


# Assessing the New Product Development Process for the Industrial Decarbonization of Sustainable Economies

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## Abstract

This study aims to find out the significant stages of new product development process for the industrial decarbonization of sustainable economies by using interval type-2 (IT2) fuzzy decision-making trial and evaluation laboratory (DEMATEL). The findings demonstrate that commercialization is the most significant process of new product generation process of industrial decarbonization. Moreover, it is also concluded that with respect to the sub-criteria, cost analysis, and performance evaluation have the highest weights. An effective cost analysis is required in the new product development process. The costs of the product development process can in some cases be much higher than anticipated. This situation eliminates the effectiveness of the newly developed product. In this context, companies need to make the necessary plans for the costs of these new products correctly. On the other hand, it is important to follow the costs in detail during the process. Otherwise, the product that does not provide a cost advantage will not be preferred by industrial companies. This will cause the actions to be taken to reduce carbon emissions to fail.

## Keywords

decarbonization, new product development, DEMATEL, IT2 fuzzy DEMATEL, clean energy

## Introduction

With the increase in industrialization, the need for energy has increased. In this process, the use of fossil energy sources increases the amount of carbon gas in the atmosphere. However, carbon dioxide emissions have many negative effects on the environment. The emission of this gas pollutes the air and threatens the life of the living things. In addition, because carbon dioxide emission creates air pollution, it also leads to serious illnesses for the people. For instance, there is an increase in lung cancer patients (Monyei et al., 2019). Due to these problems, decarbonization in the industry has become increasingly important. This concept aims to minimize the negative effects of carbon dioxide emissions by using carbon-based technologies in the industry (Salina et al., 2020).

Most countries implement some policies to reduce carbon dioxide emissions. In fact, this constitutes the agenda of international energy institutions (Yang et al., 2019). Renewable energy sources are the most prominent issues in this process. They represent the energy obtained from the existing energy flow in the continuous natural processes (Huang, 2019). Hence, it can be said that carbon dioxide emissions are low in sources where natural processes are used for energy production such as wind, solar, and geothermal (Tantau & Staiger, 2020). From

this point of view, sustainable energy can be obtained through renewable energy sources.

Industrial decarbonization aims to decrease carbon dioxide emissions caused by industrial production. Therefore, with decarbonization, it will be easier to attract both domestic and foreign investors. Paying attention to the reduction of carbon dioxide emissions in a country will increase the confidence of investors. Because of high initial costs, it is difficult for energy companies to provide funds in this process. While international credit institutions give loans to energy companies, they pay attention to whether these companies

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are environmentally sensitive (Zhang, Zhou et al., 2020). On the other hand, because carbon dioxide emission causes serious illnesses, the treatment of them can cause high amount of costs. Owing to this aspect, the process of industrial decarbonization can contribute sustainable economic development of the countries (Rathore & Ilavarasan, 2020).

One of the biggest causes of carbon emission is the lack of attention to this issue in the industrial production process. Therefore, there is a serious need for products that will reduce carbon emissions, especially in the industrial production process. However, developing new products for industrial decarbonization is difficult. There is a risk that this new product to be developed cannot meet the needs of the market (Ku, 2020). Since this situation will cause customer dissatisfaction, there is a possibility that this new product to be developed will fail. On the other hand, the new product to be developed for industrial decarbonization will bring serious technological innovations. In this process, there is a risk that customers may find these products difficult to use. This will cause a decrease in the sales volume of the product.

Many different factors should be taken into consideration at the same time while generating new products for industrial decarbonization. New product development is a process that has certain stages. First, different ideas for carbon-free products need to be collected. In this context, the opinion of both employees and experts in the market should be obtained. Then, the more important of these ideas collected by the expert team within the company should be identified. Afterward, the new product needs to be developed by making the latest arrangements. However, one of the most important processes occurs after the development of this product. In this context, this developed product should be tested before it is put on the market. In this way, it will be possible to prevent a possible failure in the development process of the product. The new product, which successfully survives the test phase, is launched (Roy et al., 2020). In this process, the introduction of the properties of the product is also important. Because of the use of this developed herd in the industry, carbon emissions can be reduced.

This study aims to determine the most important stages in the development of new products with low carbon emissions. In this process, literature review on new product development has been conducted and five different stages have been identified. Additionally, 10 sub-criteria are also selected for these stages. Moreover, IT2 fuzzy DEMATEL method is used to define which of these stages is more important than the others. In the literature, there are different methods to weight the factors, such as analytic hierarchy process (AHP) and analytic network process (ANP). However, the main superiority of DEMATEL approach is creating impact relation map of the items (Song et al., 2020). Thus, causality relationship between these factors can also be evaluated (Fazli et al., 2015; Kaya & Yet, 2019). Furthermore, while considering IT2 fuzzy logic in the analysis process, it can be

more possible to handle uncertainties in decision-making process (Runkler et al., 2018; Wu et al., 2019).

The main motivation of this study is to present an appropriate strategy while developing new products for industrial decarbonization. There are limited studies that indicate which of these steps should be prioritized to generate effective new products for the industrial decarbonization. Hence, it is believed that this study makes a significant contribution to the literature. Additionally, it will also be able to develop a strategy on how to avoid the carbon dioxide emission problem that needs to be solved for the economic development of a country. By determining the importance of product development processes, it will be possible to develop these strategies accurately and in place. Hence, it can be much easier to generate necessary products to improve industrial decarbonization so that economic and environment development can be achieved.

There are five different parts in this study. The first part includes general information about the concept. Secondly, literature review is given. For this purpose, new product development process, the concept of industrial decarbonization and the evaluation of similar studies are explained. Additionally, the third part is related to the detailed information about IT2 fuzzy DEMATEL methodology. In the fourth part, analysis results are demonstrated. Also, the final part includes discussion and conclusion.

## Literature Review

In this section, new product development process, the concept of industrial decarbonization and the evaluation of similar studies are given.

### *General Information About New Product Development*

Companies develop and offer products to customers for their purchase. At the end of this process, they increase their profit margins owing to their sales revenues. The important point is that this process can be continuous. Otherwise, after a while, companies will be unable to sell, and their profitability will decrease. As a result of globalization, international trade has improved considerably and competition in all sectors has increased. Because of this increasing competition, the risk of losing the customers of the companies increased. In summary, this situation reduces the continuity of companies to sell their products to customers. Due to these issues, it is imperative that companies continuously develop new products. Otherwise, in this competitive environment in the market, companies have no chance of survival. Therefore, most companies attach serious importance to the new product development process. Jugend et al. (2020) focused on the eco-design practices and tools for new product development. They claimed that even profitable companies are constantly striving to develop new products. Although they are the

market leaders, they are developing new products in order not to lose this power. Moreover, companies with a low market share should pay extra attention to this situation. The most basic instrument of this is that these companies must introduce new products to the market to increase their competitiveness.

It is possible that this new product to be developed can be offered to the market in different types. It may be a product that has never been on the market before. For this purpose, companies should give importance to research and development. Companies that allocate more budgets to this issue are more likely to be successful in this process. The most important advantage of introducing a non-existent product is that it will significantly increase the company's market share when preferred by customers. Yu et al. (2020) tried to evaluate the innovation performance of new products in China's high-technology industry. They discussed that the company can also offer the product to the current market. In other words, this product is not a new product for the company, but a new product for the market. It is possible to mention both advantages and disadvantages of this type of product. In case of positive demand from the market for this developed product, it will be easier for the company to increase its competitiveness in the market. On the other hand, the company can produce this product for the first time, which already exists in the market. In this type of product, the company develops a product used by customers for the first time. Because customers have already tested this product, there is a risk that the company will not satisfy customers.

It is possible that the existing product in the market cannot respond to changing customer requests and needs over time. In this case, companies should make some changes in product properties. For this purpose, some changes can be made in the quality or packaging of the product. In this way, the company has developed a new product. In other words, the company has already made an existing product and made some changes to make it a new product. In this way, it aims to increase the market share by attracting the attention of customers. Frizziero et al. (2020) defined that factors such as rapid changes in technology, the dynamics of the market and the constant change in demand have made it essential for companies to develop new products. In other words, new product development efforts have become the most important power for the companies that want to maintain and grow their market shares. However, new product development process is costly, risky, and difficult for companies. Nevertheless, companies are committed to new product development in order to survive in this difficult environment.

One of the reasons why companies develop new products is their market strategies. Companies have started to offer different products in order to meet the expectations of the customers. When companies offer many different products to their customers, it can be easier to win them. The main reason for this is that customers may be reluctant to go to different companies to meet their different demands. In summary,

companies that develop new products can expand the range of products they offer to their customers, which in turn contributes to customer satisfaction. Pereira et al. (2020) claimed that every company wants to get better than the current situation, so they take action to have a better market share, to make more sales and to increase their profitability. The most important factor that will enable the company to grow is the adherence of new products to the market. In this framework, the critical point is that not every product can contribute to the growth of the company. Therefore, the continuity of the company's success in the market is important. Hence, the planning of the newly developed product must be carried out carefully.

The most effective factor in the new product development process is to gain competitive advantage. If a business wants to hold and exist in a competitive market, it must reach an advantageous position in competition. One of the easiest ways to do this is to develop new products that meet customers' demands. The company, whose products are preferred by customers, has a significant advantage over its competitors. Another important issue in this process is that the company follows the current developments in the market. In this way, the firm will be able to determine its strategies in line with current developments and develop new products. Technological developments are another important issue in this process. Companies should primarily follow current developments in technology. Wang and Chen (2020) identified that the products of the companies that are behind the technology are not preferred by the customers. This situation leads the customers to turn to the products of competing companies and the company to lose customers. Another important point is that the company is technologically sufficient. Within this framework, it is important that companies allocate budget for research and development. Owing to effective research and development activities, companies will be able to develop themselves technologically. In this process, the perspective of the top management of the company and the employment of competent personnel play an important role.

The new product development process starts with the emergence of an idea in line with customer and market needs. Within this context, it is necessary to identify among the many ideas that will contribute to the company's goals. In line with this aim, it is important at first to collect different ideas from different segments. In order to reach effective ideas, opinions from all sources should be provided. Within this framework, the company should primarily consult the opinions of its employees. O'Brien (2020) determined that idea development departments can be established within the company. On the other hand, external resources, such as customers, suppliers, and universities, can also be beneficial to the company in this process. The next step after the provision of ideas is the selection of the more important ones. In this context, ideas that are not in line with the company's objectives need to be eliminated. Ross (2020) discussed that the most important issue in this process is the extent to which the

ideas are compatible with the strategies of the company. Therefore, even if an idea is important, it should not be considered if it does not parallel the company's strategies. On the other hand, the cost-benefit analysis of ideas is another important issue in this process. If the new product to be developed does not increase the profit margin of the company, it should be eliminated in this process.

After that, the company should determine its strategies for this new product. In other words, things like what the company intend, and which customers aim to reach should be clarified in this process. Ravi and Ranganathan (2020) stated that it is important to determine the sales volume and price of the product. Economic analysis of the product should then be carried out. In this context, the possible contribution of this product to the profitability of the enterprise should be analyzed. For this purpose, all cost-effective aspects of this product must be considered. At the final stage of this process, this new product should be tested and put on the market. In the testing phase of the new product, it is basically tried to determine whether the sales of the product will meet the expectations. In other words, it is aimed to understand the possible success of the product in the market. Stark (2020) discussed that at the stage of its introduction to the market, it should be determined when and to whom this new product will be introduced. On the other hand, all the details of the advertisements to be made in this process should be determined.

### *The Concept of Industrial Decarbonization*

Carbon emissions are known to have serious damages and threats. Due to the release of this gas into the atmosphere, global warming is experienced on the world. Therefore, many living beings are at risk of losing their lives. In addition, many sectors such as agriculture are adversely affected by factors such as drought caused by global warming. This problem will affect the countries negatively in economic terms as well. Therefore, many meetings are organized around the world that tries to emphasize the importance of the problem of carbon dioxide emissions. Zheng et al. (2020) tried to examine the carbon dioxide emission reduction potential in China's leading markets. They underlined that one of the most important factors causing carbon dioxide emissions is industrial companies. The development of industry is vital for the economic development of the country. The main reason for this is the growth of the economy with the developing industry and new business opportunities for people. In this way, the industrial sector is considered as a source of prosperity. Wen and Wang (2020) identified that most industrial companies emit gases harmful to the environment.

Because of these problems, the ways of carbon dioxide release are sought. The most prominent factor in this regard is renewable energies. Renewable energies are energy alternatives such as solar, wind and geothermal which take their resources from nature. As can be understood from this

definition, fossil fuels are not used in renewable energies. Because of this, it is possible to say that renewable energies are more environmentally friendly. Qiao et al. (2020) aimed to forecast carbon emission problems in the future. They also highlighted the significance of the renewable energy alternatives for this purpose. They also stated that the problem of these investments is having high costs. A substantial amount of funds may be required to install a solar panel or wind power plant. Therefore, investors may not be willing to use renewable energy instead of fossil fuels. Therefore, countries are expected to provide significant support to the use of renewable energy. Chi et al. (2020) and Skytt et al. (2020) also discussed that renewable energy investors may be exempt from certain taxes to reduce the mentioned costs. In addition, the state can provide these investors with funds for their solar panels and wind power plants. This will contribute to the direction of investors in this area. By using low-carbon energy sources in the industry, it will be possible to reduce the emission of carbon dioxide.

Vulin et al. (2020) and Conci et al. (2019) also concluded that carbon dioxide capture and storage technology can also contribute to industrial decarbonization. In its simplest definition, it means the capture of carbon dioxide gas from industrial production before it is released into the atmosphere. As can be seen from this definition, significant technological investment is required in this regard. By preventing the release of the resulting carbon dioxide into the atmosphere, damage to the environment can be eliminated. Governments have serious duties in this process. With the new regulations to be made, industrial decarbonization applications can be made compulsory for companies.

### *Review of Current Studies*

In the literature, the subject of decarbonization was mainly discussed by different academicians. Some studies focused on the relationship between climate change and decarbonization. Bernstein and Hoffmann (2018) focused on different country groups and identified that decarbonization implementations play a significant role to reduce global warming problem. In other words, it is argued that when there are some works to improve industrial decarbonization, the climate of the country will be affected positively from this situation. In addition to these studies, some researchers also indicated that renewable energy should be used to minimize carbon emission problem. Arabzadeh et al. (2020) and Verbruggen and Yurchenko (2019) determined that renewable energy usage plays the most critical role to achieve industrial decarbonization. On the other side, Dejuán et al. (2017) and Faria et al. (2019) explained the positive economic and environmental impacts of industrial decarbonization.

In addition to the industrial decarbonization, the concept of new product development is also popular in the literature. Generally, the stages of this process are included in the

studies conducted on the generation of the new products. Schemmann et al. (2016) defined that the most important step of this issue is to gather ideas on the subject. On the other hand, Roper et al. (2016) conducted a research on manufacturing companies in Ireland and emphasized the importance of the same issue. Schoenherr and Wagner (2016) stated that it is necessary to collect ideas from different segments in the process of developing new products. To this end, they argued that the ideas of customers, suppliers and employees could be considered.

Technological competence of companies is also important in the process of developing new products and services. A technologically self-investing company can develop new products more effectively (Lawson et al., 2015; Rubera et al., 2016). Therefore, companies should have necessary technological capacity for this purpose. Accordingly, Bouncken et al. (2018) stated that companies should improve their technological capacity to become successful in new product development process. Also, Mu et al. (2017) concluded that there should be effective communication in the company for this issue. Customer expectations should also be considered in the process of developing new products. As a result, customers will use these new products. Accordingly, what customers want is vital. Therefore, customer expectations should be determined in detail (Leenders & Dolfsma, 2016). In this way, customers will be able to be more satisfied. This will increase the performance of new products and services developed. La Rocca et al. (2016) stated that the most important factor for the success of developing new products is the customer.

It is also important to test the developed product before it is put on the market and to determine effective marketing strategies. Fuller (2016) and Lei and Moon (2015) have argued that testing the effectiveness of the product is the most important step. In addition, Gonzalez-Zapatero et al. (2016) and Mu (2015) stated that marketing strategies should be effective. Likewise, Zahay et al. (2018) concluded that the newly developed product should be successfully transferred to consumers. There are also several studies on carbon dioxide emissions. In general, studies have addressed the problems posed by this issue (Sovacool et al., 2018). Environmental damage due to carbon emissions is the leading issue. This is also likely to cause financial difficulties (Barrett et al., 2018). The main reason for this is that investors will not want to invest in environmentally damaging areas. In addition, financial institutions will be reluctant to lend to these areas. Hence, governments should implement emission reduction policies to solve this problem (Gerres et al., 2019; Kronsell et al., 2019).

On the other hand, in some studies, decarbonization activities on different sectors have been discussed. Griffin and Hammond (2019) conducted a similar study for the iron industry. Fortes et al. (2019) examined the activities in the silver sector. The effect of decarbonization activities on the economic development of the countries was also studied. Gowreesunker et al. (2018), Fais et al. (2016) and Maroto-Valer (2019) stated that decarbonization activities should be

taken into consideration to achieve economic development. In addition, the issue of industrial decarbonization has been addressed by different researchers in the literature. Renner and Giampietro (2020) conducted an analysis of the European electricity market. In this study, it is stated that decarbonization is necessary in industry. Within this framework, it is stated that it is important for companies to make the necessary technological investments. Tozer (2020) emphasized this result for urban buildings. On the other hand, Sparkman and Attari (2020) conducted an analysis on climate change. In this study, parallel results are underlined.

The literature review shows that the generation of new products for decarbonization in industry is important both in environmental and economic terms. Therefore, new studies will be of serious benefit. There are mainly two important issues in new product generation process which product side and process side. Product side mainly gives information about what the company is producing whereas process side explains how it is produced. Additionally, regarding product side, different development tools can be considered, such as quality testing methods. On the other side, the process side focuses on the harmony of the stages in this process with each other.

Most of the studies focused on the product side of new product generation process. In this framework, they mainly defined the important steps in this process. However, for the newly developed product to be successful, attention should be paid to every stage of this process. Hence, this study aims to calculate the importance levels of these steps to generate new products or services more effectively. Thus, it is thought that this study makes both the managerial and theoretical contributions to the literature.

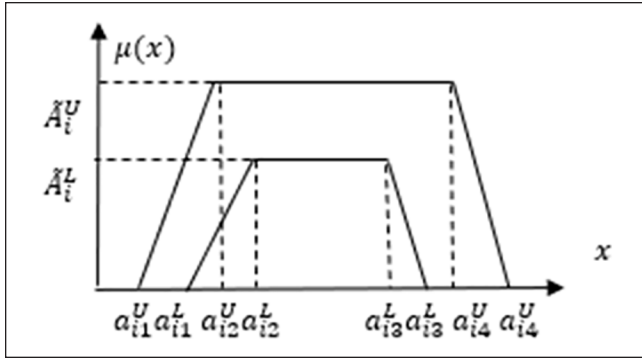
In the literature, it can be understood that survey and regression approaches were mainly preferred. Hence, it is believed that new approaches should be implemented in these studies to make a comparative analysis. In this study, this issue will also be analyzed by IT2 fuzzy DEMATEL method. Another important point learnt from the literature review is that industrial decarbonization is a broad concept. Because it is an essential topic for both environment and economic development, more specific studies should be conducted to minimize carbon emission problem. To satisfy this situation, this study focuses on the important points to generate new products in industrial decarbonization.

## Methodology

In this section, firstly, detailed information is given regarding IT2 fuzzy sets and DEMATEL. After that, the novelties of the proposed model are also discussed.

### IT2 Fuzzy Sets

The type 2 fuzzy set is defined as  $\tilde{A}$ . Additionally, this set can be explained by a type-2 membership function  $\mu_{\tilde{A}(x,u)}$ , where  $x \in X$  and  $u \in J_x \subseteq [0,1]$ . Equation (1) identifies the



**Figure 1.** The membership function of the IT2 fuzzy set.  
Source: Lee and Chen (2008).

details of this situation (Hong & Buay, 2020; Huang et al., 2018).

$$\tilde{A} = \left\{ \left( (x, u), \mu_{\tilde{A}}(x, u) \right) \mid \forall x \in X, \forall u \in J_x \subseteq [0, 1] \right\},$$

$$\text{or } \tilde{A} = \int_{x \in X} \int_{u \in J_x} \mu_{\tilde{A}}(x, u) / (x, u) J_x \subseteq [0, 1] \quad (1)$$

Within this context,  $\int$  defines the union over all admissible  $x$  and  $u$ . Moreover,  $\mu_{\tilde{A}}(x, u)$  can be between 0 and 1. Furthermore,  $\int$  can also be used for  $\Sigma$  regarding the discrete universes of discourse. Therefore, if all  $\mu_{\tilde{A}}(x, u)$  equals to 1, the IT2 fuzzy sets can be defined as in the equation (2) (Wu & Mendel, 2019; Zhou et al., 2020).

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} 1 / (x, u) J_x \subseteq [0, 1] \quad (2)$$

Additionally, Figure 1 illustrates the upper and lower membership functions of an IT2 fuzzy sets.

In Figure 1,  $\tilde{A}_i$  gives information about the IT2 fuzzy set. Moreover, the upper and lower trapezoidal membership functions are stated as  $\tilde{A}_i^U$  and  $\tilde{A}_i^L$ . These issues are also identified in the equation (3).

$$\tilde{A}_i = \left( \tilde{A}_i^U, \tilde{A}_i^L \right) = \left( \left( a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^U) \right), \left( a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(\tilde{A}_i^L), H_2(\tilde{A}_i^L) \right) \right) \quad (3)$$

In this equation,  $a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U, a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L$  explain the reference values of the IT2 fuzzy set  $\tilde{A}_i$ . On the other hand,  $H_j(\tilde{A}_i^U)$  indicates the membership value of the element  $a_{i(j+1)}^U$ . Within this framework,  $j$  can be between 1 and 2. Also, arithmetic operations of these sets are given in the appendix part.

**Dematel.** The DEMATEL approach is used to determine which of the different criteria that are effective on an issue

are more important (Fontela & Gabus, 1976; Gabus & Fontela, 1973). In addition, by using this method, the impact relationship map between the criteria can be created (Jayant, 2020; Saġnak, 2020). Thus, it is possible to determine the causality relationship between the factors. This point is accepted as the most important advantage of DEMATEL method compared to other approaches. In the first stage of this method, the evaluations of the experts on the criteria are provided. These evaluations are then converted into fuzzy numbers. In the second stage, the initial direct-relation fuzzy matrix ( $\tilde{Z}$ ) is created. In this framework, average values of expert opinions are taken into consideration. In the third stage, normalized matrix ( $\tilde{X}$ ) is generated. Fourthly, the total influence fuzzy matrix ( $\tilde{T}$ ) is created. In the next step, the defuzzified total influence matrix is implemented.

In this context,  $\alpha$  and  $\beta$  represent the maximum membership degrees of the lower membership function. Additionally,  $u_U$  and  $l_U$  state the largest and least possible values of the upper membership function. On the other side,  $m_{1U}$  and  $m_{2U}$  give information about the second and third parameters of the upper membership function. Furthermore,  $u_L$  and  $l_L$  explain the largest and least possible values of the lower membership function. Finally,  $m_{1L}$  and  $m_{2L}$  indicate the second and third parameters of the lower membership function. After the defuzzification process, the weights of the criteria are computed. Within this framework,  $\tilde{D}_i^{def}$  and  $\tilde{R}_i^{def}$  show the sum of all vector rows and columns.  $(\tilde{D}_i + \tilde{R}_i)^{def}$  value is used to find the significance values of the criteria. On the other hand,  $(\tilde{D}_i - \tilde{R}_i)^{def}$  value can be considered to find the causal relationship among the factors. When this value is positive, it gives an information that criterion  $i$  influences other ones. However, the negative value shows that the criterion is influenced by other criteria.

### The Details of the Proposed Model

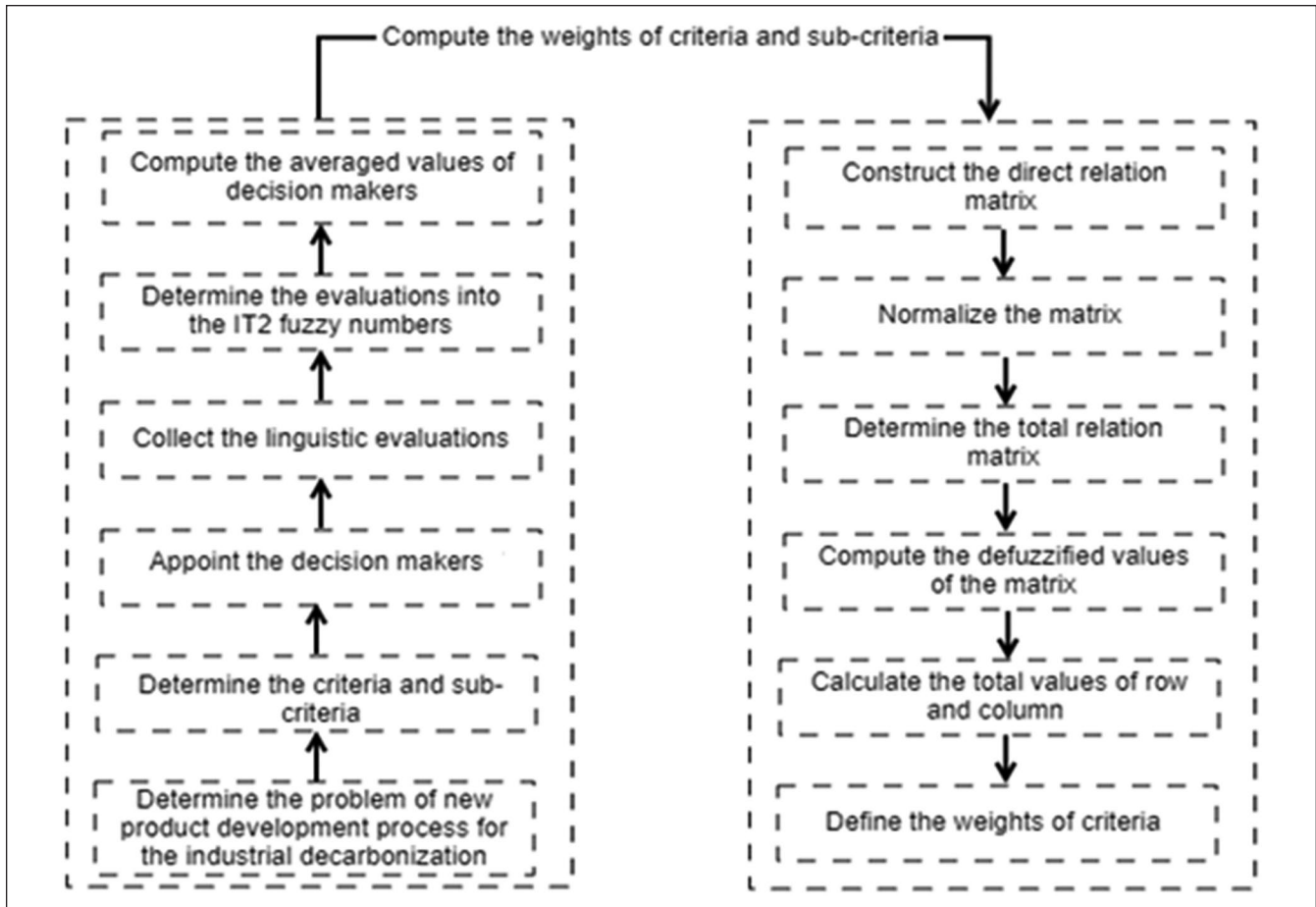
In this study, it is aimed to identify the significant stages of new product development process regarding the industrial decarbonization of sustainable economies. The details of the analysis process are illustrated on Figure 2.

Figure 2 indicates that in the analysis process, there are two different stages. The details of the proposed model are explained below.

Stage 1: The problem of the study is identified.

Step 1: The problem of new product development process for the industrial decarbonization is defined. For this purpose, it is aimed to define significant stages while developing new products for industrial decarbonization.

Step 2: Defining the criteria and sub-criteria. Within this framework, 5 criteria and 10 sub-criteria are determined based on a comprehensive literature evaluation. The details of these factors are presented in the following section.



**Figure 2.** The flowchart of the proposed model.  
Source. Authors.

Step 3: Appointment of the experts. In this context, an expert team is created which includes five different people who have sufficient background regarding, renewable energies, new service development, cost management and industrial decarbonization.

Step 4: Linguistic evaluations are collected. For this purpose, nine different scales are considered (Chen et al., 2013). The details of these scales are given on Table A1.

Step 5: Evaluations are converted into IT2 fuzzy numbers. By considering the details shown in Table A1, the evaluations of the experts are converted into the trapezoidal fuzzy numbers.

Step 6: Average values of the decision-makers are calculated.

Stage 2: The weights of the criteria and sub-criteria are calculated.

Step 7: Direct relation matrix is constructed.

Step 8: The normalized matrix is generated.

Step 9: Total relation matrix is created.

Step 10: Defuzzified values of the matrix are calculated.

Step 11: Total values of the rows and columns are computed.

Step 12: The weights of the factors are identified.

This proposed model has some novelties. Firstly, an analysis is performed by using IT2 fuzzy DEMATEL to define the more important factors. There are different MCDM approaches in the literature to calculate the weights of the criteria, such as analytic hierarchy process (AHP) and analytic network process (ANP) (Liu et al., 2020; Mistarihi et al., 2020; Wang et al., 2020; Yadav & Singh, 2020). However, impact relation map can only be created with DEMATEL methodology (Farooque et al., 2020; Ocampo & Yamagishi, 2020). In other words, the causality analysis among the criteria can be made owing to this approach (Raval et al., 2021; Zhang, Zhou et al., 2020). In this study, five different criteria for new product generation process of industrial decarbonization are examined that are idea generation, evaluation, improvement, finalization, and commercialization. These criteria consist of factors that can affect each other. Therefore, it is important to determine which of these criteria are affecting/affected. These issues contribute to the production of more effective strategies for the solution of the problem. In this context, the most suitable MCDM method

**Table 1.** Criteria and Sub-Criteria for New Product Generation Process of Industrial Decarbonization in Sustainable Economies.

Criteria	Sub-criteria	Supported Literature
Criterion 1—Idea Generation (P1)	Internal idea (C1)	Schemmann et al. (2016)
	External idea (C2)	Roper et al. (2016)
Criterion 2— Evaluation (P2)	Company profile (C3)	Lawson et al. (2015)
	Market conditions (C4)	Rubera et al. (2016)
Criterion 3— Improvement (P3)	Internal feedback (C5)	Mu et al. (2017)
	External feedback (C6)	Bouncken et al. (2018)
Criterion 4— Finalization (P4)	Prototype testing (C7)	Fuller (2016)
	Final version checking (C8)	Lei and Moon (2015)
Criterion 5—Commercialization (P5)	Cost analysis (C9)	Gonzalez-Zapatero et al. (2016)
	Performance analysis (C10)	Zahay et al. (2018)

Source. Authors.

for the analysis process of these criteria is DEMATEL. Another novelty of this proposed model is considering IT2 fuzzy sets. Decision making processes have become increasingly complex (Dinçer & Yüksel, 2020; Dinçer et al., 2020). This situation shows that more detailed approaches are needed to solve the problem (Qiu et al., 2020; Zhou et al., 2020). In this context, MCDM methods have started to be taken into consideration in the framework of fuzzy logic, especially in recent years. However, with the increasing complexity of these processes, more different approaches have been taken into consideration. These sets have a positive contribution to handle the uncertainties in decision-making process more effectively (Li et al., 2020; Zhao et al., 2021; Zhong et al., 2020).

## Empirical Analysis

In this section, different stages of the proposed model are detailed in the following sub-sections.

### Identifying the Criteria

The carbon dioxide emission problem has many disadvantages for countries. These issues have serious damages both in terms of health, environment, and economy. Therefore, this problem should be minimized. Decarbonization process is a concept developed for this purpose. In this framework, it is important that industrial companies use products that prevent carbon emission. However, the challenge is how to develop this product. The main reason for this is that it is both difficult and complex to develop such a product. Thus, for industrial companies to develop an effective new product for this purpose, processes need to be analyzed in detail. Hence, it can be possible to follow a more effective path in this difficult and complex process. By identifying the different steps identified in the new product development process for decarbonization, it will be possible to see which process needs more focus. The details of new product development process of industrial decarbonization based on the literature review are given on Table 1.

Table 1 indicates that the new product development process for industrial decarbonization is divided into five different criteria. Additionally, all these criteria include two different sub-criteria. The first criterion is generating new ideas for decarbonization thoughts. Within this framework, the idea can be obtained from both internal and external sources. The second criterion is evaluation which includes monitoring the new service outcomes with the efficient ideas of industrial decarbonization. For this purpose, company potential and market conditions are taken into consideration. After the evaluation, some improvement will be made in the third criterion. Within this context, innovation of industrial decarbonization is reshaped with the potential modifications by considering both internal and external feedbacks. In the fourth criterion of this process, the final version of service development activities is tested. In this scope, there can be prototype testing and final version checking. The last criterion is related to the commercialization of the product. In this context, there should be cost evaluation and outcomes of the improving activities should be examined.

### Weighting the Criteria

In the next stage, five different decision makers (DMs) made evaluations regarding the criteria and sub-criteria for new product generation process of industrial decarbonization. The details of these people are given on Table 2.

While considering the details in Table 2, the experts have enough qualification to evaluate the stages in the new product generation process of industrial decarbonization. After that, these evaluations are converted to the IT2 fuzzy numbers which are detailed in Table A1. Additionally, the details of the evaluations of DMs are demonstrated on Table A2.

In the next step, initial direct relation matrix is created, and this matrix is normalized. These two different matrixes are detailed on the appendix part (Tables A3-A4). In addition, total influence matrix is created in the following step. This matrix is illustrated on Table A5. In the final step, defuzzification process has been implemented and the sum of all vector rows and columns are calculated. The details are



**Table 2.** The Details of DMs.

DM Number	Education status	Experience	Occupation	Areas of expertise
DM1	PhD	29 years	Academician in industrial decarbonization	Renewable energies, cost management, industrial decarbonization
DM2	PhD	26 years	Academician and top-level manager in wind energy companies	Renewable energies, strategy development, TRIZ
DM3	PhD	24 years	Academician and top-level manager in solar energy companies	Renewable energies, new product development, cost management
DM4	PhD	19 years	Academician in industrial decarbonization	Renewable energies, strategy development, industrial decarbonization
DM5	PhD	17 years	Academician and middle level manager in solar energy companies	Renewable energies, cost management

Source. Authors.

**Table 3.** The Weights for the Criteria and Sub-criteria.

Criteria	Criteria weights	Sub-criteria	Sub-criteria weights
P1	0.185	C1	0.095
		C2	0.090
P2	0.197	C3	0.102
		C4	0.095
P3	0.201	C5	0.099
		C6	0.102
P4	0.196	C7	0.098
		C8	0.098
P5	0.221	C9	0.113
		C10	0.108

Source. Authors.

demonstrated on Table A6. Finally, the weights of the criteria and sub-criteria are calculated. The results are identified in Table 3.

Table 3 indicates that commercialization (P5) is the most significant criterion of new product generation process of industrial decarbonization. Additionally, improvement (P3) is another important criterion for this process. On the other side, with respect to the sub-criteria, cost analysis (C9) has the highest importance. It is also found that performance analysis (C10) plays a key role in this regard. Nonetheless, internal idea (C1), external idea (C2) and market conditions (C4) has lowest weights in comparison with others.

## Discussions and Conclusions

In this study, it is aimed to identify important stages of new product development process for the industrial decarbonization of sustainable economies. In this context, the process of developing new products is divided into five different criteria. Furthermore, 10 sub-criteria are also defined for these new product development stages. The significance weights of these stages are calculated by IT2 fuzzy DEMATEL method. It is concluded that commercialization is the most significant stage of new product generation process of

industrial decarbonization. Moreover, improvement is also found as a critical new product development criterion for industrial decarbonization. As for the sub-criteria, it is concluded that cost analysis, which is the sub-criteria of the commercialization, is the most essential factor in this respect. It is also determined that performance analysis has a key role in this regard. On the other side, internal idea, external idea, and market conditions have lowest weights by comparing with other factors.

The results show that companies should mainly focus on commercialization to generate products to reduce carbon emission. Similarly, the subtitle of commercialization, cost analysis, plays the most significant role in this regard. In other words, for these companies to be successful in the commercialization of the products, a comprehensive cost analysis should be made. However, there are some factors that limit the effective management of costs during the development of these products. For a successful cost management, the costs of the developed product should be budgeted. Within this context, all costs to be encountered in the product development process should be considered. However, due to the uncertainty in the market, it is not easy to accurately predict all costs that will occur in this process. In this regard, one of the most important uncertainties is that it is not clear how the developed product will be met in the market. It is also unclear how the new technology developed will be perceived by customers. In some cases, customers may prefer not to use technology because they are worried about technology that they do not fully understand. This situation will increase the costs in the newly developed product process. Therefore, it would be appropriate to consider these risks in the cost analysis to be made. Otherwise, the product that does not provide a cost advantage will not be preferred by industrial companies.

This situation was highlighted by many different researchers in the literature. Parra et al. (2019) tried to evaluate the ways to minimize carbon emission problems. For this purpose, they focused on the hydrogen energy systems. However, they mainly highlighted the high-cost problem of

this situation. Similarly, Bataille et al. (2018) also examined the new products for industrial decarbonization. They mainly discussed that technological development provides an opportunity to decrease the costs of these products. Hence, due to this financial advantage, these products can be preferred by the companies so that it can be more possible to minimize carbon emission problem. Ziegler et al. (2019) stated that renewable energy alternatives should be prioritized to reduce carbon emissions. They also identified that these energy alternatives have high initial costs. Because of this problem, they cannot be considered by the companies.

Nonetheless, in the literature, there are also some studies which point different factors for the success of the new product development for industrial decarbonization. These studies did not disagree with the importance of the costs, but they also underlined the significance of some other factors as well. For instance, Åhman and Nilsson (2015) aimed to examine the decarbonizing industry in the European countries. They reached a conclusion that market conditions should be mainly considered while generating new products for this purpose. Like this study, Li et al. (2020) focused on the innovation strategies for renewable energy alternatives. While using hybrid interval type-2 fuzzy decision-making approach, they determined that new products should be

generating by evaluating the market conditions. On the other side, Jakobsen and Clausen (2016) focused on the direct and indirect effects of generating new products that reduce carbon emission. They identified that because it is a complex situation, companies should consider feedbacks from both employees and the customers.

The most important limitation of this study is to focus on only five stages of the product to be developed to prevent carbon emission. In the following studies, seven different stages of the new product development process can be taken into consideration which are design planning, development, testing, verification, validation, manufacturing, and improvement (Thompson et al., 2018). New studies may focus on strategies to reduce carbon emissions. In this context, an assessment can be made on the new technology available on the market to prevent the carbon emission problem. In addition, the impact of carbon emissions on financial and economic development in countries can be examined. On the other hand, different methods can be used to ensure originality in the studies. Another important limitation of this study is that there is no industrial implication. Instead of this situation, important factors are only presented. However, in the following studies, different case studies can be conducted to examine the significance of this situation in the market.

## Appendix

### A1: Arithmetical Operation of IT2 Fuzzy Sets

$$\begin{aligned}
 \tilde{A}_1 \oplus \tilde{A}_2 &= (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L) = \left( \begin{array}{l} \left( a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \right) \\ \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)) \\ \left( a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \right) \\ \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)) \end{array} \right) \\
 \tilde{A}_1 \ominus \tilde{A}_2 &= (\tilde{A}_1^U, \tilde{A}_1^L) \ominus (\tilde{A}_2^U, \tilde{A}_2^L) = \left( \begin{array}{l} \left( a_{11}^U - a_{24}^U, a_{12}^U - a_{23}^U, a_{13}^U - a_{22}^U, a_{14}^U - a_{21}^U; \right. \\ \left. \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)) \right) \\ \left( a_{11}^L - a_{24}^L, a_{12}^L - a_{23}^L, a_{13}^L - a_{22}^L, a_{14}^L - a_{21}^L; \right. \\ \left. -a_{21}^L; \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)) \right) \end{array} \right) \\
 \tilde{A}_1 \otimes \tilde{A}_2 &= (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_2^L) = \left( \begin{array}{l} \left( a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; \right. \\ \left. \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U)) \right) \\ \left( a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \right. \\ \left. \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L)) \right) \end{array} \right) \\
 k\tilde{A}_1 &= \left( k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \right), \left( k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \right) \\
 \frac{\tilde{A}}{k_1} &= \left( \frac{1}{k} \times a_{11}^U, \frac{1}{k} \times a_{12}^U, \frac{1}{k} \times a_{13}^U, \frac{1}{k} \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \right), \left( \frac{1}{k} \times a_{11}^L, \frac{1}{k} \times a_{12}^L, \frac{1}{k} \times a_{13}^L, \frac{1}{k} \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \right)
 \end{aligned}$$

A2: Equations of DEMATEL

$$\tilde{Z} = \begin{bmatrix} 0 & \tilde{z}_{12} & \cdots & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & 0 & \cdots & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \cdots & 0 \end{bmatrix}$$

$$\tilde{Z} = \frac{\tilde{Z}^1 + \tilde{Z}^2 + \tilde{Z}^3 + \dots + \tilde{Z}^n}{n}$$

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \cdots & \tilde{x}_{nn} \end{bmatrix}$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r}$$

$$\left( \frac{Z_{a'_i}}{r}, \frac{Z_{b'_i}}{r}, \frac{Z_{c'_i}}{r}, \frac{Z_{d'_i}}{r}; H_1(z_{ij}^U), H_2(z_{ij}^U) \right),$$

$$\left( \frac{Z_{e'_i}}{r}, \frac{Z_{f'_i}}{r}, \frac{Z_{g'_i}}{r}, \frac{Z_{h'_i}}{r}; H_1(z_{ij}^L), H_2(z_{ij}^L) \right)$$

$$r = \max \left( \max_{1 \leq i \leq n} \sum_{j=1}^n Z_{a'_i}, \max_{1 \leq i \leq n} \sum_{j=1}^n Z_{d'_i} \right)$$

$$X_{a'} = \begin{bmatrix} 0 & a'_{12} & \cdots & \cdots & a'_{1n} \\ a'_{21} & 0 & \cdots & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \dots,$$

$$X_{h'} = \begin{bmatrix} 0 & h'_{12} & \cdots & \cdots & h'_{1n} \\ h'_{21} & 0 & \cdots & \cdots & h'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h'_{n1} & h'_{n2} & \cdots & \cdots & 0 \end{bmatrix}$$

$$\tilde{T} = \lim_{k \rightarrow \infty} \tilde{X} + \tilde{X}^2 + \dots + \tilde{X}^k$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \cdots & \tilde{t}_{nn} \end{bmatrix}$$

$$\tilde{t}_{ij} = (a''_{ij}, b''_{ij}, c''_{ij}, d''_{ij}; H_1(\tilde{t}_{ij}^U), H_2(\tilde{t}_{ij}^U)), \\ (e''_{ij}, f''_{ij}, g''_{ij}, h''_{ij}; H_1(\tilde{t}_{ij}^L), H_2(\tilde{t}_{ij}^L))$$

$$[a''_{ij}] = X_{a'} \times (I - X_{a'})^{-1}, \dots, [h''_{ij}] = X_{h'} \times (I - X_{h'})^{-1}$$

$$\frac{(u_U - l_U) + (\beta_U \times m_{1U} - l_U) + (\alpha_U \times m_{2U} - l_U)}{4} + l_U +$$

$$Def_T = \frac{\left[ \frac{(u_L - l_L) + (\beta_L \times m_{1L} - l_L) + (\alpha_L \times m_{2L} - l_L)}{4} + l_L \right]}{2}$$

$$Def_T = T = [t_{ij}]_{n \times n}, i, j = 1, 2, \dots, n$$

$$\tilde{D}_i^{def} = r = \left[ \sum_{j=1}^n t_{ij} \right]_{n \times 1} = (r_i)_{n \times 1} = (r_1, \dots, r_i, \dots, r_n)$$

$$\tilde{R}_i^{def} = y = \left[ \sum_{i=1}^n t_{ij} \right]'_{1 \times n} = (y_j)'_{1 \times n} = (y_1, \dots, y_i, \dots, y_n)$$

**Table A1.** Linguistic Scales and IT2 Trapezoidal Fuzzy Numbers.

Linguistic scales	IT2TrFNs
Absolutely Low (AL)	((0,0,0,0,0,0,0,0;1,0), (0,0,0,0,0,0,0,0;1,0))
Very Low (VL)	((0,0075, 0,0075, 0,015, 0,0525;0,8), (0,0,0,0,0,02,0,07;1,0))
Low (L)	((0,0875, 0,12, 0,16, 0,1825;0,8), (0,04,0,10,0,18,0,23;1,0))
Medium Low (ML)	((0,2325, 0,255, 0,325, 0,3575;0,8), (0,17,0,22,0,36,0,42;1,0))
Medium (M)	((0,4025, 0,4525, 0,5375, 0,5675;0,8), (0,32,0,41,0,58,0,65;1,0))
Medium High (MH)	((0,65, 0,6725, 0,7575, 0,79;0,8), (0,58,0,63,0,80,0,86;1,0))
High (H)	((0,7825, 0,815, 0,885, 0,9075;0,8), (0,72,0,78,0,92,0,97;1,0))
Very High (VH)	((0,9475, 0,985, 0,9925, 0,9925;0,8), (0,93,0,98,1,0,1,0;1,0))
Absolutely High (AH)	((1,0, 1,0, 1,0, 1,0; 1,0), (1,0, 1,0, 1,0, 1,0; 1,0))

Source: Chen et al. (2013).

**Table A2.** Linguistic Evaluations by the Decision Makers.

Criteria	C1					C2				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C1	—	—	—	—	—	MH	ML	M	ML	M
C2	M	MH	ML	M	MH	—	—	—	—	—
C3	ML	M	MH	M	MH	H	ML	M	MH	H
C4	M	ML	M	ML	M	MH	ML	M	MH	MH
C5	ML	M	MH	M	MH	M	ML	M	ML	M
C6	M	MH	MH	M	VH	H	ML	M	ML	M
C7	MH	MH	M	ML	M	M	ML	M	M	MH
C8	M	ML	M	M	MH	M	M	ML	M	MH
C9	VH	VH	AH	VH	AH	VH	H	VH	VH	H
C10	VH	AH	M	MH	MH	VH	MH	H	MH	VH

Criteria	C3					C4				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C1	M	ML	M	M	MH	H	M	ML	M	M
C2	MH	M	ML	M	M	M	M	ML	M	M
C3	—	—	—	—	—	M	ML	M	M	VH
C4	ML	M	M	M	M	—	—	—	—	—
C5	ML	M	MH	H	MH	M	H	M	M	VH
C6	H	ML	M	VH	VH	ML	M	M	VH	MH
C7	ML	M	H	ML	M	M	ML	M	ML	M
C9	H	VH	AH	VH	AH	VH	H	VH	AH	VH
C10	H	AH	VH	VH	H	H	MH	H	VH	AH

Criteria	C5					C6				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C1	VH	M	ML	M	VH	ML	M	MH	MH	MH
C2	M	ML	M	M	M	ML	M	MH	MH	H
C3	ML	M	VH	M	M	VH	MH	H	ML	M
C4	ML	M	M	VH	M	VH	ML	M	MH	H
C5	—	—	—	—	—	ML	M	H	H	VH
C6	ML	M	ML	M	MH	—	—	—	—	—
C7	H	ML	M	H	ML	M	ML	M	VH	H
C8	H	ML	ML	M	ML	M	H	ML	M	H
C9	VH	AH	VH	H	VH	VH	H	VH	VH	VH
C10	VH	H	H	H	MH	VH	MH	MH	H	H

Criteria	C7					C8				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C1	ML	M	ML	M	MH	ML	M	H	MH	H
C2	MH	ML	M	ML	M	MH	M	ML	M	MH
C3	VH	VH	MH	ML	M	VH	MH	ML	M	H
C4	VH	ML	M	MH	MH	ML	M	MH	MH	VH
C5	ML	M	MH	VH	VH	MH	ML	M	MH	VH
C6	ML	M	MH	VH	MH	ML	M	VH	ML	M
C7	—	—	—	—	—	MH	ML	M	MH	H
C8	ML	M	VH	MH	MH	—	—	—	—	—
C9	H	H	VH	VH	AH	VH	AH	VH	VH	H
C10	VH	H	MH	H	MH	MH	MH	MH	VH	VH

Criteria	C9					C10				
	DM1	DM2	DM3	DM4	DM5	DM1	DM2	DM3	DM4	DM5
C1	MH	M	MH	ML	M	ML	M	M	ML	M
C2	M	ML	ML	M	M	ML	M	M	ML	M
C3	M	M	M	M	M	VH	M	M	ML	M
C4	MH	ML	ML	M	M	H	ML	M	M	M
C5	ML	M	MH	M	M	MH	M	MH	M	M
C6	ML	ML	M	M	MH	M	ML	MH	M	M
C7	M	M	ML	M	MH	M	M	M	M	M
C8	ML	ML	M	ML	M	M	ML	M	MH	MH
C9	—	—	—	—	—	M	MH	MH	MH	VH
C10	M	M	M	M	MH	—	—	—	—	—

Source. Authors.

**Table A3.** Initial Direct Relation Matrix.

Criteria	C1	C2	C3	C4	C5
C1	((0,0,0;0,80), (0,0,0;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,44,0,49,0,56,0,59;0,80), (0,37,0,45,0,6,0,67;1,00))	((0,59,0,63,0,68,0,7;0,80), (0,53,0,6,0,7,0,74;1,00))
C2	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,57,0,6,0,68,0,71;0,80), (0,5,0,56,0,72,0,77;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,37,0,41,0,5,0,53;0,80), (0,29,0,37,0,54,0,6;1,00))	((0,37,0,41,0,5,0,53;0,80), (0,29,0,37,0,54,0,6;1,00))
C3	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,57,0,6,0,68,0,71;0,80), (0,5,0,56,0,72,0,77;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,48,0,52,0,59,0,61;0,80), (0,41,0,49,0,62,0,67;1,00))	((0,48,0,52,0,59,0,61;0,80), (0,41,0,49,0,62,0,67;1,00))
C4	((0,33,0,37,0,45,0,48;0,80), (0,26,0,33,0,49,0,56;1,00))	((0,52,0,55,0,63,0,66;0,80), (0,45,0,5,0,67,0,73;1,00))	((0,37,0,41,0,5,0,53;0,80), (0,29,0,37,0,54,0,6;1,00))	((0,0,0,0;0,80), (0,0,0,0;1,00))	((0,48,0,52,0,59,0,61;0,80), (0,41,0,49,0,62,0,67;1,00))
C5	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,57,0,6,0,68,0,71;0,80), (0,5,0,56,0,72,0,77;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,59,0,63,0,7,0,72;0,80), (0,52,0,6,0,73,0,78;1,00))	((0,41,0,49,0,62,0,67;1,00))
C6	((0,61,0,65,0,72,0,74;0,80), (0,55,0,61,0,75,0,8;1,00))	((0,41,0,45,0,52,0,55;0,80), (0,34,0,41,0,56,0,62;1,00))	((0,66,0,7,0,75,0,76;0,80), (0,61,0,67,0,77,0,81;1,00))	((0,53,0,56,0,63,0,66;0,80), (0,46,0,53,0,66,0,72;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,31,0,38,0,54,0,6;1,00))
C7	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,41,0,45,0,52,0,55;0,80), (0,34,0,41,0,56,0,62;1,00))	((0,33,0,37,0,45,0,48;0,80), (0,26,0,33,0,49,0,56;1,00))	((0,49,0,52,0,59,0,62;0,80), (0,42,0,48,0,63,0,69;1,00))
C8	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,6,0,64,0,7,0,72;0,80), (0,54,0,6,0,73,0,78;1,00))	((0,33,0,37,0,45,0,48;0,80), (0,26,0,33,0,49,0,56;1,00))	((0,38,0,41,0,48,0,51;0,80), (0,31,0,37,0,52,0,58;1,00))
C9	((0,97,0,99,1,1;0,80), (0,96,0,99,1,1;1,00))	((0,88,0,92,0,95,0,96;0,80), (0,85,0,9,0,97,0,99;1,00))	((0,94,0,96,0,97,0,98;0,80), (0,92,0,95,0,98,0,99;1,00))	((0,93,0,95,0,97,0,98;0,80), (0,9,0,94,0,98,0,99;1,00))	((0,93,0,95,0,97,0,98;0,80), (0,9,0,94,0,98,0,99;1,00))
C10	((0,73,0,76,0,81,0,83;0,80), (0,68,0,73,0,84,0,87;1,00))	((0,8,0,83,0,88,0,89;0,80), (0,75,0,8,0,9,0,94;1,00))	((0,89,0,92,0,95,0,96;0,80), (0,86,0,9,0,97,0,99;1,00))	((0,83,0,86,0,9,0,92;0,80), (0,79,0,83,0,93,0,96;1,00))	((0,79,0,82,0,88,0,9;0,80), (0,73,0,79,0,91,0,95;1,00))
Criteria	C6	C7	C8	C9	C10
C1	((0,52,0,55,0,63,0,66;0,80), (0,45,0,5,0,67,0,73;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,31,0,38,0,54,0,6;1,00))	((0,57,0,6,0,68,0,71;0,80), (0,5,0,56,0,72,0,77;1,00))	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,33,0,37,0,45,0,48;0,80), (0,26,0,33,0,49,0,56;1,00))
C2	((0,54,0,57,0,65,0,68;0,80), (0,47,0,53,0,69,0,75;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,31,0,38,0,54,0,6;1,00))	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))	((0,33,0,37,0,45,0,48;0,80), (0,26,0,33,0,49,0,56;1,00))	((0,48,0,52,0,59,0,61;0,80), (0,41,0,49,0,62,0,67;1,00))
C3	((0,6,0,64,0,7,0,72;0,80), (0,54,0,6,0,73,0,78;1,00))	((0,64,0,67,0,72,0,74;0,80), (0,59,0,64,0,75,0,79;1,00))	((0,6,0,64,0,7,0,72;0,80), (0,54,0,6,0,73,0,78;1,00))	((0,4,0,45,0,54,0,57;0,80), (0,32,0,41,0,58,0,65;1,00))	((0,48,0,52,0,59,0,61;0,80), (0,41,0,49,0,62,0,67;1,00))
C4	((0,6,0,64,0,7,0,72;0,80), (0,54,0,6,0,73,0,78;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,31,0,38,0,54,0,6;1,00))	((0,44,0,49,0,56,0,59;0,80), (0,37,0,45,0,6,0,67;1,00))
C5	((0,63,0,66,0,73,0,75;0,80), (0,57,0,63,0,76,0,8;1,00))	((0,64,0,67,0,72,0,74;0,80), (0,59,0,64,0,75,0,79;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,5,0,54,0,63,0,66;0,80), (0,42,0,5,0,67,0,73;1,00))
C6	((0,0,0,0;0,80), (0,0,0,0;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,44,0,48,0,54,0,57;0,80), (0,38,0,45,0,58,0,63;1,00))	((0,38,0,42,0,5,0,53;0,80), (0,31,0,38,0,54,0,6;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))
C7	((0,55,0,59,0,66,0,68;0,80), (0,49,0,56,0,69,0,74;1,00))	((0,0,0,0;0,80), (0,0,0,0;1,00))	((0,54,0,57,0,65,0,68;0,80), (0,47,0,53,0,69,0,75;1,00))	((0,42,0,46,0,54,0,57;0,80), (0,34,0,42,0,58,0,65;1,00))	((0,4,0,45,0,54,0,57;0,80), (0,32,0,41,0,58,0,67;1,00))
C8	((0,52,0,56,0,63,0,66;0,80), (0,45,0,52,0,67,0,73;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,58,0,61,0,67,0,7;0,80), (0,52,0,57,0,71,0,76;1,00))	((0,3,0,33,0,41,0,44;0,80), (0,23,0,3,0,45,0,51;1,00))	((0,4,0,45,0,54,0,57;0,80), (0,32,0,41,0,58,0,65;1,00))
C9	((0,91,0,95,0,97,0,98;0,80), (0,89,0,94,0,98,0,99;1,00))	((0,89,0,92,0,95,0,96;0,80), (0,86,0,9,0,97,0,99;1,00))	((0,0,0,0;0,80), (0,0,0,0;1,00))	((0,0,0,0;0,80), (0,0,0,0;1,00))	((0,47,0,5,0,58,0,61;0,80), (0,39,0,46,0,62,0,69;1,00))
C10	((0,76,0,79,0,86,0,88;0,80), (0,71,0,76,0,89,0,93;1,00))	((0,76,0,79,0,86,0,88;0,80), (0,71,0,76,0,89,0,93;1,00))	((0,93,0,95,0,97,0,98;0,80), (0,9,0,94,0,98,0,99;1,00))	((0,45,0,5,0,58,0,61;0,80), (0,37,0,45,0,62,0,69;1,00))	((0,66,0,69,0,76,0,79;0,80), (0,6,0,66,0,8,0,85;1,00))

Source: Authors.



**Table A5. Total Relation Matrix.**

Criteria	C1	C2	C3	C4	C5
C1	((0.06,0.08,0.13,0.15;0.80), (0.04,0.06,0.16,0.23;1.00))	((0.1,0.12,0.18,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))	((0.11,0.14,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.1,0.13,0.19,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.13,0.15,0.2,0.22;0.80), (0.1,0.13,0.23,0.31;1.00))
C2	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.29;1.00))	((0.05,0.07,0.11,0.14;0.80), (0.03,0.05,0.14,0.22;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.1,0.12,0.17,0.19;0.80), (0.07,0.1,0.2,0.28;1.00))	((0.1,0.12,0.17,0.19;0.80), (0.07,0.1,0.2,0.28;1.00))
C3	((0.12,0.14,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))	((0.13,0.15,0.21,0.23;0.80), (0.1,0.13,0.24,0.33;1.00))	((0.08,0.11,0.14,0.17;0.80), (0.05,0.08,0.18,0.26;1.00))	((0.12,0.15,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))	((0.12,0.15,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))
C4	((0.1,0.12,0.18,0.21;0.80), (0.07,0.1,0.22,0.3;1.00))	((0.12,0.14,0.19,0.22;0.80), (0.09,0.12,0.23,0.31;1.00))	((0.11,0.13,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.06,0.08,0.13,0.15;0.80), (0.04,0.06,0.16,0.23;1.00))	((0.12,0.14,0.19,0.22;0.80), (0.09,0.12,0.23,0.3;1.00))
C5	((0.12,0.14,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.07,0.1,0.22,0.3;1.00))	((0.14,0.16,0.22,0.24;0.80), (0.1,0.14,0.25,0.34;1.00))	((0.13,0.16,0.21,0.24;0.80), (0.1,0.14,0.25,0.33;1.00))	((0.07,0.09,0.14,0.16;0.80), (0.05,0.07,0.17,0.25;1.00))
C6	((0.13,0.15,0.21,0.23;0.80), (0.1,0.13,0.24,0.32;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.14,0.16,0.22,0.24;0.80), (0.1,0.14,0.25,0.34;1.00))	((0.12,0.15,0.2,0.23;0.80), (0.09,0.12,0.23,0.31;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))
C7	((0.11,0.13,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.11,0.13,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))	((0.12,0.14,0.19,0.21;0.80), (0.09,0.12,0.22,0.3;1.00))
C8	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.13,0.15,0.2,0.23;0.80), (0.1,0.13,0.24,0.32;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))
C9	((0.22,0.25,0.3,0.33;0.80), (0.19,0.22,0.35,0.43;1.00))	((0.21,0.23,0.29,0.32;0.80), (0.17,0.21,0.34,0.43;1.00))	((0.22,0.25,0.31,0.34;0.80), (0.19,0.23,0.35,0.44;1.00))	((0.21,0.24,0.3,0.33;0.80), (0.18,0.22,0.34,0.43;1.00))	((0.21,0.24,0.3,0.33;0.80), (0.18,0.22,0.34,0.43;1.00))
C10	((0.18,0.2,0.26,0.3;0.80), (0.14,0.18,0.31,0.4;1.00))	((0.18,0.2,0.27,0.3;0.80), (0.15,0.18,0.31,0.4;1.00))	((0.2,0.23,0.29,0.32;0.80), (0.17,0.2,0.33,0.42;1.00))	((0.19,0.21,0.27,0.3;0.80), (0.15,0.19,0.31,0.4;1.00))	((0.18,0.21,0.27,0.3;0.80), (0.15,0.18,0.31,0.4;1.00))

Criteria	C6	C7	C8	C9	C10
C1	((0.13,0.15,0.21,0.24;0.80), (0.1,0.13,0.25,0.33;1.00))	((0.11,0.13,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.13,0.15,0.21,0.24;0.80), (0.1,0.13,0.25,0.33;1.00))	((0.1,0.12,0.17,0.19;0.80), (0.07,0.1,0.2,0.27;1.00))	((0.09,0.11,0.16,0.19;0.80), (0.06,0.09,0.2,0.27;1.00))
C2	((0.12,0.14,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))	((0.11,0.13,0.18,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))	((0.11,0.13,0.19,0.22;0.80), (0.08,0.11,0.23,0.31;1.00))	((0.08,0.1,0.14,0.17;0.80), (0.05,0.08,0.18,0.25;1.00))	((0.09,0.1,0.15,0.18;0.80), (0.06,0.09,0.19,0.26;1.00))
C3	((0.15,0.17,0.23,0.26;0.80), (0.12,0.15,0.27,0.35;1.00))	((0.15,0.17,0.22,0.25;0.80), (0.12,0.15,0.26,0.34;1.00))	((0.15,0.17,0.22,0.25;0.80), (0.11,0.15,0.26,0.35;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.28;1.00))	((0.1,0.13,0.19,0.21;0.80), (0.08,0.11,0.22,0.3;1.00))
C4	((0.14,0.16,0.22,0.25;0.80), (0.11,0.14,0.26,0.34;1.00))	((0.14,0.16,0.21,0.24;0.80), (0.11,0.14,0.25,0.33;1.00))	((0.14,0.16,0.21,0.24;0.80), (0.11,0.14,0.25,0.33;1.00))	((0.09,0.11,0.16,0.18;0.80), (0.06,0.09,0.19,0.27;1.00))	((0.1,0.12,0.18,0.2;0.80), (0.08,0.1,0.21,0.29;1.00))
C5	((0.15,0.17,0.23,0.26;0.80), (0.12,0.15,0.27,0.36;1.00))	((0.15,0.17,0.23,0.25;0.80), (0.12,0.15,0.26,0.35;1.00))	((0.14,0.16,0.22,0.25;0.80), (0.11,0.14,0.26,0.35;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.28;1.00))	((0.12,0.14,0.19,0.22;0.80), (0.09,0.12,0.23,0.31;1.00))
C6	((0.08,0.1,0.15,0.17;0.80), (0.05,0.08,0.18,0.26;1.00))	((0.14,0.16,0.21,0.24;0.80), (0.11,0.14,0.25,0.33;1.00))	((0.12,0.15,0.2,0.23;0.80), (0.09,0.12,0.24,0.32;1.00))	((0.09,0.11,0.16,0.19;0.80), (0.07,0.09,0.2,0.27;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))
C7	((0.13,0.15,0.21,0.24;0.80), (0.1,0.13,0.25,0.33;1.00))	((0.07,0.09,0.13,0.16;0.80), (0.05,0.07,0.17,0.24;1.00))	((0.13,0.15,0.21,0.23;0.80), (0.1,0.13,0.24,0.33;1.00))	((0.09,0.11,0.16,0.19;0.80), (0.07,0.09,0.2,0.27;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.29;1.00))
C8	((0.13,0.15,0.2,0.23;0.80), (0.1,0.13,0.24,0.33;1.00))	((0.13,0.15,0.2,0.23;0.80), (0.1,0.13,0.24,0.32;1.00))	((0.07,0.09,0.13,0.16;0.80), (0.05,0.07,0.17,0.24;1.00))	((0.08,0.1,0.15,0.17;0.80), (0.05,0.08,0.18,0.25;1.00))	((0.1,0.12,0.17,0.2;0.80), (0.07,0.1,0.21,0.28;1.00))
C9	((0.23,0.26,0.32,0.35;0.80), (0.2,0.24,0.37,0.46;1.00))	((0.23,0.25,0.31,0.34;0.80), (0.19,0.23,0.36,0.45;1.00))	((0.23,0.26,0.32,0.35;0.80), (0.19,0.23,0.36,0.45;1.00))	((0.09,0.11,0.16,0.19;0.80), (0.06,0.09,0.2,0.28;1.00))	((0.17,0.2,0.26,0.29;0.80), (0.13,0.17,0.3,0.39;1.00))
C10	((0.2,0.22,0.29,0.32;0.80), (0.16,0.2,0.34,0.43;1.00))	((0.19,0.22,0.28,0.31;0.80), (0.16,0.19,0.33,0.42;1.00))	((0.19,0.22,0.28,0.31;0.80), (0.16,0.19,0.33,0.42;1.00))	((0.13,0.15,0.21,0.24;0.80), (0.09,0.13,0.25,0.34;1.00))	((0.08,0.1,0.16,0.19;0.80), (0.06,0.08,0.2,0.28;1.00))

Source: Authors.

**Table A6.** Defuzzified Total Relation Matrix and the Values of  $\tilde{D}_i^{def}$  and  $\tilde{R}_i^{def}$ .

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	$\tilde{D}_i^{def}$	$\tilde{R}_i^{def}$	$(\tilde{D}_i + \tilde{R}_i)^{def}$	$(\tilde{D}_i - \tilde{R}_i)^{def}$
C1	0.11	0.15	0.17	0.16	0.17	0.18	0.17	0.18	0.14	0.14	1.58	1.79	3.37	-0.21
C2	0.16	0.10	0.16	0.15	0.15	0.18	0.16	0.16	0.13	0.13	1.46	1.73	3.19	-0.27
C3	0.18	0.18	0.13	0.17	0.17	0.20	0.20	0.20	0.15	0.16	1.74	1.87	3.61	-0.13
C4	0.16	0.17	0.16	0.11	0.17	0.19	0.19	0.19	0.14	0.15	1.62	1.75	3.38	-0.13
C5	0.18	0.16	0.19	0.19	0.12	0.20	0.20	0.20	0.15	0.17	1.75	1.76	3.51	-0.01
C6	0.18	0.16	0.19	0.17	0.16	0.13	0.19	0.18	0.14	0.15	1.65	1.99	3.64	-0.34
C7	0.16	0.16	0.16	0.15	0.16	0.18	0.12	0.18	0.14	0.15	1.57	1.92	3.49	-0.35
C8	0.16	0.16	0.18	0.15	0.15	0.18	0.18	0.11	0.13	0.15	1.54	1.93	3.48	-0.39
C9	0.27	0.26	0.28	0.27	0.27	0.29	0.28	0.28	0.14	0.23	2.57	1.44	4.01	1.14
C10	0.23	0.24	0.26	0.24	0.24	0.26	0.25	0.25	0.18	0.14	2.28	1.57	3.86	0.71

Source: Authors.



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## References

- Åhman, M., & Nilsson, L. J. (2015). Decarbonizing industry in the EU: Climate, trade and industrial policy strategies. In C. Dupont & S. Oberthür (Eds.), *Decarbonization in the European Union* (pp. 92–114). Palgrave Macmillan.
- Arabzadeh, V., Mikkola, J., Jasiūnas, J., & Lund, P. D. (2020). Deep decarbonization of urban energy systems through renewable energy and sector-coupling flexibility strategies. *Journal of Environmental Management*, *260*, 110090.
- Barrett, J., Cooper, T., Hammond, G. P., & Pidgeon, N. (2018). Industrial energy, materials and products: UK decarbonisation challenges and opportunities. *Applied Thermal Engineering*, *136*, 643–656.
- Bataille, C., Åhman, M., Neuhoﬀ, K., Nilsson, L. J., Fishedick, M., Lechtenböhmer, S., Solano-Rodriguez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O., & Rahbar, S. (2018). A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris agreement. *Journal of Cleaner Production*, *187*, 960–973.
- Bernstein, S., & Hoffmann, M. (2018). The politics of decarbonization and the catalytic impact of subnational climate experiments. *Policy Sciences*, *51*(2), 189–211.
- Bouncken, R. B., Fredrich, V., Ritala, P., & Kraus, S. (2018). Coopetition in new product development alliances: Advantages and tensions for incremental and radical innovation. *British Journal of Management*, *29*(3), 391–410.
- Chen, T. Y., Chang, C. H., & Rachel Lu, J. F. (2013). The extended QUALIFLEX method for multiple criteria decision analysis based on interval type-2 fuzzy sets and applications to medical decision making. *European Journal of Operational Research*, *226*(3), 615–625.
- Chi, Y., Yang, P., Ren, S., Ma, N., Yang, J., & Xu, Y. (2020). Effects of fertilizer types and water quality on carbon dioxide emissions from soil in wheat-maize rotations. *The Science of the Total Environment*, *698*, 134010.
- Conci, M., Konstantinou, T., van Den Dobbelsteen, A., & Schneider, J. (2019). Trade-off between the economic and environmental impact of different decarbonisation strategies for residential buildings. *Building and Environment*, *155*, 137–144.
- Dejuán, Ó., Lenzen, M., & Cadarso, M. Á. (Eds.). (2017). *Environmental and economic impacts of decarbonization: Input-output studies on the consequences of the 2015 Paris agreements*. Routledge.
- Dinçer, H., & Yüksel, S. (2020). Defining the strategic impact-relation map for the innovative investments based on IT2 fuzzy DEMATEL: Evidence from the European tourism sector. In U. Akkucuk (Ed.), *Handbook of research on creating sustainable value in the global economy* (pp. 103–124). IGI Global.
- Dinçer, H., Yüksel, S., Canbolat, Z. N., & Pınarbaşı, F. (2020). Data mining-based evaluating the customer satisfaction for the mobile applications: An analysis on Turkish banking sector by using IT2 fuzzy dematel. In R. Das (Ed.), *Tools and techniques for implementing international E-trading tactics for competitive advantage* (pp. 320–339). IGI Global.
- Fais, B., Sabio, N., & Strachan, N. (2016). The critical role of the industrial sector in reaching long-term emission reduction, energy efficiency and renewable targets. *Applied Energy*, *162*, 699–712.
- Faria, M. V., Duarte, G. O., Varella, R. A., Farias, T. L., & Baptista, P. C. (2019). Driving for decarbonization: Assessing the energy, environmental, and economic benefits of less aggressive driving in Lisbon, Portugal. *Energy Research & Social Science*, *47*, 113–127.
- Farooque, M., Jain, V., Zhang, A., & Li, Z. (2020). Fuzzy DEMATEL analysis of barriers to blockchain-based life cycle assessment in China. *Computers & Industrial Engineering*, *147*, 106684.
- Fazli, S., Kiani Mavi, R., & Vosooghizajji, M. (2015). Crude oil supply chain risk management with DEMATEL-ANP. *Operational Research*, *15*(3), 453–480.
- Fontela, E., & Gabus, A. (1976). *The DEMATEL observer*. Battelle Geneva Research Centre.
- Fortes, P., Simoes, S. G., Gouveia, J. P., & Seixas, J. (2019). Electricity, the silver bullet for the deep decarbonisation of the energy system? Cost-effectiveness analysis for Portugal. *Applied Energy*, *237*, 292–303.
- Frizziero, L., Donnici, G., Liverani, A., & Dhaimini, K. (2020). Design for additive manufacturing and advanced development methods applied to an innovative multifunctional fan. In *Additive manufacturing: Breakthroughs in research and practice* (pp. 52–85). IGI Global.
- Fuller, G. W. (2016). *New food product development: From concept to marketplace*. CRC Press.
- Gabus, A., & Fontela, E. (1973). Perceptions of the World Problematique: Communication Procedure, Communicating with those Bearing Collective Responsibility. Battelle Geneva Research Centre, Geneva, Switzerland. (DEMATEL Report No. 1)
- Gerres, T., Chaves Ávila, J. P., Llamas, P. L., & San Román, T. G. (2019). A review of cross-sector decarbonisation potentials in the European energy intensive industry. *Journal of Cleaner Production*, *210*, 585–601.
- Gonzalez-Zapatero, C., Gonzalez-Benito, J., & Lannelongue, G. (2016). Antecedents of functional integration during new product development: The purchasing–marketing link. *Industrial Marketing Management*, *52*, 47–59.
- Gowreesunker, B., Tassou, S., & Atuonwu, J. (2018). Cost-Energy optimum pathway for the UK food manufacturing industry to meet the UK national emission targets. *Energies*, *11*(10), 2630.

- Griffin, P. W., & Hammond, G. P. (2019). Industrial energy use and carbon emissions reduction in the iron and steel sector: A UK perspective. *Applied Energy*, *249*, 109–125.
- Hong, Y. Y., & Buay, P. M. P. (2020). Robust design of type-2 fuzzy logic-based maximum power point tracking for photovoltaics. *Sustainable Energy Technologies and Assessments*, *38*, 100669.
- Huang, A. Q. (2019). Power semiconductor devices for smart grid and renewable energy systems. In B. K. Bose (Ed.), *Power electronics in renewable energy systems and smart grid: Technology and applications* (pp. 85–152). Wiley Online Library.
- Huang, J., Ri, M., Wu, D., & Ri, S. (2018). Interval type-2 fuzzy logic modeling and control of a mobile two-wheeled inverted pendulum. *IEEE Transactions on Fuzzy Systems*, *26*(4), 2030–2038.
- Jakobsen, S., & Clausen, T. H. (2016). Innovating for a greener future: The direct and indirect effects of firms' environmental objectives on the innovation process. *Journal of Cleaner Production*, *128*, 131–141.
- Jayant, A. (2020). Decision support framework for smart implementation of green supply chain management practices. In S. Patnaik (Ed.), *New paradigm of industry 4.0* (pp. 49–98). Springer.
- Jugend, D., Pinheiro, M. A. P., Luiz, J. V. R., Junior, A. V., & Cauchick-Miguel, P. A. (2020). Achieving environmental sustainability with ecodesign practices and tools for new product development. In C. M. Galanakis (Ed.), *Innovation strategies in environmental science* (pp. 179–207). Elsevier.
- Kaya, R., & Yet, B. (2019). Building Bayesian networks based on DEMATEL for multiple criteria decision problems: A supplier selection case study. *Expert Systems with Applications*, *134*, 234–248.
- Kronsell, A., Khan, J., & Hildingsson, R. (2019). Actor relations in climate policymaking: Governing decarbonisation in a corporatist green state. *Environmental Policy and Governance*, *29*, 399–408.
- Ku, S. W. (2020). Platform strategy for new product development: The mediating effect of product platform strategy in the Korean high technology industry. In U. Hacıoglu (Ed.), *Handbook of research on strategic fit and design in business ecosystems* (pp. 123–143). IGI Global.
- La Rocca, A., Moscatelli, P., Perna, A., & Snehota, I. (2016). Customer involvement in new product development in B2B: The role of sales. *Industrial Marketing Management*, *58*, 45–57.
- Lawson, B., Krause, D., & Potter, A. (2015). Improving supplier new product development performance: The role of supplier development. *Journal of Product Innovation Management*, *32*(5), 777–792.
- Lee, L. W., & Chen, S. M. (2008, July). Fuzzy multiple attributes group decision-making based on the extension of TOPSIS method and interval type-2 fuzzy sets. In 2008 international conference on machine learning and cybernetics, Kunming, China, Volume 6, pp. 3260–3265. IEEE.
- Leenders, R. T. A. J., & Dolfisma, W. A. (2016). Social networks for innovation and new product development. *Journal of Product Innovation Management*, *33*(2), 123–131.
- Lei, N., & Moon, S. K. (2015). A decision support system for market-driven product positioning and design. *Decision Support Systems*, *69*, 82–91.
- Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert Systems with Applications*, *161*, 113738.
- Li, X., Zhu, S., Yüksel, S., Dinçer, H., & Ubay, G. G. (2020). Kano-based mapping of innovation strategies for renewable energy alternatives using hybrid interval type-2 fuzzy decision-making approach. *Energy*, *211*, 118679.
- Maroto-Valer, M. M. (2019). CCUS: Solving the conundrum of decoupling sustainable economic growth and CO<sub>2</sub> emissions. *Greenhouse Gases Science and Technology*, *9*(2), 128–129.
- Mistarihi, M. Z., Okour, R. A., & Mumani, A. A. (2020). An integration of a QFD model with fuzzy-ANP approach for determining the importance weights for engineering characteristics of the proposed wheelchair design. *Applied Soft Computing*, *90*, 106136.
- Monyei, C. G., Sovacool, B. K., Brown, M. A., Jenkins, K. E. H., Viriri, S., & Li, Y. (2019). Justice, poverty, and electricity decarbonization. *The Electricity Journal*, *32*(1), 47–51.
- Mu, J. (2015). Marketing capability, organizational adaptation and new product development performance. *Industrial Marketing Management*, *49*, 151–166.
- Mu, J., Thomas, E., Peng, G., & Di Benedetto, A. (2017). Strategic orientation and new product development performance: The role of networking capability and networking ability. *Industrial Marketing Management*, *64*, 187–201.
- Ocampo, L., & Yamagishi, K. (2020). Modeling the lockdown relaxation protocols of the Philippine government in response to the COVID-19 pandemic: An intuitionistic fuzzy DEMATEL analysis. *Socio-Economic Planning Sciences*, *72*, 100911.
- O'Brien, K. (2020). Innovation types and the search for new ideas at the fuzzy front end: Where to look and how often? *Journal of Business Research*, *107*, 13–24.
- Parra, D., Valverde, L., Pino, F. J., & Patel, M. K. (2019). A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. *Renewable and Sustainable Energy Reviews*, *101*, 279–294.
- Pereira, M., Pina, L., Reis, B., Miguel, R., Silva, M., & Rafael, P. (2020). Digital technology for global supply chain in fashion: A contribution for sustainability development. In G. Vignali, L. F. Reid, D. Ryding, & C. E. Henninger (Eds.), *Technology-Driven sustainability* (pp. 117–136). Palgrave Macmillan.
- Qiao, W., Lu, H., Zhou, G., Azimi, M., Yang, Q., & Tian, W. (2020). A hybrid algorithm for carbon dioxide emissions forecasting based on improved lion swarm optimizer. *Journal of Cleaner Production*, *244*, 118612.
- Qiu, D., Dinçer, H., Yüksel, S., & Ubay, G. G. (2020). Multi-faceted analysis of systematic risk-based wind energy investment decisions in E7 economies using modified hybrid modeling with IT2 fuzzy sets. *Energies*, *13*(6), 1423.
- Rathore, A. K., & Ilavarasan, P. V. (2020). Pre- and post-launch emotions in new product development: Insights from twitter analytics of three products. *International Journal of Information Management*, *50*, 111–127.
- Raval, S. J., Kant, R., & Shankar, R. (2021). Analyzing the critical success factors influencing lean Six Sigma implementation: Fuzzy DEMATEL approach. *Journal of Modelling in Management*, *16*, 728–764.
- Ravi, T., & Ranganathan, R. (2020). Topology and build path optimization for reducing cost in FDM uPrint SE. In T. Ravi & R.

- Ranganathan (Eds.), *Advances in additive manufacturing and joining* (pp. 189–198). Springer.
- Renner, A., & Giampietro, M. (2020). Socio-technical discourses of European electricity decarbonization: Contesting narrative credibility and legitimacy with quantitative story-telling. *Energy Research & Social Science*, *59*, 101279.
- Roper, S., Micheli, P., Love, J. H., & Vahter, P. (2016). The roles and effectiveness of design in new product development: A study of Irish manufacturers. *Research Policy*, *45*(1), 319–329.
- Ross, F. (2020). Co-creation via digital fashion technology in new business models for premium product innovation: Case-studies in menswear and womenswear adaptation. In *Sustainable business: Concepts, methodologies, tools, and applications* (pp. 1147–1172). IGI Global.
- Roy, S., Modak, N., & Dan, P. K. (2020). Managerial support to control entrepreneurial culture in integrating environmental impacts for sustainable new product development. In S. K. Ghosh (Ed.), *Sustainable waste management: Policies and case studies* (pp. 637–646). Springer.
- Rubera, G., Chandrasekaran, D., & Ordanini, A. (2016). Open innovation, product portfolio innovativeness and firm performance: The dual role of new product development capabilities. *Journal of the Academy of Marketing Science*, *44*(2), 166–184.
- Runkler, T. A., Chen, C., & John, R. (2018). Type reduction operators for interval type-2 defuzzification. *Information Sciences*, *467*, 464–476.
- Saĝnak, M. (2020). Selecting the most appropriate supplier in the green environment: A hybrid multi-criteria decision-making application. In J. Luis García-Alcaraz, G. Leal Jamil, L. Avelar-Sosa, & A. Juan Briones Peñalver (Eds.), *Handbook of research on industrial applications for improved supply chain performance* (pp. 101–124). IGI Global.
- Salina, F. H., de Almeida, I. A., & Bittencourt, F. R. (2020). RenovaBio opportunities and biofuels outlook in Brazil. In A. Sayigh (Ed.), *Renewable energy and sustainable buildings* (pp. 391–399). Springer.
- Schemmann, B., Herrmann, A. M., Chappin, M. M. H., & Heimeriks, G. J. (2016). Crowdsourcing ideas: Involving ordinary users in the ideation phase of new product development. *Research Policy*, *45*(6), 1145–1154.
- Schoenherr, T., & Wagner, S. M. (2016). Supplier involvement in the fuzzy front end of new product development: An investigation of homophily, benevolence and market turbulence. *International Journal of Production Economics*, *180*, 101–113.
- Skytt, T., Nielsen, S. N., & Jonsson, B. G. (2020). Global warming potential and absolute global temperature change potential from carbon dioxide and methane fluxes as indicators of regional sustainability – A case study of Jämtland, Sweden. *Ecological Indicators*, *110*, 105831.
- Song, W., Zhu, Y., & Zhao, Q. (2020). Analyzing barriers for adopting sustainable online consumption: A rough hierarchical DEMATEL method. *Computers & Industrial Engineering*, *140*, 106279.
- Sovacool, B. K., Kester, J., de Rubens, G. Z., & Noel, L. (2018). Expert perceptions of low-carbon transitions: Investigating the challenges of electricity decarbonisation in the Nordic region. *Energy*, *148*, 1162–1172.
- Sparkman, G., & Attari, S. Z. (2020). Credibility, communication, and climate change: How lifestyle inconsistency and do-gooder derogation impact decarbonization advocacy. *Energy Research & Social Science*, *59*, 101290.
- Stark, J. (2020). PLM, techniques and methods. In J. Stark (Ed.), *Product lifecycle management* (Vol. 1, pp. 309–333). Springer.
- Tantau, A., & Staiger, R. (2020). Evolving business models in the renewable energy. In *Sustainable business: Concepts, methodologies, tools, and applications* (pp. 395–413). IGI Global.
- Thompson, M. K., Juel Jespersen, I. K., & Kjærgaard, T. (2018). Design for manufacturing and assembly key performance indicators to support high-speed product development. *Procedia CIRP*, *70*, 114–119.
- Tozer, L.; Durham University. (2020). Catalyzing political momentum for the effective implementation of decarbonization for urban buildings. *Energy Policy*, *136*, 111042.
- Verbruggen, A., & Yurchenko, Y. (2019). The collision of atomic and flow renewable power in decarbonization of electricity supply. In R. Haas, L. Mez, & A. Ajanovic (Eds.), *The technological and economic future of nuclear power* (pp. 77–95). Springer VS, Wiesbaden.
- Vulin, D., Arnaut, M., Jukić, L., & Sedlar, D. K. (2020). Using European carbon dioxide emission allowances for investments in storage technologies. In U. Akkucuk (Ed.), *Handbook of research on creating sustainable value in the global economy* (pp. 313–331). IGI Global.
- Wang, F., & Chen, K. (2020). Do product imitation and innovation require different patterns of organizational innovation? Evidence from chinese firms. *Journal of Business Research*, *106*, 60–74.
- Wang, Y., Xu, L., & Solangi, Y. A. (2020). Strategic renewable energy resources selection for Pakistan: Based on SWOT-fuzzy AHP approach. *Sustainable Cities and Society*, *52*, 101861.
- Wen, W., & Wang, Q. (2020). Re-examining the realization of provincial carbon dioxide emission intensity reduction targets in China from a consumption-based accounting. *Journal of Cleaner Production*, *244*, 118488.
- Wu, D., & Mendel, J. M. (2019). Recommendations on designing practical interval type-2 fuzzy systems. *Engineering Applications of Artificial Intelligence*, *85*, 182–193.
- Wu, Q., Zhou, L., Chen, Y., & Chen, H. (2019). An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods. *Information Sciences*, *502*, 394–417.
- Yadav, S., & Singh, S. P. (2020). An integrated fuzzy-ANP and fuzzy-ISM approach using blockchain for sustainable supply chain. *Journal of Enterprise Information Management*, *34*, 54–78.
- Yang, M., An, Q., Ding, T., Yin, P., & Liang, L. (2019). Carbon emission allocation in China based on gradually efficiency improvement and emission reduction planning principle. *Annals of Operations Research*, *278*(1–2), 123–139.
- Yu, L., Duan, Y., & Fan, T. (2020). Innovation performance of new products in China's high-technology industry. *International Journal of Production Economics*, *219*, 204–215.
- Zahay, D., Hajli, N., & Sihi, D. (2018). Managerial perspectives on crowdsourcing in the new product development process. *Industrial Marketing Management*, *71*, 41–53.
- Zhang, G., Zhou, S., Xia, X., Yuksel, S., Bas, H., & Dincer, H. (2020). Strategic mapping of youth unemployment with interval-valued intuitionistic hesitant fuzzy DEMATEL based on 2-tuple linguistic values. *IEEE Access*, *8*, 25706–25721.
- Zhao, Y., Xu, Y., Yuksel, S., Dinçer, H., & Ubay, G. G. (2021). Hybrid IT2 fuzzy modelling with alpha cuts for hydrogen energy investments. *International Journal of Hydrogen Energy*, *46*(13), 8835–8851.

- Zheng, J., Sun, X., Jia, L., & Zhou, Y. (2020). Electric passenger vehicles sales and carbon dioxide emission reduction potential in China's leading markets. *Journal of Cleaner Production*, *243*, 118607.
- Zhong, J., Hu, X., Yuksel, S., Dincer, H., & Ubay, G. G. (2020). Analyzing the investments strategies for renewable energies based on multi-criteria decision model. *IEEE Access*, *8*, 118818–118840.
- Zhou, P., Zhou, P., Yüksel, S., Dinçer, H., & Uluer, G. S. (2020). Balanced scorecard-based evaluation of sustainable energy investment projects with it2 fuzzy hybrid decision making approach. *Energies*, *13*(1), 82.
- Ziegler, M. S., Mueller, J. M., Pereira, G. D., Song, J., Ferrara, M., Chiang, Y. M., & Trancik, J. E. (2019). Storage requirements and costs of shaping renewable energy toward grid decarbonization. *Joule*, *3*(9), 2134–2153.