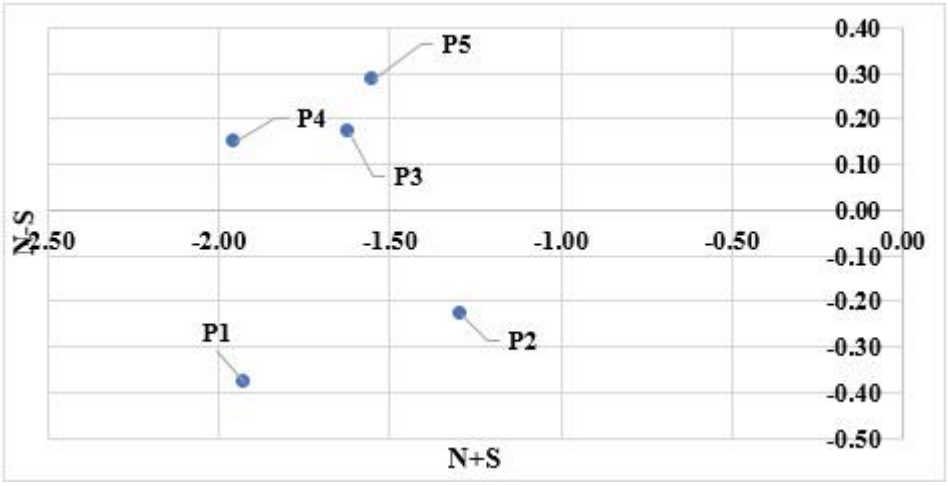

Figure 4. Relationship, importance, impacting and being impactedof policy making criteria

We used DEMATEL method for 5 criteria in the innovation category. Referring to the results obtained from table 7, the criteria in this section are significantly linked to each other.

Table 7: Relationships between Innovation systems criteria

	IN1	IN2	IN3	IN4	IN5
IN1	1	0	1	0	1
IN2	0	1	0	1	0
IN3	1	0	1	0	1
IN4	0	1	0	1	0
IN5	0	1	0	1	1

In table 8, the greatest impact is related to the criterion of inability to explain real expectations on the category of innovation systems (2.87) followed by employment creation on the category of innovation systems (0.26). Job creation is associated with contradictory laws and economic potential. The availability of suitable structures provides enhanced economic potential and suitable chances of employment.

Table 8: Cause-effect results of the final criteria of innovation systems category

criterion	index	R	C	R+C	R-C	Cause/Effect
Inability to explain real expectations	IN1	1.96	-0.91	1.04	2.87	Cause
conflicting laws between different sections	IN2	-1.00	-1.00	-2.00	0.00	cause
Inappropriate market structure	IN3	-0.39	2.39	2.00	-2.78	Effect
Economical potential	IN4	-1.65	-1.30	-2.96	-0.35	Effect
employment creation	IN5	0.09	-0.17	-0.09	0.26	Cause

According to figure 5, considering the criteria of innovation systems, the criteria of inability to explain real expectations, employment creation and conflicting laws between different sectors have the most influential, respectively, and the criteria of economic potential and inappropriate market structure have the most affected and also importance, respectively. Furthermore, the presence of reciprocating arrows among the criteria of innovation systems is a clear indication of the existence of simultaneous and reciprocal impacting and being impacted of the innovation systems criteria and the proper use of the DEMATEL method in this research.

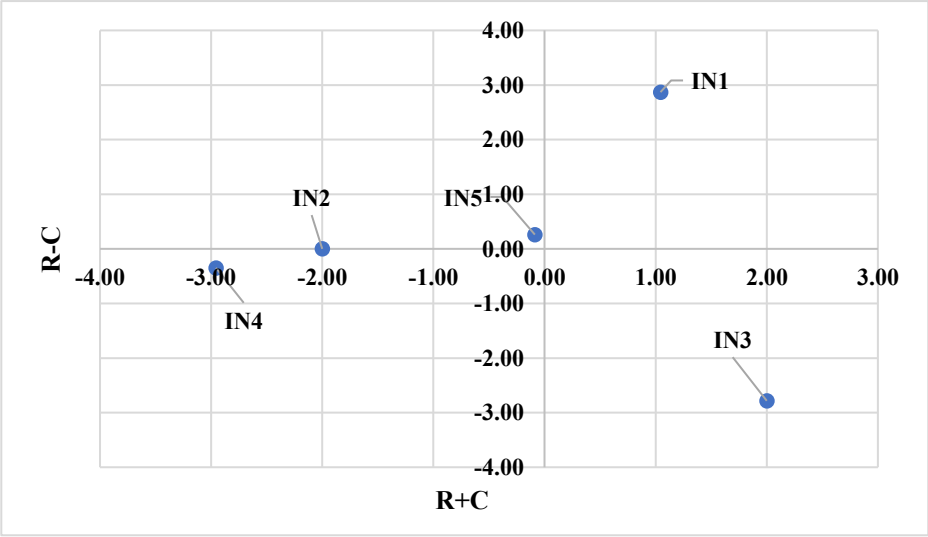

Figure 5. Relationship, importance, impacting and being impacted of Innovation systems criteria

We used the DEMATEL method for 3 criteria in the demand elasticity category. Referring to the results obtained from Table 9, the criteria in this section are significantly linked to each other.

Table 9: Relationships between Demand Elasticity criteria

	EN1	EN2	EN3
EN1	1	1	0
EN2	0	1	0
EN3	1	1	1

According to Table 10, the greatest impact is related to the country's economic growth criterion on the demand Elasticity category (0.72) followed by the environmental treaties on the demand Elasticity category (-0.17).

Table 10: Cause-effect results of the final criteria of Demand Elasticity category

criterion	index	R	C	R+C	R-C	Cause/Effect
Environmental treaties	EN1	-0.84	-0.67	-1.52	-0.17	Effect
Increase in environmental pollution	EN2	-0.94	-0.39	-1.34	-0.55	Effect
Country's economic growth	EN3	-0.36	-1.08	-1.44	0.72	Cause

Based on the information in Figure 6, among the demand elasticity criteria, the country's economic growth criterion was the most influential, and environmental treaty criteria and increased environmental pollution were the most affected and important criteria, respectively. Economic growth is directly related to environmental pollution and environmental treaties. As the pollution level increases, more attempts are made to use biofuels, which affects the cost and reduction of pollution in the long run, which in turn leads to economic growth.

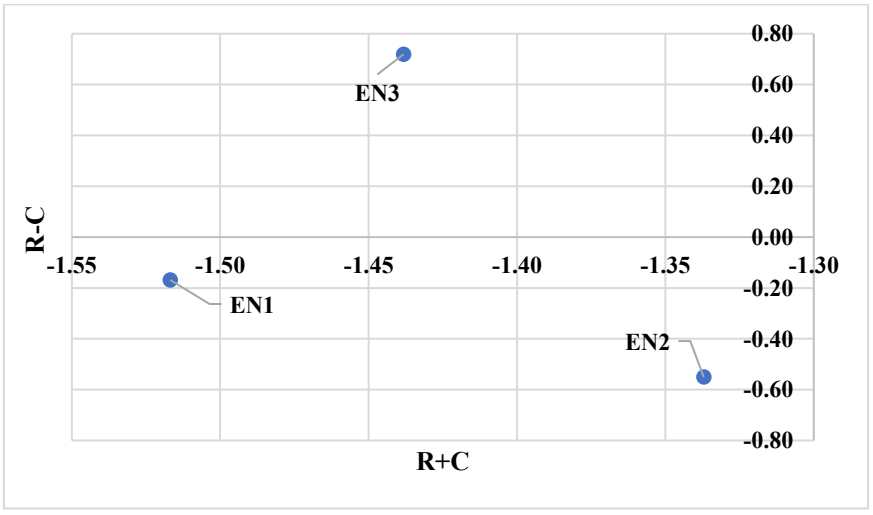

Figure 6. Relationship, importance impacting and being impacted of Demand Elasticity criteria

After investigating cause and effect relation in each category using DEMATEL method, we ranked them using the OPA method.OPA solver (Web-based) software was used to rank the criteria. Experts in each class were ranked according to their level of education, knowledge, work experience and interest. In the next step, each expert ranked the criteria with respect to their significance. Finally, Table 11 was obtained.

Table 11: Weighting the criteria using the OPA

Weight	index	criteria
Effective factors from investment point of view		
1210/	I1	High costs of investment projects
1340/	I2	The uncertainty of the price of replacement fuels of energy supply
1280/	I3	Compete with Renewable Energy Technologies
1380/	I4	Risk of profitability and economic feasibility
1370/	I5	Barriers to market entry
1210/	I6	access to financial resources
1200/	I7	Market development policies
0970/	I8	Dependence on geographical conditions
Effective factors from policy-making's point of view		
2580/	P1	Pricing of fossil fuels
1640/	P2	Climate Change
1840/	P3	Economic prosperity
1180/	P4	Sanction
2750/	P5	Environmental and social compatibility
Effective factors from innovation system point of view		
1930/	IN1	Inability to explain real expectations
1310/	IN2	conflicting laws between different sections
1820/	IN3	Inappropriate market structure
2010/	IN4	Economical potential
2910/	IN5	employment creation
Effective factors from demand Elasticity point of view		
3030/	EN1	Environmental treaties
4050/	EN2	Increase in environmental pollution
2910/	EN3	Country's economic growth

The obtained results from the solving method (OPA) are shown in table 11. In the table 11, the criteria of risk profitability and economic feasibility, environmental and social compatibility, employment creation and increase in environmental pollution have the highest weight in the four categories. For instance, in the investor category, the criterion of profitability risk has the highest weight, because in the process of investing in any economic project, the investor, whether a government or an individual or an investor group, tries to invest in projects that have the least risk of profitability. Furthermore, in the policy-making category, the reason that environmental and social compatibility has the first rank is that the use of biofuels not only reduces pollution but also helps better utilize water and environmental resources.

Then for choose the appropriate technology, we ranked the technologies according to efficiency and importance using the OPA method. Four types of technology, (A1) to (A4), in the weighting process are evaluated and ranked by experts. Table 12 shows the weight and importance of the four technologies. The technology of gasification, have the most importance

and weight, this is because almost enough infrastructure is available to modify the macro policies of this technology and adapt them to the environment.

Table 12: Ranking of the technologies using the OPA method

Weight	Index	Technology
0.066	A1	Direct combustion(Bergthorson et al., 2015; Mandø, 2013; Tillman, 2000)
0265	A2	Pyrolysis(Hasan, Rasul, Khan, Ashwath, & Jahirul, 2021; Liu et al., 2020; Venderbosch & Prins)
0.505	A3	Gasification(An, Zagorščak, & Thomas, 2022; Wang et al., 2021; Yan, Afxentiou, & Fokaides, 2021)
0.164	A4	Anaerobic digestion(Diamantis et al., 2021; Uddin et al., 2021; Vyas, Prajapati, Shah, Srivastava, & Varjani, 2022)

5. Conclusion

Excessive use of fossil fuels, increased pollution and environmental problems have made the production and use of biofuels a necessity. Due to the high capacity of the resources and their wide range and high diversity, as well as their low cost and ease of access, it can be argued that suitable infrastructure for production is available. In today's competitive market, and due to environmental pollution and demand capacity, technologies and their use play a leading role. The use of new technologies is effective in reducing production costs and greenhouse gas emissions and increasing welfare. One of the main drawbacks in the biofuel production is the lack of attention to the evaluation criteria of technologies and picking an appropriate technology. Hence, first, according to previous studies and expert opinions, the criteria of technologies in the biofuels industry were identified and evaluated comprehensively. Approximately 100 criteria were identified, and then 21 important criteria were finalized using three Delphi stages. Then, using the DEMATEL method, the relationships, effects, and influences of the criteria were examined. Ultimately, the weights of the criteria were determined using the OPA method. In the categories of investors, policymakers, innovation systems, and demand elasticity, the criteria of profitability risk, environmental and social compatibility, employment creation and increase in environmental pollution had the most importance and weight in the four categories. The technology of gasification has the most importance and weight, this is because enough infrastructure is available to modify the macro policies of this technology and adapt them to the environment. According to the obtained results, the gasification technology has the least risk and the most compatibility with the environment, reduces pollutants, and creates employment. This is because it provides more coverage for sustainability criteria. The use of this technology helps to reduce costs and pollution and increase welfare and service levels.

References

Abdi, H., & Nozari, H. (2025). AIoE-enhanced multi-objective optimization for sustainable bioprocesses in smart bioreactors. In Artificial Intelligence of Everything and Sustainable Development (pp. 19-38). Singapore: Springer Nature Singapore.

Aleina, S. C., Viola, N., Fusaro, R., & Saccoccia, G. (2016). Effective methodology to derive strategic decisions from ESA exploration technology roadmaps. Acta Astronautica, 126, 316-324.

Alizadeh, R., Soltanisehat, L., Lund, P. D., & Zamanisabzi, H. (2020). Improving renewable energy policy planning and decision-making through a hybrid MCDM method. Energy Policy, 137, 111174.

Amer, M., & Daim, T. U. (2010). Application of technology roadmaps for renewable energy sector. Technological forecasting and social change, 77(8), 1355-1370.

An, N., Zagorščak, R., & Thomas, H. R. (2022). Adsorption characteristics of rocks and soils, and their potential for mitigating the environmental impact of underground coal gasification technology: A review. Journal of Environmental Management, 305, 114390.

Ataei, Y., Mahmoudi, A., Feylizadeh, M. R., & Li, D.-F. (2020). Ordinal priority approach (OPA) in multiple attribute decision-making. Applied Soft Computing, 86, 105893.

Balin, A. (2020). A novel fuzzy multi-criteria decision-making methodology based upon the spherical fuzzy sets with a real case study. Iranian Journal of Fuzzy Systems, 17(4), 167-177.

Bergthorson, J., Goroshin, S., Soo, M., Julien, P., Palecka, J., Frost, D., & Jarvis, D. (2015). Direct combustion of recyclable metal fuels for zero-carbon heat and power. Applied Energy, 160, 368-382.

Bertel, S., Fenies, P., & Roux, O. (2008). Optimal cash flow and operational planning in a company supply chain. International Journal of Computer Integrated Manufacturing, 21(4), 440-454.

Chen, Y., Mazlack, L. J., Minai, A. A., & Lu, L. J. (2015). Inferring causal networks using fuzzy cognitive maps and evolutionary algorithms with application to gene regulatory network reconstruction. Applied Soft Computing, 37, 667-679.

Chobar, A. P., Adibi, M. A., & Kazemi, A. (2022). Multi-objective hub-spoke network design of perishable tourism products using combination machine learning and meta-heuristic algorithms. Environment, Development and Sustainability, 1-28.

Cottam, H., Roe, M., & Challacombe, J. (2004). Outsourcing of trucking activities by relief organisations. Journal of Humanitarian Assistance, 1(1), 1-26.

Del Río, P., Peñasco, C., & Mir-Artigues, P. (2018). An overview of drivers and barriers to concentrated solar power in the European Union. Renewable and sustainable energy reviews, 81, 1019-1029.

Diamantis, V., Eftaxias, A., Stamatelatou, K., Noutsopoulos, C., Vlachokostas, C., & Aivasidis, A. (2021). Bioenergy in the era of circular economy: Anaerobic digestion technological solutions to produce biogas from lipid-rich wastes. Renewable Energy, 168, 438-447.

Durmaz, Y. G., & Bilgen, B. (2020). Multi-objective optimization of sustainable biomass supply chain network design. Applied Energy, 272, 115259.

Feng, X., Moon, I., & Ryu, K. (2015). Supply chain coordination under budget constraints. Computers & Industrial Engineering, 88, 487-500.

Geum, Y., Kim, J., Son, C., & Park, Y. (2013). Development of dual technology roadmap (TRM) for open innovation: Structure and typology. Journal of Engineering and Technology Management, 30(3), 309-325.

Ghorbannia Ganji, G., Afzoon, E., Kaveh, F., Keihani, H., & Alamiparvin, R. (2025). Optimizing Facility Breakdown in Multi-Period Routing and Location for Heterogeneous Vehicles in a Circular Supply Chain. Journal of Industrial Engineering and Management Studies, 12(2), 42-58.

Guillen, G., Badell, M., & Puigjaner, L. (2007). A holistic framework for short-term supply chain management integrating production and corporate financial planning. International Journal of Production Economics, 106(1), 288-306.

Haddad, C. R., & Maldonado, M. U. (2017). A functions approach to improve sectoral technology roadmaps. Technological Forecasting and Social Change, 115, 251-260.

Han, Y., & Deng, Y. (2018). An enhanced fuzzy evidential DEMATEL method with its application to identify critical success factors. Soft computing, 22(15), 5073-5090.

Hasan, M., Rasul, M., Khan, M., Ashwath, N., & Jahirul, M. (2021). Energy recovery from municipal solid waste using pyrolysis technology: A review on current status and developments. Renewable and sustainable energy reviews, 145, 111073.

Hasheminezhad, A., Hadadi, F., & Shirmohammadi, H. (2021). Investigation and prioritization of risk factors in the collision of two passenger trains based on fuzzy COPRAS and fuzzy DEMATEL methods. Soft Computing, 25(6), 4677-4697.

Hua, Y., Oliphant, M., & Hu, E. J. (2016). Development of renewable energy in Australia and China: A comparison of policies and status. Renewable Energy, 85, 1044-1051.

Jeong, Y., & Yoon, B. (2015). Development of patent roadmap based on technology roadmap by analyzing patterns of patent development. Technovation, 39, 37-52.

Jimenez, M., Franco, C. J., & Dyner, I. (2016). Diffusion of renewable energy technologies: The need for policy in Colombia. Energy, 111, 818-829.

Karthigadevi, G., Vignesh, K., Chozhavendhan, S., & Sundaramoorthy, R. (2021). Nanocatalyst-mediated biodiesel production from microalgae: sustainable renewable energy feedstock. Nanomaterials, 411-424.

Keihani, H. (2025). Simulation-based on multi-objective optimization in complex system: A meta-modeling approach. Complexity Analysis and Applications, 2(1), 25-38.

Keihani, H., & Keihani, H. (2025). Transitioning corporate models and processes towards sustainable practices and adopting a circular economy approach. Canadian Journal of Business, Economics and Health Managemen, 8(2), 31-46.

Kim, C., Kim, H., Han, S. H., Kim, C., Kim, M. K., & Park, S. H. (2009). Developing a technology roadmap for construction R&D through interdisciplinary research efforts. Automation in Construction, 18(3), 330-337.

Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and sustainable energy reviews, 69, 596-609.

Lee, C.-Y., & Huh, S.-Y. (2017). Forecasting the diffusion of renewable electricity considering the impact of policy and oil prices: The case of South Korea. Applied energy, 197, 29-39.

Liu, J., Hou, Q., Ju, M., Ji, P., Sun, Q., & Li, W. (2020). Biomass pyrolysis technology by catalytic fast pyrolysis, catalytic co-pyrolysis and microwave-assisted pyrolysis: A review. Catalysts, 10(7), 742.

Mandø, M. (2013). Direct combustion of biomass Biomass combustion science, technology and engineering (pp. 61-83): Elsevier.

Martin, H., & Daim, T. U. (2012). Technology roadmap development process (TRDP) for the service sector: A conceptual framework. Technology in Society, 34(1), 94-105.

Mastrocinque, E., Ramírez, F. J., Honrubia-Escribano, A., & Pham, D. T. (2020). An AHP-based multi-criteria model for sustainable supply chain development in the renewable energy sector. Expert Systems with Applications, 150, 113321.

Mignon, I., & Bergek, A. (2016). System-and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. Journal of Cleaner Production, 128, 105-115.

Miller, K. A., Collada, B., Tolliver, D., Audi, Z., Cohen, A., Michelson, C., & Newman, L. R. (2020). Using the modified Delphi method to develop a tool to assess pediatric residents supervising on inpatient rounds. Academic Pediatrics, 20(1), 89-96.

Moglia, M., Cook, S., & McGregor, J. (2017). A review of Agent-Based Modelling of technology diffusion with special reference to residential energy efficiency. Sustainable Cities and Society, 31, 173-182.

Moriarty, P., & Honnery, D. (2021). New Energy Technologies: Microalgae, Photolysis and Airborne Wind Turbines. Sci, 3(1), 5.

Naeini, M. A., Zandieh, M., Najafi, S. E., & Sajadi, S. M. (2020). Analyzing the development of the third-generation biodiesel production from microalgae by a novel hybrid decision-making method: The case of Iran. Energy, 195, 116895.

Noorazar, H., Brady, M. P., Savalkar, S., Norouzi Kandelati, A., Liu, M., Beale, P., ... & Rajagopalan, K. (2025). Monitoring Double-Cropped Extent with Remote Sensing in Areas with High Crop Diversity. Plants, 14(9), 1362.

Pfeiffer, B., & Mulder, P. (2013). Explaining the diffusion of renewable energy technology in developing countries. Energy Economics, 40, 285-296.

Quezada, L. E., López-Ospina, H. A., Palominos, P. I., & Oddershede, A. M. (2018). Identifying causal relationships in strategy maps using ANP and DEMATEL. Computers & Industrial Engineering, 118, 170-179.

Rinne, M. (2003). Technology roadmaps: Infrastructure for innovation. Technological forecasting & social change, 71, 5-26.

Rivero, A. R. G., & Daim, T. (2017). Technology roadmap: Cattle farming sustainability in Germany. Journal of Cleaner Production, 142, 4310-4326.

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. Research Policy, 45(8), 1620-1635.

Roudaki, M., Pourghader Chobar, A., Nagahi, A., Keihani, H., & Alamiparvin, R. (2025). Evaluation of supply chain performance using combination of DEA and fuzzy TOPSIS: A case from Iranian electric industry. Journal of industrial engineering and management studies, 12(1), 114-124.

Shah, S., Solangi, Y., & Ikram, M. (2019). Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process. Journal of Cleaner Production, 235, 1037-1050.

Shao, M., Han, Z., Sun, J., Xiao, C., Zhang, S., & Zhao, Y. (2020). A review of multi-criteria decision making applications for renewable energy site selection. Renewable Energy, 157, 377-403.

Strand, J., Carson, R. T., Navrud, S., Ortiz-Bobea, A., & Vincent, J. R. (2017). Using the Delphi method to value protection of the Amazon rainforest. Ecological Economics, 131, 475-484.

Suh, J. H., & Park, S. C. (2009). Service-oriented technology roadmap (SoTRM) using patent map for R&D strategy of service industry. Expert Systems with Applications, 36(3), 6754-6772.

Tillman, D. A. (2000). Biomass cofiring: the technology, the experience, the combustion consequences. Biomass and bioenergy, 19(6), 365-384.

Touti, E., & Chobar, A. P. (2020). Utilization of AHP and MCDM integrated methods in urban project management (A case study for eslamshahr-tehran). International journal of industrial engineering and operational research, 2(1), 16-27.

Uddin, M., Siddiki, S., Arafat, Y., Mofijur, M., Djavanroodi, F., Hazrat, M., . . . Chu, Y.-M. (2021). Prospects of bioenergy production from organic waste using anaerobic digestion technology: a mini review. Frontiers in Energy Research, 9, 33.

Venderbosch, R., & Prins, W. Fast pyrolysis technology development. Biofuels, Bioprod Bioref 2010; 4: 178–208.

von der Gracht, H. A. (2008). The Delphi technique for futures research. The Future of Logistics: Scenarios for 2025, 21-68.

Vyas, S., Prajapati, P., Shah, A. V., Srivastava, V. K., & Varjani, S. (2022). Opportunities and knowledge gaps in biochemical interventions for mining of resources from solid waste: a special focus on anaerobic digestion. Fuel, 311, 122625.

Wang, F., Yu, G., Liu, H., Li, W., Guo, Q., Xu, J., . . . Shen, Z. (2021). Opposed multi-burner gasification technology: Recent process of fundamental research and industrial application. Chinese Journal of Chemical Engineering, 35, 124-142.

Wath, S. B., Vaidya, A. N., Dutt, P., & Chakrabarti, T. (2010). A roadmap for development of sustainable E-waste management system in India. Science of the Total Environment, 409(1), 19-32.

Welfle, A., Thornley, P., & Röder, M. (2020). A review of the role of bioenergy modelling in renewable energy research & policy development. Biomass and bioenergy, 136, 105542.

Wicker, R. J., Kumar, G., Khan, E., & Bhatnagar, A. (2021). Emergent green technologies for cost-effective valorization of microalgal biomass to renewable fuel products under a biorefinery scheme. Chemical Engineering Journal, 415, 128932.

Yan, M., Afxentiou, N., & Fokaides, P. A. (2021). The state of the art overview of the biomass gasification technology. Current Sustainable/Renewable Energy Reports, 1-14.