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CAUSE AND EFFECT ANALYSIS OF GREEN SUPPLY CHAIN CHALLENGES IN POST-COVID-19 CONDITIONS BASED ON HESITANT FUZZY DEMATEL METHOD

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Abstract. After the COVID-19 pandemic, all organizations are involved in tackling the challenges of the disease, which continues after vaccination. It has affected various sectors of organizations including the supply chain, and has made coordination along the supply chain extremely difficult. The present study purpose to analyze the challenges of green supply chain in post-COVID-19 conditions. This study has an applied and developmental objective with a hybrid approach. This study was conducted in two stages and each stage had several consecutive steps. In the first stage, based on the results of thematic analysis, 21 challenges affecting the green supply chain in post-COVID-19 conditions were identified which were classified into 10 main challenges and 11 sub-challenges. In the second stage, the main challenges were analyzed based on hesitant fuzzy DEMATEL technique. Four challenges in an optimistic mode and five in a pessimistic mode were known as the causes. resulting in affecting all of the three levels in the supply chain and its disruption at the national and global level.

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1. Introduction

The supply chain is essentially dynamic and complex and is a network of multiple operational loops in which value-added can be created [1]. Suppliers are at the beginning of the supply chain, and customers are at its end. In fact, it is the alliance of companies which provide goods and services to the market [5]. In other words, the integration of information flow, financial and physical resources through a series of value-added activities means supply chain. Nowadays, there are different forms of supply chain in organizations. Green supply chain is a new approach, which is responsive to environmental challenges in addition to the desired issues of supply chain [18]. In Green supply chain, environmental and green requirements are paramount and the Green supply chain defines added restrictions than those defined in traditional supply chains. Besides functions of traditional supply chains, Green supply chain needs to sustain greenness and, thereby, is more susceptible than its traditional counterpart(s). Concerning the paramountcy of this issue for firms and organizations, it is pivotal to identify the challenges the Green supply chain encounters.

Keywords. COVID-19, green supply chain, green supply chain challenges, hesitant fuzzy DEMATEL, thematic analysis.

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The COVID-19 pandemic has affected all aspects of human life [15]. In such a circumstances, companies and organizations have faced fundamental challenges in their performance [3], and their working method has changed a lot [27]. The challenges resulting from the COVID-19 pandemic have directly or indirectly affected the supply chain [6, 33]. Resulting in devastating issues in both the traditional supply chain and Green supply chain. Again, these adverse effects are proceeding even post-COVID-19 vaccination, with the currently leading issues: (1) Future uncertainties and skepticism over the recurrence of this pandemic (or even more exuberated conditions). (2) Economic issues emanating from the pandemic (*e.g.*, demand fluctuations, scarcity of resources, business bankruptcies, and financial losses of the firms). (3) Additional efforts for intensive stockpiling to avert the pandemic's harsh effects on the supply chain, and (4) Other issues (*e.g.*, workplace health and safety, formerly compiled protocols, etc). Such impacts cause severe disruption in supply chain, consumption patterns and business models in various industries such as transportation, real estate, manufacturing, tourism, retail [6].

A special combination of competitive, environmental, technological and geographical conditions has been created under COVID-19 conditions [7], and green supply chain has severely affected the companies. Green supply chain is defined as integrating green innovative activities in the flow of goods or services from supplier to final customers [35], which has been influenced by some main challenges such as reducing green supplier and green supply chain flexibility during COVID-19 conditions.

The challenges should be evaluated properly in order to improve the performance of the green supply chain in post-coronavirus (COVID-19) conditions. The COVID-19 disease has shown that the supply chain is considered as highly vulnerable to challenges [2]. Paul *et al.* [30] emphasized the need to identify challenges in order to take corrective measures in the supply chain to reduce vulnerability. They indicated that identifying challenges is regarded as the first action for correction. Few studies have been conducted to identify the challenges related to the green supply chain during the post-COVID-19 era. Such challenges should be identified due to the long-term effects of COVID-19 [24].

Previous studies [17, 23, 29, 36] used the stochastic model, FISM, best-worst method (BWM), and fuzzy analytic hierarchy process (FAHP) to examine the challenges, respectively. The challenges of the green supply chain in the post-coronavirus era are interrelated, and the DEMATEL technique classifies the factors and indices into cause and effect groups, as well as providing an appropriate framework for investigating the challenging factors [13]. In addition, Asan *et al.* [4] presented a new approach of the technique based on hesitant valued hesitant fuzzy sets to solve decision-making problems, which performs better than the traditional and fuzzy DEMATEL methods. To this aim, the hesitant fuzzy DEMATEL was utilized to study the challenges related to the green supply chain in the post-coronavirus era.

The present study aims to review the challenges related to the green supply chain in post-COVID-19 conditions. To this aim, the following questions are asked.

What are the challenges of the green supply chain in the post-COVID-19 era?

What is the causal analysis of green supply chain challenges in the post-COVID-19 era?

2. Research literature

2.1. Green supply chain

Supply chain plays an important role in organizational environmental measures by increasing acceptance of ISO 14001 environmental standards [16, 35]. Companies have introduced a variety of green methods to optimize their supply chains [19]. Green supply chain is used as a critical approach to balance the economic, social and environmental issues of companies, and promote organizational sustainability [21]. It is defined as the integrator of green activities, including green purchasing, green manufacturing, green packaging, green marketing and reverse logistics, in the flow of goods or services from primary sources to final customers [10, 11]. Nowadays, green supply chain is considered as an ideal way for companies to pursue higher business profits and realize the supply chain by minimizing the waste of resources and improving environmental efficiency [37].

Green supply chain refers to the practice of integrating environmental thought in supply chain management [31], which is related to the company's performance. The implementation of green supply chain practices responds to the global concern of engaging in green activities [35], which helps companies reduce the cost of raw materials and packaging [14]. Companies, which adopt green supply chain initiatives make higher profits by using recycled materials, thus improve their performance [21]. In addition, those running green supply chain can meet customers' needs by providing products which protect the environment to achieve better performance in supply chain [12] and create competitive advantage, leading to an improvement in the performance of the company. Further, the implementation of the green supply chain helps reduce waste of resources and minimize energy consumption so that it can contribute to sustainable development of society and the environment [28].

2.2. Green supply chain challenges in post-COVID-19 conditions

Choi [8] considered an increase in companies' bankruptcy as a supply chain challenge. Holidays, lock-down, supply network disruption, etc. are considered as the factors which can be involved in companies' bankruptcy. Leite *et al.* [20] reported that the lack of financial and physical resources are the main challenges of the supply chain, which has been worsened under the influence of the conditions resulting from the COVID-19. In COVID-19 conditions, communication along the supply chain has been reduced, leading to the cancelation of many orders. Thus, companies have faced a shortage of financial resources and consequently a lack of physical resources. According to Nagurney [26], the COVID-19 conditions have caused financial resources of companies to decrease and as a result, the employees' layoff to increase. According to Pael *et al.* [30], flexibility reduction, along with cooperation, sourcing, and communication problems, as well as repeated cancellation of orders are fundamental challenges and have greatly affected the supply chain. Sen [34] believes that COVID-19 conditions greatly affect the activities of final customers, and low levels of financial flow in the supply chain are considered as a major challenge.

Palouj *et al.* [29] refer to two other challenges. First, there is a great tendency to store scarce goods, which continue in the post-COVID-19 period. Second, since future of the COVID-19 crisis is unpredictable, there are many restrictions on planning and investing which have affected the supply chains of the companies. Sharma *et al.* [32] introduced low levels of readiness and inappropriate infrastructure as supply chain challenges, which have spread after COVID-19 outbreak. These challenges may originate from the previous unpreparedness to face COVID-19 and Corona problems to use infrastructure.

2.3. Multi-criteria decision making

Multi-criteria decision making (MCDM) is classified into multi-objective decision making (MODM) and multi-attribute decision making (MADM). The MODM is applied to determine the optimal solution in a continuous or discrete space, which is performed by considering a set of objectives and constraints. The MADM methods are employed in ranking and selection problems where the candidate options are predetermined [23].

Zayat *et al.* [38] divided the MADM methods into several main groups as follows.

(1) Paired comparisons technique: This technique discusses the options and indices based on paired comparisons. Analytic hierarchy process (AHP), analytic network process (ANP), and best-worst method (BWM) are among the most significant techniques in this group.
(2) Outranking methods: In this method, the outranking relationship is defined by considering the superiority of one option over other ones, resulting in selecting the option superior to others. ELECTRE, PROMETHEE, and TODIM are among the most significant outranking methods.
(3) Distance-based methods: In this group, the best option is selected, considering the smallest distance from the positive and negative ideal solution. TOPSIS, VIKOR and EDAS are among the most significant techniques in this group.
(4) Interaction-based techniques: These techniques are used when the factors in the decision-making problem affect each other. DEMATEL and Grey Relational Analysis (GRA) are among the most popular methods in this group.

(5) Techniques based on appropriateness: There are different approaches for the MADM which are based on the appropriateness of indices. WSM, WASPAS, and COPRAS are among the most significant techniques in this group.
(6) Other techniques: There are other techniques utilized in the MADM which are not among the aforementioned groups and each has its own features. DEA, SAW, and SMART are among the most significant techniques in this group.

Here, the DEMATEL technique is applied, considering the internal relations in the challenges related to the green supply chain in the post-coronavirus era.

2.4. Hesitant fuzzy DEMATEL

DEMATEL is among the MADM techniques, which considers internal relationships and categorizes factors into two groups of cause and effect. A group of experts is employed to collect information in DEMATEL method. To improve the quality of information at this stage, two aspects should be considered. First, the evaluation scales by which experts present their opinions should be regarded. For example, five, seven, and nine-level scales can be used [13]. Second, expressing the experts' judgment in which scales become numbers should be considered. In this aspect, issues such as uncertainty are raised and a fuzzy approach is presented to deal with uncertainty. Han *et al.* [13] argued that all of the previous approaches have ended in the condition in which only one language scale is selected, while experts may observe two language scales as doubtful. The concept of hesitant fuzzy linguistic term set (HFLTS) is proposed in order to model such situations. The HFLTS approach is considered as a more convenient method for experts to express their opinions, resulting in improving the flexibility and ability to extract linguistic information. Each member of the expert group can apply the degree of membership in the above-mentioned approach.

In addition, Asan *et al.* [4] presented the advantages of the hesitant fuzzy DEMATEL method as follows.

– Expressing the experts' intra-individual and inter-group doubts.
– Unlike other fuzzy approaches, additional information such as the membership function is not needed in dealing with uncertainty, and two values can be utilized in each scale in situations where uncertainty is difficult with definite numbers.
– All of the steps are expressed employing features of hesitant fuzzy sets, leading to better output.

Here, the numbers of each scale are assessed in two values, considering all of the cases used to face the uncertainty. In addition, the output result is presented in two optimistic and pessimistic states, considering the features of uncertain fuzzy sets. These two states make it possible to fully exhibit human uncertainties in the output. Unlike previous studies, the uncertainties in the output of the model are not considered definitively.

2.5. Research background

After the COVID-19 pandemic, the challenges of the disease have been analyzed and pathologized in various topics. Similarly, different studies have been conducted in the supply chain along with its importance.

Yazdekhasti *et al.* [36] presented a multi-part random model for supply chain affected by COVID-19 conditions in the poultry industry in the United States and two models were presented in order to reduce the negative effects of the COVID-19 pandemic through the policy of crop accumulation. In the first model, the distribution system is presented in accordance with the multi-component structure, while the second model allows direct communication among suppliers and final demanders. Sharma *et al.* [32] examined the impact of COVID-19 on supply chain decisions of 100 companies using Twitter account analysis. The results show that companies face challenges due to supply and demand mismatch in technology and flexible supply chain development. In addition to profitability, companies have difficulty to build a sustainable supply chain. Nagarajan and Sharma [25] evaluated the long-term effects of COVID-19 in the process of internationalization of companies. The results showed that companies with foreign assets faced more with negative expectations of investors for restructuring and suffered from more negative effects in COVID-19 conditions. In another study, Nagurney [26] improved the supply chain network regarding labor force as an important variable in linking network economic activities, along with related capacities by creating a supply chain network optimization model. During an epidemic, the unavailability of labor force due to the disease, fear of contagion, necessity of social/physical distancing and other disruptive conditions are considered as the problems. Therefore, the framework of a model was presented by considering the tensile demand for a product and then constant demands, as well as a variety of capacities to obtain and access to valuable source of labor in a pandemic disease. Palouj *et al.* [29] investigated the effect of the COVID-19 on supply chain disruptions. First, the steps of the poultry supply chain were considered and then the specific disruptions of each step were explained. The disruptions were ranked based on a FAHP technique. The results showed that the COVID-19 pandemic has had the greatest impact on the input source as one of the steps of the poultry supply chain. The disruptions occurring in the bottom of the supply chain are related to direct side effects of the epidemic, and indirect consequences. Table 1 indicates some of the challenges mentioned in the literature.

Table 1 shows some challenges of the previous studies. Based on the background, two gaps can be expressed. First, since they have identified the challenges of the supply chain, the concepts should be examined based on thematic analysis in the application of green supply chain. Second, since the research background of COVID-19 is related to the last two years and is not rich enough, new concepts and challenges should be considered. In addition, after vaccination, some of the effects of challenges reduced, which should not be ignored.

3. Methodology

The methods used in this study are as follows.

– The philosophy of the current study is pragmatism. Based on this study, companies and organizations can use of green supply chain capabilities to deal with the effects of the COVID-19.
– The research approach is inductive. It means that the challenging factors affecting the green supply chain are identified and appropriate analysis is presented based on the techniques presented in the study.
– The study is quantitative and qualitative and has an applied objective. It is conducted to explore and describe the challenges affecting the green supply chain.
– The research strategy is thematic analysis and analysis is presented by using the hesitant fuzzy DEMATEL.
– Interview and questionnaire are used to collect information.
– Scaling method is used for quantitative easing, and categorization method is applied for qualitative easing. The analysis method is also descriptive-interpretive.

Based on thematic analysis method and the hesitant fuzzy DEMATEL technique, which are expert-oriented, the experts should have the scientific and technical competence. This study was conducted using the opinions of five experts who studied green supply chain in various industries with enough knowledge about the related challenges in different fields. All the five experts enrolled in this research were assessed for the following characteristics:

– Educational background: All the experts had a Ph.D. degree in industrial management and operations and were involved in supply chain research.
– Executive background: All the experts had executive experiences in supply chain domains, with one of them involved in the automotive industry, one in the pharmaceutical industry, and one in the food and oil industries, and two experts were faculty members.
– Geographic distribution: Of all the experts, three were from Iran, one was a faculty member in the UK, and one had work experience in Asia and South American studies.

As shown in Figure 1, the research process is conducted in two general stages. Each consists of several consecutive steps.

Table 1. Challenges affecting supply chain in post-COVID-19 conditions.

Authors/Year	Challenge	Objective	Solution	Utilization
Choi (2020) [8]	Bankruptcy of partners	Estimating the cost of services in covid-19 condition	Applied models	Mobile services
Leite *et al.* (2020) [20]	Physical and Financial Resources	Evaluating the health care systems	Thematic analysis of managers' viewpoints	Health care organizations, doctors and governments
Majumdar *et al.* (2020) [22]	Demand and supply reduction	Understanding the reasons for social instability in the clothing supply chain	Interviews with experts and Thematic analysis	Clothing supply chain
Nagurney (2021) [26]	Layoffs of workers	Supply chain optimization	Probable optimization (stochastic)	COVID-19 challenge of supply chain
Pael *et al.* (2021) [30]	Changes in distribution network, reduction in flexibility, sourcing disruption, communication problems, order cancellation, and cooperation problems	Analysis of supply chain challenges	DELPHI Fuzzy & DEMATEL	Strategies for improving supply chain in COVID-19 conditions
Sen (2020) [34]	Activity disruption, customer communication disruption, low level of financial flow and market challenges	Understanding the impact of COVID-19 on the garment industry and workers of garment industry	Thematic analysis of academic texts, newspapers, press, reports and web pages	Garment industry
Sharma *et al.* (2020) [32]	Low level of readiness and inappropriate infrastructure	Response strategies to the impact of COVID-19	Learning theory	At the country level
Palouj *et al.* (2020) [29]	Lack of facilities, disruption of transportation, storage, scarcity of materials and special goods, planning problems, investment problems and the unpredictability of crisis	Identifying the supply chain disruptions	Interview and AHP	Poultry Industry

First stage: Thematic analysis

Clark and Brown's [9] model thematic analysis was used as follows.

First step. Familiarizing the researcher with the collected data: It is important that the researchers be familiar with data in this model. They should provide a suitable explanation of the data from the data transcription stage to the challenge expression stage. The initial idea starts with the authors and it is necessary to read the qualitative data several times.

Second step. Initial coding: The coding operation begins on the concepts. Each concept constitutes a challenge based on a common feature with other concepts. Concepts are obtained, first by reviewing the background and then are completed by interviewing.

Third step. Searching for themes: Based on coding, the author should look for suitable themes in this step. These themes should express the features of the codes (concepts).

Fourth step. Reviewing the themes: After introducing the themes (challenges in this study), the features of the concepts are rechecked, and the analyses are revised if there is any discrepancy.

Fifth step. Naming themes: Since the result of the previous step is summarized in 21 challenges, it is necessary to identify the main and subordinate challenges. Therefore, the themes are summarized in two main and subordinate parts based on the qualitative control of the expert panel. As the previous step delivered 21 challenges and regarding the necessity of identifying the main and subordinate challenges, the themes were summarized into main and subordinate groups based on the expert panel's quality control. Briefly, all the themes were first open-coded once by the authors to elucidate if they are the main and subordinate post-COVID-19 challenges. Next, the list of main and subordinate challenges was submitted to the experts, where the experts ultimately approved the final list of main and subordinate challenges after vigilant appraisals.

Sixth step. Writing a report: A report is written based on the main and subordinate themes and the main challenges of the green supply chain in COVID-19 situation are introduced.

After each coding, the thematic analysis results were supplied to the experts for validation; as such, the outputs were ultimately reported after approval by the experts. To ensure the validity of the interviews and questionnaires, the experts were strictly appraised for their competency in having adequate data on the concerned topic(s). Likewise, all the main and subordinate data collected were subjected to stringent accuracy evaluations. The research supplied adequate clarifications with no personal bias to confirm the research's reliability and ensure that the experts have profound knowledge about the research topic(s). Furthermore, all the results (from each step) were shared with the experts for final approval.

Second stage: Analyzing the factors using the hesitant Fuzzy DEMATEL technique

The hesitant fuzzy DEMATEL technique is used to analyze the challenges. This technique was introduced in 1970. It is necessary to use fuzzy linguistic variables to reduce uncertainty since expert judgment is used in this technique [13]. Several methods such as fuzzy sets, intuitive fuzzy, gray, etc., are proposed to reduce the uncertainty of this technique. In this study, the hesitant fuzzy sets proposed by Asan *et al.* in 2018. Asan *et al.* [4] stated that the uncertainty caused by human skepticism may have been created in the determination of membership degrees during the evaluation, which was completely ignored in other studies using DEMATEL method in uncertainty conditions. Therefore, to answer this problem, a new hesitant fuzzy approach is proposed for DEMATEL technique, which has the ability to evaluate uncertainty and provides a better representation.

The followings are the steps of the y DEMATEL method.

First step. Stating the objective of decision-making and forming a committee of experts: The objective of decision-making is to identify the problem related to the study as well as making a panel of experts, in which using the opinions and judgments of experts to analyze the problem.

Second step. Determining the relevant factors: In order to obtain a complete outlook of the system, a number of experts should examine the factors that make up the system or topic of the study. It is impossible to identify the correlations without this analysis.

Third step. Forming the initial hesitant Fuzdirect-relation matrix: First, the experts denoted by $k(k = 1, \ldots, K)$, express the equations between factors. Then, as equation (1) indicates, the score of the hesitant fuzzy matrix equations of the factors is obtained.

$$Z^{(K)} = \begin{bmatrix} 0 & h_{12}^{(K)} & \dots & h_{1n}^{(k)} \\ h_{21}^{(K)} & 0 & \dots & h_{2n}^{(k)} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n1}^{(k)} & h_{n2}^{(k)} & \dots & 0 \end{bmatrix}, \qquad k = 1, 2, \ldots, P. \tag{1}$$

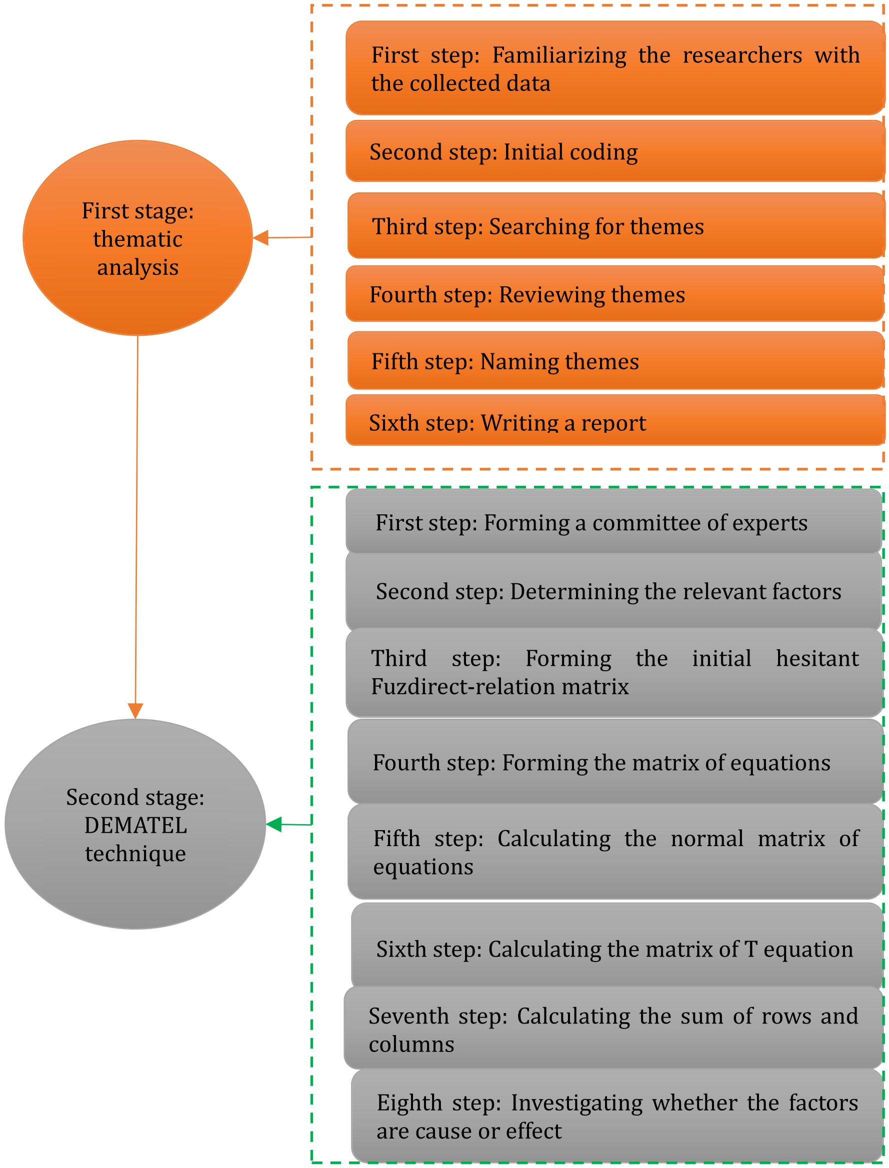

FIGURE 1. The general process of the study.

The matrix of equation (1) is obtained based on hesitant fuzzy linguistic set with equal distance of $h_{ij}^{(K)} = (y_{ij}^{(l)}, y_{ij}^{(u)})$. Table 2 indicates hesitant fuzzy linguistic variables respectively, and each expert can choose one symbol or a combination of several symbols. The average numeric value of the selected symbols is used to calculate the initial equations if an expert chooses several symbols. Based on equation (2), s represents the selected numeric value and n is the number of expert selections. Take, *e.g.*, a case where the expert chooses three symbols $S5$, $S6$, and $S7$ to calculate the average of upper and lower limits from equation (2). The corresponding numerical values for symbols $s5$, $S6$, and $S7$ are 1, 1, and 0.9 (for the upper limit) 1, 0.9, and 0.6 (for the lower limit), respectively (Tab. 2). Taking $n = 3$, the values $y_{ij}^{(u)} = \frac{1+1+0.9}{3}$ and $y_{ij}^{(l)} = \frac{1+0.9+0.6}{3}$ are

TABLE 2. Hesitant fuzzy numbers corresponding to linguistic words.

Numerical value	Symbol	Linguistic words
$(1, 1)$	$S7$	Completely effective
$(1, 0.9)$	$S6$	Very high effective
$(0.9, 0.6)$	$S5$	High effective
$(0.6, 0.4)$	$S4$	Medium effective
$(0.4, 0.1)$	$S3$	Low effective
$(0.1, 0)$	$S2$	Very low effective
$(0, 0)$	$S1$	Without effect

calculated in equation (2), ultimately delivering values $y_{ij}^{(u)} = 0.9667$ and $y_{ij}^{(l)} = 0.8333$.

$$s(h) = \frac{\sum s_i}{n}. \tag{2}$$

Fourth step. Forming the matrix of equations: The hesitant fuzzy operator of equation (3) is used to calculate the matrix of equations. In equation (3), w represents the weight of each y_{ij}. This study used the opinions of five experts, thus $w = \frac{1}{5}$.

$$\left\{\left[1 - \prod\left(1 - y_{ij}^{(l)}\right)^{w},\ \ 1 - \prod\left(1 - y_{ij}^{(u)}\right)^{w}\right], y_{ij}^{1} \in h_{ij}^{(1)}, \ldots, y_{ij}^{1} \in h_{ij}^{(K)}\right\}. \tag{3}$$

Therefore, based on equation (3), hesitant fuzzy matrix of D is formed. Based on equation (4), D represents the relationship between i and j.

$$D = \begin{bmatrix} 0 & d_{12} & \ldots & d_{1n} \\ d_{21} & 0 & \ldots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n2} & d_{n2} & \ldots & 0 \end{bmatrix}. \tag{4}$$

Fifth step. Calculating the normal matrix of equations: The normal matrix is obtained based on equations (5) and (6). In equation (5), the maximum value of the limit-up is calculated.

$$b = \max\left\{\sum \text{score } d_{ij}^{u}\right\} \tag{5}$$

$$S_{ij} = \left(S_{ij}^{(l)}, S_{ij}^{(u)}\right) = \left(\frac{d_{ij}^{L}}{b}, \frac{d_{ij}^{u}}{b}\right). \tag{6}$$

Sixth step. Calculating the matrix of T equation (total-relation): The matrix of T can also be defined based on the equation (7) so that m should be large enough to provide the calculation the matrix of S. The exponentiation of S should continue until the entries of matrix approaches zero. In this study, $m = 6$ is considered.

$$T = S + S^2 + \ldots + S^m. \tag{7}$$

Based on the feature of hesitant fuzzy set, equation (7) is expanded as equation (8).

$$S + S^2 = \left(Y + Y^2\right) - \left(Y \times Y^2\right)$$
$$S + S^2 + S^3 = \left(\left(S + S^2\right) + Y^3\right) - \left(\left(S + S^2\right) \times Y^2\right)$$

$$\vdots$$

$$S+S^2+\ldots+S^m=\left(\left(Y+Y^2\right)-\left(Y\times Y^2\right)\right)+\ldots+\left(\left(\left(S+S^2+\ldots+S^{m-1}\right)+Y^m\right)\right)$$
$$-\left(\left(S+S^2+S^{m-1}\right)\times Y^m\right). \tag{8}$$

In addition, in equation (7), Ses continue up to the power of m, and a multiplication operation is performed at each stage of exponentiation. The multiplication property of hesitant fuzzy sets is based on equation (9).

$$S_1\times S_2=Y_1\times Y_2. \tag{9}$$

Based on equations (7), (10) and (11) are used to calculate the low and high limit of T matrix.

$$T^L=S^L+\left(S^L\right)^2+\ldots+\left(S^L\right)^m. \tag{10}$$

$$T^U=S^U+\left(S^U\right)^2+\ldots+\left(S^U\right)^m. \tag{11}$$

Therefore, hesitant fuzzy of T matrix is based on the equation (12).

$$T=\begin{bmatrix}\left\{t_{11}^L\ t_{12}^U\right\} & \cdots & \left\{t_{1n}^L\ t_{1n}^U\right\}\\ \left\{t_{21}^L\ t_{22}^U\right\} & & \left\{t_{2n}^L\ t_{2n}^U\right\}\\ \vdots & \ddots & \vdots\\ \left\{t_{n1}^L\ t_{n2}^U\right\} & \cdots & \left\{t_{nn}^L\ t_{nn}^U\right\}\end{bmatrix}. \tag{12}$$

Seventh step. Calculating the row sum (r_{ij}) and column sum (c_{ij}): The row and column sum of the hesitant fuzzy of T matrix is calculated for each index or factor.

Eighth step. Investigating whether the factors are cause or effect: In this step, (r_i-c_i) and (r_i+c_i) are calculated and finally two groups of numbers remain: (r_i+c_i) which indicates the importance of the criteria and (r_i-c_i) indicates whether the criteria are cause or dependent. In general, if (r_i-c_i) is positive, the corresponding criterion is placed in the stimulating (causal) group, and if (r_i-c_i) is negative, the criterion is putin the effect (influential) group.

4. Implemention model

Based on the research process, the factors of green supply chain challenges were identified through thematic analysis. Concepts identified through the literature review and interviews led to 21 challenges based on the Clark and Brown model. The identified challenges are summarized in Table 3 after considering the expert panel.

Based on Table 3, "changes in supply chain distribution networks (A), flexibility reduction of green supply chain (B), the reduction of green sourcing choices (C), low level of financial flow in the market to expand the green supply chain (D), Low level of readiness and inappropriate infrastructure for green supply chain (E), having constraint to substitute green technology (F), having trouble in training green supply chain during supply chain interactions (G), a decrease in green suppliers and green purchasing (H), an increase the price of raw materials of green goods (I), and a decrease in green production due to material and the market fluctuations (J)" are the challenges which have priority for DEMATEL technique respectively.

After identifying the main challenges, the challenges are analyzed based on the successive steps of the hesitant fuzzy DEMATEL technique. Table 4 shows the scores registered by the research experts.

After converting experts' scores to hesitant fuzzy numbers, the matrix of hesitant fuzzy primary equations of Table 5 is obtained.

Based on the research process, first, b must be obtained in order to obtain the hesitant fuzzy normal matrix. To obtain b, first, the row sum of the up limit of the primary relationship matrix is calculated based on Table 6, and the maximum number is considered as b. Then, based on Table 7, the hesitant fuzzy normal matrix is calculated and each of the matrix scores of the primary equation is divided into b.

TABLE 3. Challenging factors affecting green supply chain in COVID-19 conditions.

Row	Main and subordinate challenges	Challenges	Reference
1	The main challenges	Changes in supply chain distribution networks	Palouj *et al.* [29]
2		Flexibility reduction of green supply chain	Palouj *et al.* [29]
3		The reduction of green sourcing choices	Palouj *et al.* [29]
4		Low level of financial flow in the market to expand the green supply chain	Sharma *et al.* [32]
5		Low level of readiness and inappropriate infrastructure for green supply chain	Interview
6		Having constraints to substitute green technology	interview
7		Having trouble in training green supply chain during supply chain interactions	Interview
8		The reduction of green suppliers and green purchases	Interview
9		Increasing the price of raw materials of green goods	Interview
10		Decreasing green production due to material and market fluctuations	Interview
11	Subordinate challenges	Increasing bankruptcy of green supply chain partners	Choi [8]
12		Shortage of physical and financial resources	Leite *et al.* [20]
13		A sharp drop in demand for a long time	Majumdar *et al.* [22]
14		High level of worker layoffs	Nagurney [26]
15		Cooperation problems in the green supply chain	Palouj *et al.* [29]
16		Long-term effect on the activities of final customers	Sen [34]
17		Lack of transportation facilities	Palouj *et al.* [29]
18		Problems in fast communication	Palouj *et al.* [29]
19		Repeated cancellation of green orders by buyers	Palouj *et al.* [29]
20		The tendency to stock up and expect to scarcity of certain materials and goods	Palouj *et al.* [29]
21		Barriers in distribution and green marketing	Interview

After exponentiation of Table 7, the hesitant fuzzy T matrix is obtained as shown in Table 9. It is necessary to use matrix multiplication and consider the features of hesitant fuzzy sets to obtain exponents. For example, the s matrix should be multiplied by itself to obtain $(s_{11}^U)^2$. The column numbers of the hesitant fuzzy relations matrix are respectively $(0, 0.01, 0, 0.11, 0.02, 0, 0.01, 0.08, 0.05, 0.12)$ and the row numbers are respectively $(0, 0.11, 0.1, 0.03, 0.12, 0.01, 0, 0.12, 0.12, 0.12)$.

Therefore, $(s_{11}^U)^2$ is calculated in the following order.

$$\begin{aligned}\left(s_{11}^U\right)^2 &= (0*0) + (0.01*0.11) + (0*0.1) + (0.11*0.03) + (0.02*0.12) + (0*0.01) + (0.01*0)\\ &\quad + (0.08*0.12) + (0.05*0.12) + (0.12*0.12)\\ &= 0 + 0.0011 + 0 + 0.0033 + 0.0024 + 0 + 0 + 0.0096 + 0.006 + 0.0144.\end{aligned}$$

Based on hesitant fuzzy sets, the numbers is calculated together one by one from the first to the last number.

$$\begin{aligned}(s_{11}^U)^2 &= ((0 + 0.0011) - (0*0.0011)) + 0 + 0.0033 + 0.0024 + 0 + 0 + 0.0096 + 0.006 + 0.0144\\ &= ((0.0011 + 0) - (0.0011*0) + 0.0033 + 0.0024 + 0 + 0 + 0.0096 + 0.006 + 0.0144\\ &= ((0.0011 + 0.0033) - (0.0011*0.0033) + 0.0024 + 0 + 0 + 0.0096 + 0.006 + 0.0144\\ &= ((0.0044 + 0024) - (0.0044*0024) + 0 + 0 + 0.0096 + 0.006 + 0.0144 = \ldots = 0.036.\end{aligned}$$

TABLE 4. The scores of factors based on experts' opinions.

	A	B	C	D	E	F	G	H	I	J
A	0	S4, S5, S5, S5, S5	S5, S5, S5, (S5, S6), (S5, S6)	S1, S1, S1, (S2, S3), (S4, S5)	S5, S5, S5, S6, (S6, S7)	S1, S1, S1, S2, S3,	S1, S1, S1, S1, S2,	S6, (S6, S7), S7, S7, S7	(S3, S4), (S6, S7), S7, S7, S7	S6, (S6, S7), S7, S7, S7,
B	S1, S1, S1, S2, S3	0	S4, S5, S5, S5, S6	S1, S1, S1, S1, S2	S5, S5, S5, S5, (S6, S7)	S1, S1, S1, S2, S2	S3, S3, S5, S5, S5	S1, S1, S1, S2, S3	S5, S5, S5, (S5, S6), (S6, S7)	S5, (S5, S6), S6, S7, S7
C	S1, S1, S1, (S1, S2), S2	(S1, S2), S2, S2, S2, S3	0	S1, S1, S1, S2, S2	S3, S3, S5, S5, (S5, S6)	S1, S1, S1, S2, S3	S1, S1, S1, S1, S3	S5, (S6, S7), S7, S7, S7	S6, S6, S7, S7, S7	(S5, S6), (S5, S6), (S5, S6), S7, S7
D	S5, S5, S5, (S5, S6), (S5, S6)	S5, S5, S5, (S5, S6), (S6, S7)	S6, S6, S7, S7, S7	0	S3, S3, S5, S5, S5	(S5, S6), S6, (S6, S7), S7, S7	S3, (S4, S5), S5, S5, S5	S6, S6, S7, S7, S7	S1, S1, S1, S2, S3	S6, S6, S7, S7, S7
E	(S1, S2), (S1, S2), S2, (S2, S3), S3	(S5, S6), (S6, S7), S7, S7, S7	S1, S1, S1, (S1, S2), S2	S1, S1, S1, S2, S2	0	S6, S6, S7, S7, S7	(S3, S4), S4, S4, S4, S4	S4, S5, S5, S5, S6	(S3, S4), S5, S5, S5, (S6, S7)	(S6, S7), S7, S7, S7, S7
F	S1, S1, S1, S1, S2	S5, S5, S5, (S5, S6), (S6, S7)	S3, S4), S5, S5, S5, (S6, S7)	S1, S1, S1, S2, S2	S6, S6, S7, S7, S7	0	S1, S2), (S1, S2), S2, S2, S3	S1, S1, S1, S2, S2	S3, S3, S5, S5, S5	(S6, S7), S7, S7, S7, S7
G	S1, S1, S1, S2, S3	S4, S4, S4, S4, S5	(S1, S2), (S1, S2), S2, (S2, S3), S3	S1, S1, S1, S1, S2	S6, S6, S7, S7, S7	S5, (S6, S7), S7, S7, S7	0	(S1, S2), (S1, S2), S2, (S2, S3), S3	(S1, S2), S2, S2, S2, S3	(S6, S7), (S6, S7), (S6, S7), (S6, S7), S7
H	(S3, S4), S4, S4, S4, (S4, S5)	(S3, S4), S4, S4, S5, S5	(S6, S7), S7, S7, S7, S7	S1, S1, S1, S2, S2	S1, S1, S1, S2, S3	S1, S1, S1, S2, S3	S1, S2), (S1, S2), S2, (S2, S3), S3	0	S5, S5, S5, (S5, S6), (S6, S7)	S5, (S6, S7), S7, S7, S7
I	S3, S3, S3, S3, S3	(S3, S4), S4, S4, S5, S5	(S3, S4), (S6, S7), S7, S7, S7	(S1, S2), (S1, S2), S2, (S2, S3), S3	S1, S1, S1, S2, S3	(S1, S2), (S1, S2), S2, (S2, S3), S3	(S1, S2), (S1, S2), S2, (S2, S3), (S2, S3)	(S3, S4), (S6, S7), S7, S7, S7	0	(S6, S7), S7, S7, S7, S7
J	(S6, S7), (S6, S7), S7, S7, S7	(S6, S7), S7, S7, S7, S7	S6, S6, S7, S7, S7	S1, S1, S1, S2, S3	S3, S3, S3, (S3, S4), (S3, S4)	S3, S3, S3, S3, S3	S1, S1, S1, S2, S3	(S3, S4), S5, S5, S5, (S6, S7)	(S1, S2), S2, S2, S2, S3	0

The same calculations are done for all the matrix entries of the second power. For other exponents, the same operation is done entry by entry. Table 8 shows the matrix to the power of 6 of high limit to reduce the volume.

Given that S^m should be large enough that the next power has a negligible effect on the sum operation in calculations, the high limit of the sixth power is shown in Table 8, which indicates numbers with three decimal places and the result is almost shifted to four decimal places in the seventh power. Therefore, powers more than 6 do not have much effect on the calculations.

The next step is to calculate t_{11} and $t_{11} = (s_{11}^L) + (s_{11}^L)^2 + (s_{11}^L)^3 + \ldots + (s_{11}^L)^6$. The calculation of t_{11} should also be added together based on the features of the hesitant fuzzy set. For example, $t_{11} = 0 + 0.037 + 0.019 + 0.012 + 0.006 + 0.005$ thus, after the calculations, it is 0.077 as shown in Table 9.

After obtaining the hesitant fuzzy T matrix, the row and column sum of each factor should be calculated to identify the cause and effect factors. Table 10 shows $(r + c)$ and $(r - c)$ optimistically and pessimistically.

TABLE 5. The matrix of hesitant fuzzy primary relations.

	A		B		C		D		D	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0	0	0.87	0.53	0.86	0.76	0.28	0.14	1	0.8
B	0.12	0.02	0	0	1	0.71	0.02	0	1	0.8
C	0.03	0	0.16	0.02	0	0	0.04	0	0.75	0.42
D	0.92	0.67	1	0.76	1	1	0	0	0.8	0.45
E	0.18	0.03	1	1	0.03	0	0.04	0	0	0
F	0.02	0	1	0.76	1	0.7	1	0	1	1
G	0.12	0.02	0.77	0.49	0.18	0.03	0.02	0	1	1
H	0.62	0.4	0.76	0.47	1	1	0.04	0	0.12	0.02
I	0.4	1	0.68	0.42	1	1	0.18	0.03	0.12	0.02
J	1	1	1	1	1	1	0.12	0.02	0.44	0.16
	F		G		H		I		J	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0.12	0.02	0.02	0	1	1	1	1	1	1
B	0.04	0	0.8	0.47	0.12	1	1	0.76	1	1
C	0.12	0.02	0.1	0.02	1	1	1	1	1	1
D	1	1	1.41	0.51	1	1	0.12	0.02	1	1
E	1	1	0.58	0.37	1	0.67	1	0.7	1	1
F	0	0	0.15	0.02	0.04	0	0.8	0.45	1	1
G	1	1	0	0	0.18	0.03	0.7	2.02	1	1
H	0.12	0.02	0.18	0.03	0	0	1	0.76	1	1
I	0.18	0.03	0.15	0.01	1	1	0	0	1	1
J	0.4	0.1	0.12	0.02	1	0.7	0.16	0.02	0	0

TABLE 6. Calculation of the maximum row score of factors.

Factors	Total score	b
A	6.15	8.25
B	5.09	
C	4.20	
D	8.25	
E	5.84	
F	6.01	
G	4.97	
H	4.83	
I	4.71	
J	5.24	

The numbers in the $(r - c)$ column are considered as the effect if they are negative and as the cause if they are positive. Therefore, in the optimistic state, six factors and in the pessimistic state, five factors are considered as influential or effect.

TABLE 7. Matrix of hesitant fuzzy normal equation.

	A		B		C		D		E	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0	0	0.11	0.06	0.1	0.09	0.03	0.02	0.12	0.1
B	0.01	0	0	0	0.12	0.09	0	0	0.12	0.1
C	0	0	0.02	0	0	0	0.01	0	0.09	0.05
D	0.11	0.08	0.12	0.09	0.12	0.12	0	0	0.1	0.05
E	0.02	0	0.12	0.12	0	0	0.01	0	0	0
F	0	0	0.12	0.09	0.12	0.08	0.12	0	0.12	0.12
G	0.01	0	0.09	0.06	0.02	0	0	0	0.12	0.12
H	0.08	0.05	0.09	0.06	0.12	0.12	0.01	0	0.01	0
I	0.05	0.12	0.08	0.05	0.12	0.12	0.02	0	0.01	0
J	0.12	0.12	0.12	0.12	0.12	0.12	0.01	0	0.05	0.02

	F		G		H		I		J	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0.01	0	0	0	0.12	0.12	0.12	0.12	0.12	0.12
B	0.01	0	0.1	0.06	0.01	0.12	0.12	0.09	0.12	0.12
C	0.01	0	0.01	0	0.12	0.12	0.12	0.12	0.12	0.12
D	0.12	0.12	0.17	0.06	0.12	0.12	0.01	0	0.12	0.12
E	0.12	0.12	0.07	0.05	0.12	0.08	0.12	0.08	0.12	0.12
F	0	0	0.02	0	0.01	0	0.1	0.05	0.12	0.12
G	0.12	0.12	0	0	0.02	0	0.08	0.25	0.12	0.12
H	0.01	0	0.02	0	0	0	0.12	0.09	0.12	0.12
I	0.02	0	0.02	0	0.12	0.12	0	0	0.12	0.12
J	0.05	0.01	0.01	0	0.12	0.08	0.02	0	0	0

TABLE 8. Matrix of the sixth power of the high limit ($S6$).

	A	B	C	D	E	F	G	H	I	J
A	0.005	0.009	0.009	0.002	0.007	0.005	0.004	0.009	0.009	0.011
B	0.004	0.007	0.008	0.001	0.006	0.004	0.003	0.008	0.007	0.009
C	0.003	0.006	0.006	0.001	0.005	0.003	0.003	0.006	0.006	0.008
D	0.007	0.012	0.013	0.002	0.009	0.006	0.006	0.013	0.012	0.015
E	0.005	0.009	0.009	0.002	0.007	0.004	0.004	0.009	0.009	0.011
F	0.005	0.009	0.01	0.002	0.007	0.005	0.004	0.01	0.009	0.012
G	0.004	0.007	0.008	0.001	0.006	0.004	0.003	0.008	0.007	0.009
H	0.004	0.007	0.007	0.001	0.005	0.004	0.003	0.007	0.007	0.009
I	0.004	0.007	0.007	0.001	0.005	0.004	0.003	0.007	0.007	0.008
J	0.004	0.008	0.008	0.001	0.006	0.004	0.004	0.008	0.008	0.009

5. Implication of finding

In Figures 2, "Di+Ri" signifies the importance of the challenges, and "Di−Ri" specifies if the challenges are "causes" or "effects". Generally, the challenge is grouped as the "cause" or "effect" when "Di−Ri" takes, respectively, positive and negative values. As depicted in Figure 2, four post-COVID-19 green supply chain

TABLE 9. Hesitant fuzzy T matrix.

	A		B		C		D		E	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0.077	0.063	0.226	0.013	0.226	0.178	0.056	0.021	0.206	0.135
B	0.068	0.056	0.114	0.072	0.211	0.166	0.024	0.001	0.195	0.133
C	0.059	0.049	0.117	0.054	0.104	0.071	0.03	0.001	0.146	0.068
D	0.186	0.136	0.729	0.171	0.279	0.216	0.048	0.002	0.244	0.12
E	0.091	0.053	0.236	0.179	0.151	0.093	0.047	0.001	0.11	0.056
F	0.079	0.039	0.24	0.142	0.244	0.139	0.144	0	0.22	0.15
G	0.066	0.071	0.195	0.143	0.138	0.107	0.033	0.001	0.198	0.165
H	0.136	0.092	0.181	0.103	0.219	0.179	0.032	0.002	0.099	0.034
I	0.105	0.159	0.17	0.104	0.216	0.192	0.041	0.002	0.095	0.042
J	0.165	0.144	0.215	0.159	0.226	0.18	0.037	0.002	0.145	0.065

	F		G		H		I		J	
	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit	High limit	Low limit
A	0.075	0.024	0.065	0.016	0.236	0.208	0.239	0.187	0.265	0.221
B	0.073	0.027	0.138	0.07	0.128	0.192	0.215	0.163	0.24	0.211
C	0.056	0.011	0.049	0.007	0.201	0.172	0.197	0.157	0.219	0.182
D	0.202	0.144	0.233	0.076	0.262	0.212	0.202	0.112	369	0.244
E	0.17	0.135	0.122	0.063	0.218	0.152	0.236	0.148	0.262	0.213
F	0.08	0.023	0.097	0.016	0.154	0.079	0.22	0.105	0.272	0.193
G	0.167	0.143	0.052	0.018	0.124	0.106	0.181	0.3	0.239	0.23
H	0.054	0.007	0.061	0.008	0.113	0.08	0.211	0.139	0.235	0.188
I	0.063	0.009	0.061	0.008	0.206	0.194	0.11	0.075	0.236	0.202
J	0.095	0.019	0.061	0.013	0.214	0.154	0.15	0.076	0.153	0.097

TABLE 10. Matrix of influential and effectiveness of factors.

Challenges	r		c		$r+c$		$r-c$	
	High limit	Low limit	High limit	Low limit	Optimistic	Pessimistic	Optimistic	Pessimistic
A	1.67	1.18	1.03	0.86	2.7	2.04	0.64	0.33
B	1.41	1.09	1.97	1.26	3.38	2.35	−0.57	−0.17
C	1.18	0.77	2.01	1.52	3.19	2.29	−0.84	−0.75
D	2.25	1.43	0.49	0.03	2.75	1.46	1.76	1.4
E	1.64	1.09	1.66	0.97	3.3	2.06	−0.02	0.13
F	1.75	0.89	1.04	0.54	2.79	1.43	0.72	0.34
G	1.39	1.28	0.94	0.3	2.33	1.58	0.45	0.99
H	1.34	0.83	1.86	1.55	3.19	2.38	−0.52	−0.72
I	1.3	0.99	1.96	1.46	3.25	2.45	−0.66	−0.48
J	1.46	0.91	2.44	1.98	3.9	2.89	−0.97	−1.07

challenges are optimistic "causes" and the remaining challenges are "effects". Likewise, five post-COVID-19 green supply chain challenges are pessimistic "causes" and the remaining challenges are "effects" (Fig. 2).

During the first stage, 21 green supply chain challenges in the post-coronavirus era were identified based on the theme analysis method, which are divided into 11 sub-challenges and 10 main ones. The sub-challenges are

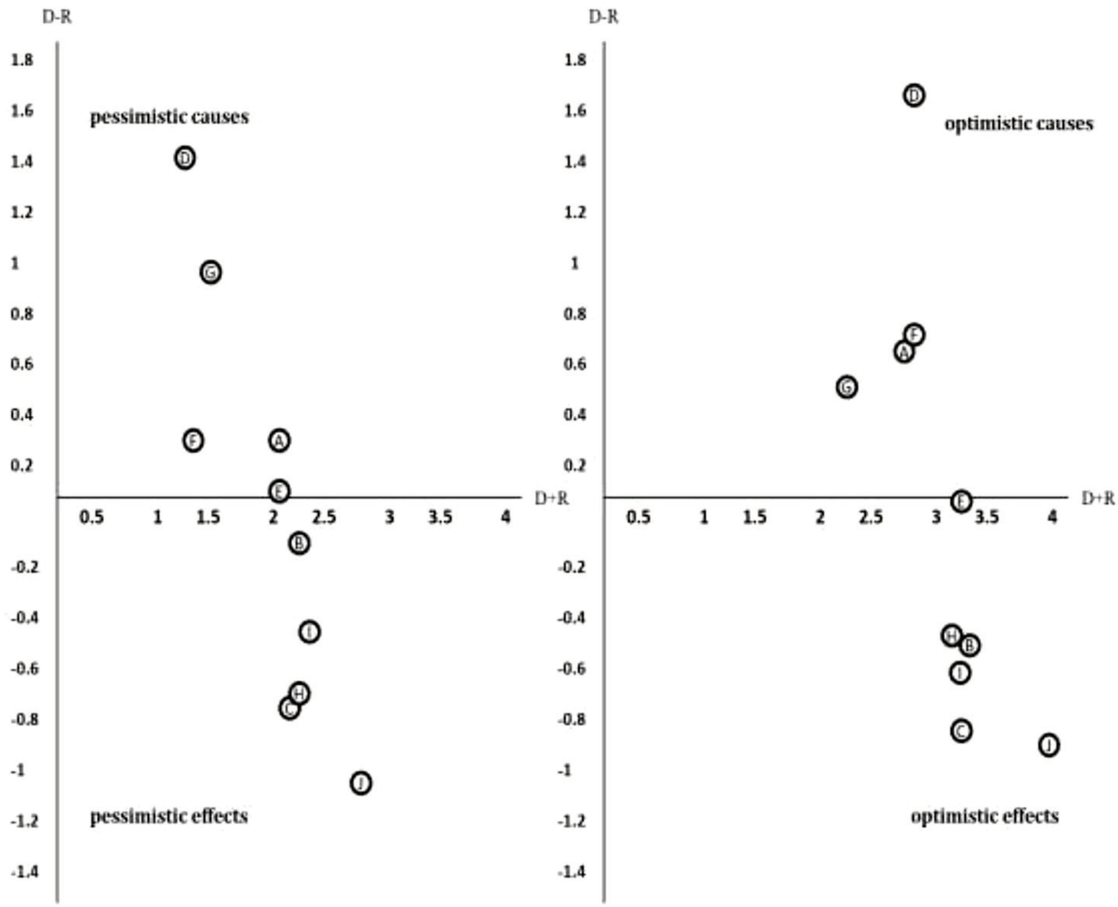

FIGURE 2. Cause and effect diagram in optimistic and pessimistic mode.

regarded as less significant, while the main ones have high significance. Thus, the main challenges were analyzed during the second stage utilizing the hesitant fuzzy DEMATEL technique.

The evaluated challenges create various obstacles at the national and global level by disrupting the supply chain and slowing or destroying all of the related activities. The obtained results can be highly useful and efficient for the situation where a new crisis is created at the world level. Therefore, companies and organizations can apply the achieved results to avoid being affected by the challenges. Causal challenges create obstacles in the globalization of the supply chain in addition to its disruption at the national level. In addition, each of these challenges alone can prevent globalization. Thus, they include the supply chain at the national and global levels.

In the optimistic case "changes in supply chain distribution networks, low level of financial flow in the market to expand the green supply chain, having constraints to substitute green technology and having trouble in training green supply chain during supply chain interactions" are known as the causes and "flexibility reduction of green supply chain, the reduction of green sourcing choices, low level of readiness and inappropriate infrastructure for green supply chain, the reduction of green suppliers and green purchases, increasing the price of raw materials of green goods and decreasing green production due to material and market fluctuations" are known as the effects.

In the pessimistic case, “changes in supply chain distribution networks, low level of financial flow in the market to expand the green supply chain, low level of readiness and inappropriate infrastructure for green supply chain, having constraints to substitute green technology and having trouble in training green supply chain during supply chain interactions” are known as the causes, while “flexibility reduction of green supply chain, the reduction of green sourcing choices, having constraints to substitute green technology, the reduction of green suppliers and green purchases, increasing the price of raw materials of green goods and decreasing green production due to material and market fluctuations” are known as the effects.

6. Conclusion

The present study analyzed the challenges of the green supply chain in the post-COVID-19 period. Since the green supply chain is very important for companies and organizations, the analysis of COVID-19 challenges affecting the green supply chain should be highlighted.

The challenges are divided into two main and subordinate parts in this study. The main challenges include “changes in supply chain distribution networks, flexibility reduction of green supply chain, reduction of green sourcing choices, low level of financial flow in the market to expand the green supply chain, having constraints to substitute green technology, having trouble in training green supply chain during supply chain interactions, reduction of green supplier and green purchase, increasing the price of raw materials of green goods and decreasing green production due to material and market fluctuations. Since controlling the main challenges reinforce the green supply chain, they are significant for the system.

It is necessary to examine the position of the challenges besides identifying them. Therefore, the challenges of this study are presented in two parts of cause and effect in optimistic and pessimistic states. Causal factors have more effectiveness because of their nature so that their control is very important. However, effect factors are more influential. In optimistic state, the challenges of “changes in supply chain distribution networks, low level of financial flow in the market to expand the green supply chain, having constraints to substitute green technology and having trouble in training green supply chain during supply chain interactions” affect other challenges and should be controlled. Moreover, in the pessimistic state, the challenge of “low level of readiness and inappropriate infrastructure for green supply chain” are recognized as the cause. In dealing with green supply chain challenges, causal challenges are more important, since the driving force on other challenges is also controlled and the system reaches balance.

Among the causal challenges, low level of financial flow in the market to expand the green supply chain, having trouble in training green supply chain during supply chain interactions, having constraints to substitute green technology, changes in supply chain distribution networks, and low level of readiness and inappropriate infrastructure for green supply chain should be highlighted.

Changes in supply chain distribution networks inflict flexibility reduction of the green supply chain, reduce (the count of) green suppliers and green purchasers, and Decreasing green production due to material and market fluctuations. Likewise, a low level of financial flow in the market to expand the green supply chain reduces the count of green sourcing choices, lessens the level of readiness and inappropriate infrastructure for green supply chain, reduces (the count of) green suppliers and green purchasers, and downsizes green production due to material and market fluctuations.

Having constraints to substitute green technology reduces the level of readiness and inappropriate infrastructure for green supply chain and (the count of) green suppliers and green purchasers. Similarly, the problem of green supply chain training in supply chain interactions reduces the level of readiness and inappropriate infrastructure for green supply chain and reduces (the count of) green suppliers and green purchasers.

Pessimistically, a “low level of readiness and inappropriate infrastructure for green supply chain” was identified as a “casual” challenge. The reason is that a negative approach to the “post-COVID-19 green supply chain challenges” has pessimistically added a new challenge to the “cause” group; at the same time, since “casual” challenges need to be critically controlled, the pessimistic view adds challenge compared to the optimistic view.

Simply put, the new challenge added to the "cause" group in the pessimistic view takes greater importance (by priority), compared to when grouping it as "effects". Thus, the challenge "low level of readiness and inappropriate infrastructure for green supply chain" inflicts flexibility reduction of the green supply chain, reduces the count of green sourcing choices, causes constraints in substituting green technology, reduces (the count of) green suppliers and green purchasers, and increases the price of raw materials of green goods.

The green supply chain encompasses three levels: (1) the supplier(s), (2) production line(s), and (3) distribution and consumption networks. Thus, the challenges need to be evaluated based on these levels, where causal challenges are prioritized to assess their impacts on the green supply chain's levels. The challenge of a "low level of financial flow in the market to expand the green supply chain" affects all three green supply chain levels, where it impacts first target consumers.

The financial flow oppositely flowing in the green supply chain first affects "production line(s)" and then the suppliers. Since all three levels of green supply chain are trained, the challenge "the problem of green supply chain training in supply chain interactions" affects all the levels. Similarly, the challenge of "having constraints to substitute green technology" is influential at both production and supplier levels. The challenge of "changes in the distribution network" fists influence the consumers, then affects both production and supplier levels and ultimately targets the entire green supply chain. The challenge of "low level of readiness and inappropriate infrastructure for green supply chain" affects all the green supply chain levels exclusively. Taking note of the above, it is crucial to control all the challenges that affect the green supply chain and its levels.

The results of this study are consistent with those reported by Palouj *et al.* [29] in changing the supply chain distribution networks, Flexibility reduction of green supply chain, and The reduction of green sourcing choices. However, other challenges identified by Palouj *et al.* [29] are classified as sub-challenges, which do not lead to the same result in terms of significance. Further, Palouj *et al.* [29] investigated the challenges in the supply chain, which were examined here. The results of this study are in line with those presented by Sharma *et al.* [32]. The low level of financial flow in the market to expanding the green supply chain is classified as main challenge. However, those identified in other studies are classified as sub-challenges and do not present the same result. Here, six new main challenges were proposed due to the green supply chain, which was mostly emphasized before.

6.1. Research contribution

The research's contribution to the literature can be appraised from the facets below:

A comprehensive review of post-COVID-19 green supply chain challenges: This research identified seven new challenges, of which six are main challenges. The research further assessed the effects of these challenges on green supply chain. By comparison, previous research has overall studied the challenges, but not in connection with the green supply chain.

A hesitant fuzzy DEMATEL approach proposed with optimistic and pessimistic modes: This is a new approach that reflects human uncertainties in the membership function. As such, the experts can themselves incorporate doubts into the membership function, thereby allowing better dealing with uncertainty. Innovatively, this approach was proposed in this research with optimistic and pessimistic modes.

6.2. Limitations

Since this research enrolled five experts, the results are ungeneralizable to the green supply chain in diverse industries. Thus, the post-COVID-19 green supply chain challenges need to be assessed with more experts in diverse industries. Eventually, the results of this research need to be validated by other research.

6.3. Suggestions for further research

The present study analyzed the main challenges and provided the results. It is suggested that some preventive measures to face supply chain challenges should be evaluated in future studies Finally, the challenges in post-

COVID-19 condition in different parts of the supply chain should be evaluated and preventive measures should be taken.

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