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Structuring the Affecting Indicators on the Sustainable Food Supply Chain Performance based on Fuzzy Cognitive Mapping and Fuzzy DEMATEL

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ABSTRACT

Today, the production and services field faces a change in the competition pattern among independent companies and supply chains. The food supply chain is among the complex supply chains with special characteristics that can toughly be adapted to general evaluation systems. The current research aims to determine the effective indicators for evaluating the performance of the sustainable food supply chain. This research is descriptive-survey in terms of method and practical in terms of purpose. In line with the research implementation, based on the study of the theoretical foundations and the background of the research conducted concerning the effective indicators in evaluating the performance of the sustainable supply chain, the effective criteria were extracted and given to 25 research experts in the form of a questionnaire. Finally, to investigate the relationships between these 26 basic criteria, another questionnaire was prepared and given to the research experts. The final factors were structured based on the answers received and using the methods of fuzzy cognitive mapping and fuzzy DEMATEL. Regarding the centrality criterion in the fuzzy cognitive mapping method, the factors "income distribution, sustainable investment, and average annual training time of employees" have the most centrality, so they were recognized as the main factors influencing the performance evaluation of the sustainable food supply chain.

1. Introduction

Today, most people in the world pay more attention to protecting the environment and biological resources. This positive sensitivity has intensified to such an extent that even the owners of industries are trying to use it to take a practical step toward accepting their products to customers and using environmental considerations as a competitive advantage. Most countries have concluded that development becomes sustainable and continuous when the utmost care is taken when using limited and non-renewable resources, and they try to protect these limited resources. Governments are also trying to act in this direction by

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establishing more environmental laws compared to the past. Under the influence of the globalization of the economy, the requirement of sustainable development, and triple responsibility for companies, new requirements have been raised for the performance of supply chain management, which requires supply chain management to target not only economic performance but also social and environmental performance. Consider the environment and manage the supply chain based on sust ainability. Therefore, sustainable supply chain management should comprehensively consider the three dimensions of economy, environment, and society in sustainable development to manage logistics, information flow, and capital flow in the supply chain and their cooperation [31]. Making strategic decisions in supply chain management is an issue that requires a framework to be based on relevant standards. If no suitable model exists in this field, supply chain management cannot have relevant factors for proper evaluation. For this purpose, organizations should consider a model to solve daily problems to have the most effective problem analysis with the least involvement .Therefore, to evaluate the supply chain performance, it is necessary to carry out a study to identify and evaluate the critical dimensions in line with the supply chain operational efficiency in areas such as employee skills development, emissions reduction, resources management, transportation optimization, and customer satisfaction. Not paying attention to these factors results in more issues and problems [28]. At the beginning of the 21st century, during the period of globalization, outsourcing of key activities, dialogue, and cooperation of stakeholders, reverse logistics, development of social responsibility of the organization, development of advanced information technology, security issues, etc.; most organizations figured out the necessity of considering a general view of business activities, especially in the field of supply chain and its management.

One of these current concepts is the concept of sustainable supply chain management as an important part of efforts to build a sustainable industrial system. Market competition is no longer between companies but between supply chains. Many specialists and organizational researchers attach great importance to supply chain management. At the same time, with the continuous improvement of the global industrial structure, the pattern of economic development dominated by resources and industries has created many adverse effects on the environment and society and no longer meets the requirements of sustainable development goals [35]. According to the World Commission on Environment and Development, "sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." How to achieve sustainable development has become a global challenge. Simultaneously with the expansion of the concept of supply chain management in various industries, evaluating the supply chain performance has also been taken into consideration.

In this regard, using appropriate tools and having a performance scale in different units makes it possible for the organization to know its performance position compared to the performance range of other competitors. One of the critical factors in the success of organizations is to measure the performance of the supply chain by considering economic, environmental, and social aspects. However, despite increasing efforts in assessing the performance of sustainable supply chains, the impact of disruption on it remains unknown to date. In addition, to benefit from competitive advantages in today's markets, paying attention to sustainability factors in evaluating supply chain performance is inevitable. Therefore, there is a need to develop performance evaluation approaches and tools to improve sustainable supply chain performance. In the last two decades, the number of proposed methods to evaluate supply chain performance has grown increasingly [16, 17, 20]. The following research questions are presented as follows.

- What are the effective indicators in evaluating the performance of a sustainable food supply chain?
- What is the relationship between the effective indicators in evaluating the performance of the sustainable food supply chain?

2. Theoretical Background

Before the 1960s, development efforts aimed to increase economic efficiency and national wealth in countries. However, from that decade onwards, the discussion of development found more comprehensive boundaries and non-economic considerations such as human growth and development, justice, and

Preservation of human and environmental values were also included. Also, models of modest growth were raised with topics such as poverty alleviation and fair income distribution. On the other hand, global thinking in development and growth replaced the limited thinking within borders, and countries were encouraged to think about international development. This development promised the improvement of the whole planet so that the relationship between the environment, Life, and economic growth in the wide world became increasingly important. From the 1980s onwards, in international circles and assemblies, the issue of sustainable development replaced economic development. The discussion of sustainable development was initially related to two major topics. One is the non-renewable resources in the world, such as fossil resources, and the other is the environmental pollution and pollution of the planet. It can be said that these two factors were the first and most important factors in raising the issue of sustainable development in the world. The current course of human activities is such that it has severe adverse effects on the planet. The growing consumption of fossil fuels, underground resources, and environmental damage has created a trend that, if continued, the resulting growth and development will be unstable. Today, the term sustainable development has become widely discussed in conferences, research institutes, and international institutions, especially countries' economic growth and development planners. It seems that sustainable development has gained broad and widespread support that the initial concepts of development (such as the development of environmental resources) did not have, and it has been expressed as a model for development in the last years of the 20th century, to the extent that It has become a familiar and customary phrase [32,10]. The design of the supply chain performance evaluation model is one of the essential decisions in supply chain management, significantly affecting the return on investment and overall performance, considering that most of the current organizations' goals are the sustainable development of the supply chain network and the change of product design to reduce risk and energy consumption and thus make it greener [24,7,9]. A sound supply chain performance evaluation system can reveal the operation performance of the entire supply chain and supply chain members: if the logistics processes among the companies are reasonable and whether the quality and costs of the supply chain products are ideal. For example, if a supplier in the supply chain is evaluated individually, the lower the product price, the better. However, considering that such cheap raw materials compromise the quality of the final product, increase production costs, and harm the overall profit of the entire supply chain, choosing this supplier is a good decision. It will not be [23,3,6].

When Kumar [19] built the sustainable supply chain evaluation index model, they divided economic performance into product cost, resource utilization, profit margin, and other measurement indicators. The ultimate goal of sustainable development is to achieve harmony between humans and nature. In their article, Desidro [8] discussed social sustainability indicators in five areas (equality of rights, health, education, life-housing, and population) and stated that there is a relationship between financial activities and social sustainability indicators.Furthermore, sustainability indicators were evaluated in the supply chain of several companies. In their study, Asgharizadeh [1] have developed a sustainable supply chain network design model. They have assumed that organizations must consider all related supply chain activities to ensure that demand for a product is met. In this model, organizations are multi-criteria decision-makers who seek to minimize construction and operation costs and minimize environmental costs. The total cost related to production releases includes the cost per unit of each release, considering that each standard's release can be distinct. In the following, the background of the research is presented in the form of a Table 1.

The research presented in this paper significantly contributes to the understanding and evaluation of sustainable performance in the food supply chain by identifying and structuring the effective indicators that influence this performance. The following points highlight the contributions of this study and provide comparisons with other approaches in the field:

This study successfully identifies 26 critical indicators across economic, social, and environmental dimensions that can be used to evaluate the sustainable performance of the food supply chain. Unlike some previous studies that focus on a limited set of criteria, this research offers a comprehensive framework that integrates various dimensions, making it applicable to a wider range of contexts within the food industry.

The application of fuzzy cognitive mapping and fuzzy DEMATEL techniques in structuring the relationships among the identified indicators is a novel approach in this context. These methods allow for a nuanced understanding of the interdependencies between indicators, which is often overlooked in traditional evaluation methods. By quantifying the degree of influence among factors, this research provides a more robust analytical framework.

Table 1. Background of related research

No	Authors	Research Title	Applied Methods and Conclusions
1	[15]	A practical method for measuring supply chain sustainability performance with incomplete information	This paper aims to develop a new methodology that assesses the entire supply chain's environmental, social, and economic sustainability, from raw material suppliers to consumers to reverse logistics providers. By combining content analysis, expert evaluation, fuzzy Shannon entropy, and fuzzy TOPSIS, they developed a new approach for measuring end-to-end supply chain sustainability performance. Researchers can use the proposed approach to measure sustainability, increase the transparency of their value chain, and identify potential environmental and social issues throughout their supply chain.
2	[21]	Defining and measuring supply chain performance: a systematic literature review	This article provides an overview of the methods used in supply chain performance measurement. Furthermore, it examines the methods used for data collection, approaches, and data analysis techniques to measure supply chain performance. It also shows that to collect data. Most authors have used statistical analysis methods, especially SEM, to review and analyze the data of the results. However, BSC, SCOR, and HPI are the most commonly applied approaches in the reviewed works, and AHP, DEA, and fuzzy logic are the most cited.
3	[16]	Assessing sustainable, flexible supply chains in public transportation: a two-stage DEA approach	This study aims to address the issue of evaluating the efficiency of supply chain sustainability and flexibility by proposing a two-stage data envelopment analysis model based on fuzzy probability (DEA) as an advanced and accurate approach to evaluating the performance of sustainable and flexible supply chains.
4	[10]	Evaluation of the performance of the sustainable supply chain management system in the automotive industry using artificial intelligence	The main objective of this paper is to develop a performance evaluation model that links specific problems with the most relevant key performance indicator for each supply chain management subsystem. This paper concludes with a graphical user interface based on neural networks using a multilayer perceptron artificial intelligence algorithm where the most reliable key performance indicator for each problem is selected. This aspect provides a highly innovative contribution to solving the supply chain management problems presented by organizations by allowing them to comprehensively track, communicate, analyze, and improve the supply chain management system and ensure the overall sustainability of the system.
5	[29]	Evaluation of food supply chain performance using hybrid fuzzy MCDM technique	In this study, six crucial performance measures and their key indicators have been identified. In addition, the fuzzy decision-making testing and evaluation (DEMATEL) approach was used to verify the interrelationships between the identified performance measures and their related indicators. This study prioritizes the performance criteria or criteria of the food supply chain with the help of the mixed multi-criteria decision-making (MCDM) technique. It uses food supply chain performance indicators that are comprehensive and reflect important characteristics. The results of three essential performance measures (i.e. "customer service", "quality" and "supply chain efficiency") with five important key indicators as "customer satisfaction", "customer complaints", "on-time delivery", "reverse logistics" and "process quality."

The study emphasizes the importance of localizing sustainability indicators to fit the specific context of Iran's food industry. By involving local experts in the identification and validation of factors, the research ensures that the proposed framework is relevant and applicable to the region. This localized approach contrasts with many global studies that may not account for regional differences in food supply chain dynamics.

The research classifies indicators into three general dimensions (economic, social, and environmental), which allows for a balanced evaluation of sustainable performance. This holistic view is advantageous compared to approaches that may prioritize one dimension over others, thereby providing a more integrated perspective on sustainability.

The computational efficiency of the proposed method is enhanced through the use of fuzzy cognitive mapping and fuzzy DEMATEL. These methods require less data input compared to traditional quantitative models, making them more accessible for practitioners who may not have extensive data resources. Additionally, the fuzzy nature of the analysis allows for better handling of uncertainty and ambiguity in the data, which is common in real-world applications.

3. Research Method

In terms of purpose, this research is included in the category of applied research, and in terms of data collection, it is considered a descriptive-survey type of quantitative research. In order to conduct this research, a questionnaire was used to obtain information, and after collecting the required information, the fuzzy cognitive mapping method and fuzzy DEMATEL technique were used for data analysis. In this research, 25 experts have been used, including university experts active in sustainable development and experts from Kale company, who cooperated in completing the questionnaires at different stages of the research.

The experts were requested to select from among 45 indicators influencing the performance of the sustainable supply chain, which were extracted concerning the discussion of sustainability through the collection of data obtained from the review of research literature and articles published in authoritative journals and library studies and interviews. For this purpose, a questionnaire was distributed among experts, and the opinions determined an average of 26 final indicators for the continuation of the research. In the following, the fuzzy DEMATEL technique is explained.

The Fuzzy DEMATEL Method

The Decision Making Trial and Evaluation Laboratory (DEMATEL) method is presented in 1973 [14], as a kind of structural modeling approach about a problem. DEMATEL is an extended method for building and analyzing a structural model for analyzing the influence relation among complex criteria. However, making decisions is very difficult in fuzzy environment to segment complex factors. The current study uses the fuzzy DEMATEL method to obtain a more accurate analysis. The steps of Fuzzy DEMATEL as follow:

Step 1: Set up fuzzy matrix which is shown by $\tilde{z}^p$ and called Assessment Data Fuzzy Matrix.
For forming fuzzy matrix, we use fuzzy linguistic variables as shown in Table 2.

Table 2. The fuzzy linguistic scale

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0.00, 0.00, 0.25)
Very low influence (VL)	(0.00, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.00)
Very high influence (VH)	(0.75, 1.00, 1.00)

Next, it must acquire and average the assessment of executives' preferences using

$$\tilde{z} = \frac{(\tilde{z}^1 \oplus \tilde{z}^2 \oplus \ldots \oplus \tilde{z}^p)}{p} \quad (1)$$

Then, fuzzy matrix z̃ is produced which is shown as

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

which is called initial direct-relation fuzzy matrix. In this matrix, $\tilde{z}_{ij} = (i_{ij}, m_{ij}, u_{ij})$ are triangular fuzzy numbers and $\tilde{z}_{ij}$ = (i = 1,2,…,n) will be regarded as triangular fuzzy number (0, 0, 0) whenever is necessary. Then, by normalizing initial direct-relation fuzzy matrix, we acquire normalized direct-relation fuzzy matrix x̃ by using

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{21} & 0 & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn} \end{bmatrix} \quad (3)$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (4)$$

$$\mathrm{R} = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} u_{ij}\right) \quad (5)$$

It is assumed at least one i such that $\sum_{j=1}^{n} u_{ij} < \mathrm{r}$

After computing the above matrices, the total-relation fuzzy matrix $\tilde{T}$ is computed. Total-relation fuzzy matrix is defined as (Lin & Wu, 2004)

$$\tilde{T} = \lim_{K \to \infty}(\tilde{X}^1 + \tilde{X}^2 + \cdots + \tilde{X}^K) \quad (6)$$

Then,

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{21} & 0 & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix} \quad (7)$$

In which $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$ and

$$[l''_{ij}] = X_l \times (I - X_l^{-1}),\ [m''_{ij}] = X_l \times (I - X_m^{-1}),\ [u''_{ij}] = X_l \times (I - X_u^{-1}) \quad (8)$$

By producing matrix $\tilde{T}$, then it is calculated $(\tilde{D}_i + \tilde{R}_i)$ and $(\tilde{D}_i - \tilde{R}_i)$ in which $\tilde{D}_i$ and $\tilde{R}_i$ are the sum of row and the sum of columns of $\tilde{T}$ respectively. To finalize the procedure, all calculated $\tilde{D}_i + \tilde{R}_i$ and $\tilde{D}_i - \tilde{R}_i$ are defuzified through suitable defuzification method. Then, there would be two sets of numbers: $(\tilde{D}_i + \tilde{R}_i)^{def}$ which shows how important the strategic objectives are, and $(\tilde{D}_i - \tilde{R}_i)^{def}$ which shows which strategic objective is cause and which one is effect. Generally, if the value $(\tilde{D}_i - \tilde{R}_i)^{def}$ is positive, the objectives belong to the cause group, and if the value $(\tilde{D}_i - \tilde{R}_i)^{def}$ is negative, the objectives belong to the effect group.

4. Case Study

In this research, experts were asked to select from among 45 indicators that influence the performance of the sustainable supply chain, which were extracted concerning the discussion of sustainability through the collection of data from the review of research literature and articles published in reputable journals, library studies, and interviews. For this purpose, the average of their opinions determined the final 26 indicators for the continuation of the research in such a way that the average scores of the selected indicators are higher than the average (average scores <3) [11,12]. The selected final indicators are presented in Table 3.

In this research, the type of variables has been investigated and analyzed using the fuzzy DEMATEl technique. In this research, the remaining 26 factors were provided to the experts after confirming the experts' opinions separately in each of the three dimensions of supply chain sustainability. Based on this, environmental, social, and economic dimension variables within the sustainable supply chain are examined in terms of how they affect other variables under their set. Tables of direct relation matrix, normalized and total relation are presented in fuzzy form [13].

Table 3. The final approved indicators

Indicator	Dimension	Indicator	Dimension	Indicator	Dimension
Dangerous factors for the work environment and society		Supply chain cost		Accountability	
environmental pollution		Supply flexibility		Labor productivity rate	
energy consumption		profitability		Effectiveness of performance management system	
Consumption of green materials		Efficiency	Economic (EC)	The amount of work-related injuries and illnesses	Social (SO)
Emission of greenhouse gases	Environmental (EN)	Sustainable investment		Noise	
Green logistics		Added Value		employee satisfaction	
Minimize waste		Distribution of income		Average annual training time of employees	
Use of recycled materials		Promotion and support of new investments		Customer status	
Eco-friendly design		Return on equity			

These tables are not presented in the article due to the limitation of pages in the publication. The fuzzy numbers for these linguistic terms are given as Table 4.

Table 4. The fuzzy linguistic scale

Linguistic terms	Triangular fuzzy numbers
No influence (No)	(0.00, 0.00, 0.25)
Very low influence (VL)	(0.00, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.00)
Very high influence (VH)	(0.75, 1.00, 1.00)

The three indicators of influence, dependence, and interaction are obtained from the total effects matrix. The more the key factor or driver interacts, the better it is for scenario planning because it has more influence and dependence [18]. Table 5 shows defuzzified degree of influence and the final ranking of each key factor. Center of area method is used for defuzzificarion of fuzzy data which is shown below:

$$DF_{ij} = \frac{[(u_{ij}-l_{ij})+(m_{ij}-l_{ij})]}{3} + l_{ij} \quad (9)$$

Table 5 shows defuzzified of experts' opinions for the identified indicators effective on the economic dimension of the sustainable supply chain.

Table 5. The defuzzified matrix summarizing the opinions of experts in the economic dimension

Indicators	ec1	ec2	ec3	ec4	ec5	ec6	ec7	ec8	ec9
supply chain cost (ec1)	0.00	0.42	0.79	0.63	0.78	0.43	0.61	0.41	0.61
Supply flexibility (ec2)	0.70	0.00	0.64	0.84	0.43	0.57	0.47	0.77	0.33
profitability (ec3)	0.56	0.24	0.00	0.57	0.73	0.31	0.61	0.84	0.70
productivity (ec4)	0.56	0.39	0.71	0.00	0.88	0.41	0.55	0.37	0.49
sustainable investment (ec5)	0.44	0.39	0.77	0.29	0.00	0.31	0.28	0.58	0.64
Added value (ec6)	0.48	0.16	0.41	0.48	0.39	0.00	0.36	0.22	0.28
income distribution (ec7)	0.50	0.17	0.59	0.30	0.46	0.23	0.00	0.65	0.51
Promotion and support of new investments (ec8)	0.07	0.10	0.12	0.36	0.46	0.01	0.03	0.00	0.19
return on equity (ec9)	0.33	0.13	0.33	0.23	0.55	0.47	0.32	0.53	0.00

Based on the aggregated matrix in Table 5 and through various steps of the fuzzy DEMATEL technique, the total relation matrix (T) for the economic dimension was formed as described in Table 6.

Table 6. Relation matrix for the economic dimension

Indicators	ec1	ec2	ec3	ec4	ec5	ec6	ec7	ec8	ec9
supply chain cost (ec1)	0.33	0.28	0.55	0.45	0.58	0.34	0.42	0.49	0.48
Supply flexibility (ec2)	0.46	0.20	0.52	0.49	0.52	0.36	0.39	0.55	0.43
profitability (ec3)	0.41	0.23	0.37	0.41	0.54	0.29	0.39	0.53	0.47
productivity (ec4)	0.42	0.26	0.51	0.31	0.57	0.32	0.39	0.46	0.44
sustainable investment (ec5)	0.34	0.23	0.45	0.32	0.34	0.26	0.29	0.43	0.40
Added value (ec6)	0.30	0.16	0.33	0.30	0.35	0.16	0.26	0.30	0.29
income distribution (ec7)	0.32	0.17	0.39	0.29	0.40	0.22	0.21	0.41	0.36
Promotion and support of new investments (ec8)	0.12	0.08	0.15	0.17	0.22	0.08	0.10	0.13	0.15
return on equity (ec9)	0.26	0.15	0.30	0.24	0.36	0.24	0.24	0.34	0.22

Based on the total relation matrix (T) for the economic dimension, it is possible to calculate the degree of Impressibility and impressiveness of the factors of this dimension. Based on this, the information in this section is shown in Table 7.

According to Table 7 in the matrix (T), the elements of row (D) for each index indicate the index's degree of impressiveness on other indicators of the system. The higher the value of this variable, the greater the effect of that indicator. Therefore, the indicators of "supply flexibility, supply chain cost, productivity" are ranked 1 to 3, respectively. The column (R) elements for each index indicate the index's Impressibility on other system indicators. In this part, the indicators of "sustainable investment, promotion, and support of new investment, profitability" are ranked from 1 to 3, respectively.

Table 7. Outputs of DEMATEL technique for economic dimension

Indicators	D	R	D+R	D-R
supply chain cost (ec1)	3.920175	2.961236	6.881411	0.958939
Supply flexibility (ec2)	3.924985	1.77022	5.695205	2.154765
profitability (ec3)	3.622328	3.573676	7.196004	0.048653
productivity (ec4)	3.692137	2.973235	6.665371	0.718902
sustainable investment (ec5)	3.07516	3.903935	6.979094	-0.82877
added value (ec6)	2.456097	2.265446	4.721542	0.190651
income distribution (ec7)	2.781802	2.700478	5.48228	0.081324
Promoting and supporting new investments (ec8)	1.204366	3.645534	4.8499	-2.44117
return on equity (ec9)	2.343398	3.226689	5.570087	-0.88329

Therefore, the horizontal vector (D + R) is the degree of Impressibility and impressiveness of the target index in the system. In other words, the higher the value of (D + R) of an index, the more interaction that index has with other system indices. The vertical vector (D-R) shows the Impressibility of each index. In general, if (D-R) is positive, the variable is considered a cause variable; if it is negative, it is regarded as an effect .Finally, a Cartesian coordinate system is drawn. In this device, the longitudinal axis is based on (D + R), and the transverse axis is based on (D - R). The position of each index is determined by a point with coordinates (D + R, D - R) in the device. In this way, a graphic diagram will also be obtained. Also, a graphic representation of the way indicators are placed in peer connection is formed, which is discussed in Figure 1.

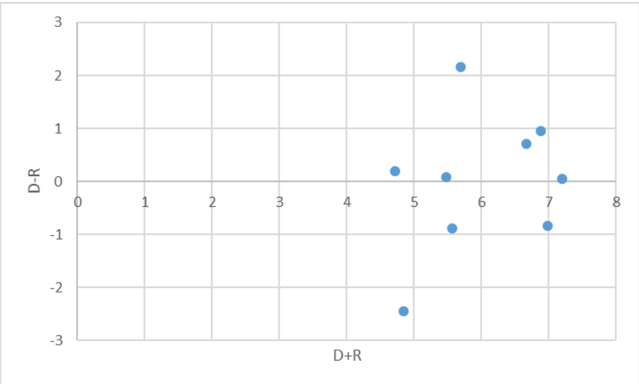

Figure 1. Graphic diagram of factors in the economic dimension

Area 1) This area includes highly impressible and impressive indicators. It is possible to refer to the indicators (ec1, ec2, ec3, ec4, ec6, ec7) which are located in the first area. A more effective, sustainable supply chain can be reached by managing these indicators.

Area 2) This area includes indicators with high Impressiveness but low Impressibility. None of the indicators are considered to be except this category. The importance of these indicators in the occurrence of changes is high, which requires special attention to be heeded.

Area 3) Includes indicators with low Impressiveness and high Impressibility. Managing these indicators is difficult because many indicators are their cause. The indicators (ec5,ec8,ec9) are located in this area.
Area 4) Indicators both with low Impressiveness and Impressibility. The importance of these indicators is less than others in change management. None of the indicators are considered for this category.

According to the mentioned steps, a graphic diagram for the other two dimensions of the stable structure was formed, as in Figures 2 and 3, based on Tables 8 and 9.

Table 8. Outputs of DEMATEL Technique for Social dimension

Indicators	D	R	D+R	D-R
Accountability (so1)	2.512770534	2.04945	4.562221	0.46332
labor productivity rate (so2)	2.063963473	3.0375	5.101463	-0.97354
The effectiveness of the performance management system (so3)	2.925749522	3.051699	5.977449	-0.12595
The rate of work-related injuries and illnesses (so4)	1.980175317	1.881925	3.8621	0.098251
noise pollution (so5)	1.857281481	1.372223	3.229504	0.485059
employee satisfaction (so6)	2.196248543	2.818315	5.014563	-0.62207
The average annual training time of employees (so7)	3.090841058	0.806098	3.896939	2.284743
client status (so8)	1.099252758	2.709073	3.808326	-1.60982

According to Table 8, in the matrix (T), the row elements (D) for each index indicate the degree of the index's Impressiveness on other system indicators. The higher the value of this variable, the greater the impressiveness of that indicator. Therefore, the indicators of "average annual training time of employees, the performance management system effectiveness, responsibility" are rated 1 to 3, respectively. Each index's column (R) elements indicate the index's Impressibility on other system indicators. In this part, the "performance management system effectiveness, employee satisfaction, customer status" indicators are rated 1 to 3, respectively. Also, a graphic representation of how indicators are placed in peer connection is formed, as discussed in Figure 2.

In this diagram, the horizontal vector (D + R) is the degree of the impressiveness of the target index in the system. In other words, the higher the value (D + R) of an index, the more interaction that index has with other system indices. In general, if (D-R) is positive, the variable is considered a cause variable; if it is negative, it is regarded as an effect.

Area 1) This area includes indicators with high Impressiveness and Impressibility. It is possible to refer to the indices (so1, so4, so7) located in the first area. A more effective, sustainable supply chain can be reached by managing these indicators.

Area 2)This area includes indicators with high Impressiveness but low Impressibility. The index (so5) is located in this area. The importance of this index is high in the occurrence of changes requiring more attention to be given.

Area 3) includes indicators that have low Impressiveness and high Impressibility. Managing these indicators is difficult because many indicators are their cause. The indicators (so2, so3, so6, so8) are located in this area.

Area 4) indicators that have both low Impressiveness and Impressibility. The importance of these indicators is less than others in change management. None of the indicators are considered for this category.

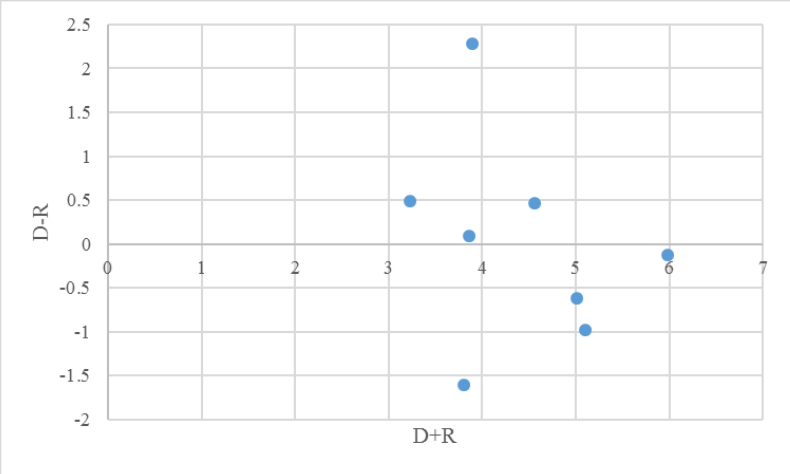

Figure 2. Graphic diagram of factors in the social dimension

Table 9. Outputs of DEMATEL Technique for environmental dimension

Indicator	D	R	D+R	D-R
Dangerous factors for the work environment and society (en1)	0.09731	0.118908	0.216218	-0.0216
environmental pollution (en2)	0.108848	0.139787	0.248635	-0.03094
Energy consumption (en3)	1.149244	0.155779	1.305024	0.993465
consumption of green materials (en4)	0.133901	0.118131	0.252032	0.01577
Greenhouse gas emissions (en5)	0.09553	0.131303	0.226833	-0.03577
Green logistics (en6)	0.149772	0.112095	0.261867	0.037676
waste minimization (en7)	0.132677	0.127267	0.259944	0.00541
Use of recycled materials (en8)	0.117922	0.099941	0.217863	0.017981
Eco-friendly design (en9)	0.170452	1.152445	1.322897	-0.98199

According to Table 9, in the matrix (T), the row elements of (D) for each index indicate the impressiveness degree of that index on other indicators of the system. The higher the value of this variable, the greater Impressiveness of that indicator. Therefore, the indicators of "energy consumption, environmentally friendly design, green logistics" are ranked from 1 to 3, respectively. The column (R) elements for each index indicate the index's Impressibility on other system indicators. In this part, the indicators of "environmentally friendly design, energy consumption, environmental pollution" are ranked 1 to 3 respectively. Also, a graphic representation of how the indicators are placed in interaction with each other is formed, which is discussed in Figure 3.

Based on Figure 3, three indicators (dangerous for the work environment and society, environmental pollution, greenhouse gas emissions) are placed in the independent area of the graphic diagram of the environmental dimension. The autonomous area is where these factors have few connections with other elements of this section and are somewhat separated from the structural and communication model. Therefore, the researcher can exclude these factors from continuing his research cycle.

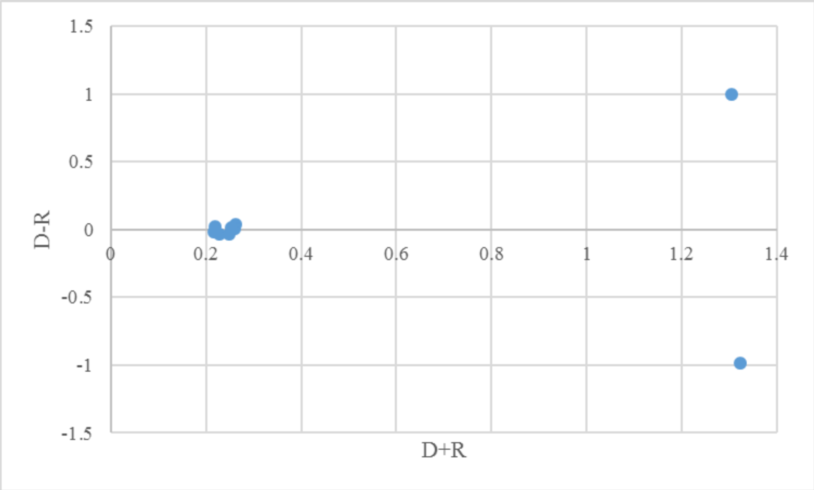

Figure 3. Graphic diagram of factors in the environmental dimension

Fuzzy Cognitive Mapping

Based on the Fuzzy DEMATEL technique, 23 of the indicators identified in this research have shown high Impressiveness and Impressibility. Based on the fuzzy cognitive mapping technique, this section has designed a communication map between the remaining 23 indicators. As discussed in the research method section, the IMS matrix should be formed first in the fuzzy cognitive mapping technique. This matrix shows each factor's current status in the Kale company, which each expert has scored. Table 10 depicts a part of the IMS matrix in this research.

Table 10. An extract of IMS matrix

IMS	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
en3	4	4	5	4	4	5
en4	5	4	5	3	4	3
en6	5	4	5	4	5	4
en7	5	4	4	3	5	4
en8	5	5	5	4	4	4
en9	4	5	3	4	5	4
so1	4	4	4	5	5	4
so2	5	4	4	5	5	5

Based on the IMS matrix, which is an n×m matrix, n is the number of concepts or variables and m represents the number of experts who were interviewed to collect information. The matrix rows indicate the importance that each individual j considers for each concept or variable i. By following the steps mentioned in the research methodology section, the correlation matrix between the indicators has been designed by removing redundant relationships. Table 11 shows a part of this matrix.

Table 11. Part of the FMS matrix

FMS	en3	en4	en6	en7
en3	1	0	0	0
en4	0	1	0.855	0
en6	0	0.855	1	0
en7	0	0	0	1
en8	0	0	0	0
en9	0	0	0	0

This matrix is used as input matrix to Fcmapper software. After entering the final communication matrix in FCMapper software, the resulting output was used as the input of Pajek software in Figure 4.

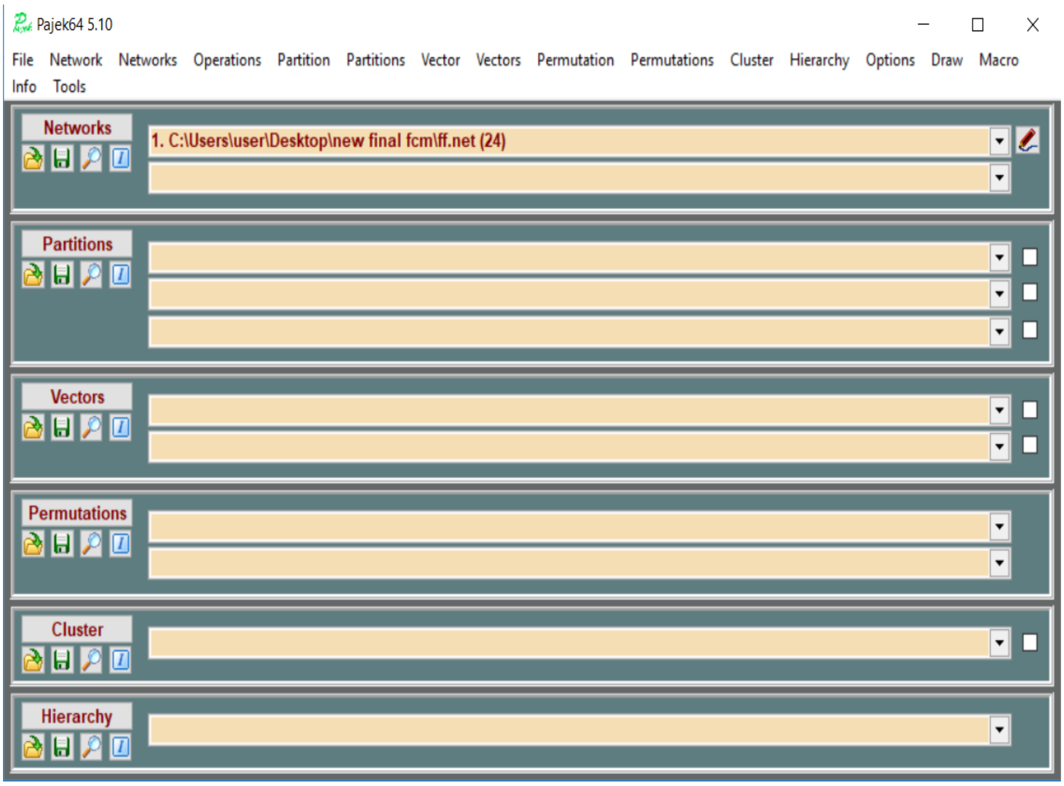

Figure 4. Input file to pajek

In the final representation, each arrow of the j and i factors has a significant weight that indicates the strength of the causal relationship between the elements and the value included in the final success matrix in the cell presented in rows i and column j. The centrality of nodes is defined based on the sum of the Impressibility and Impressiveness of concepts (nodes). Impressiveness is the sum of the absolute values of the relations output from the node, and Impressibility is the sum of the fundamental values of the relations entering the node. To draw fuzzy cognitive mapping, we use the output of FCMapper software as an input in Pajek software. And finally, the intended graph, which shows the cause-and-effect relationships between the concepts, is shown in Figure 5.

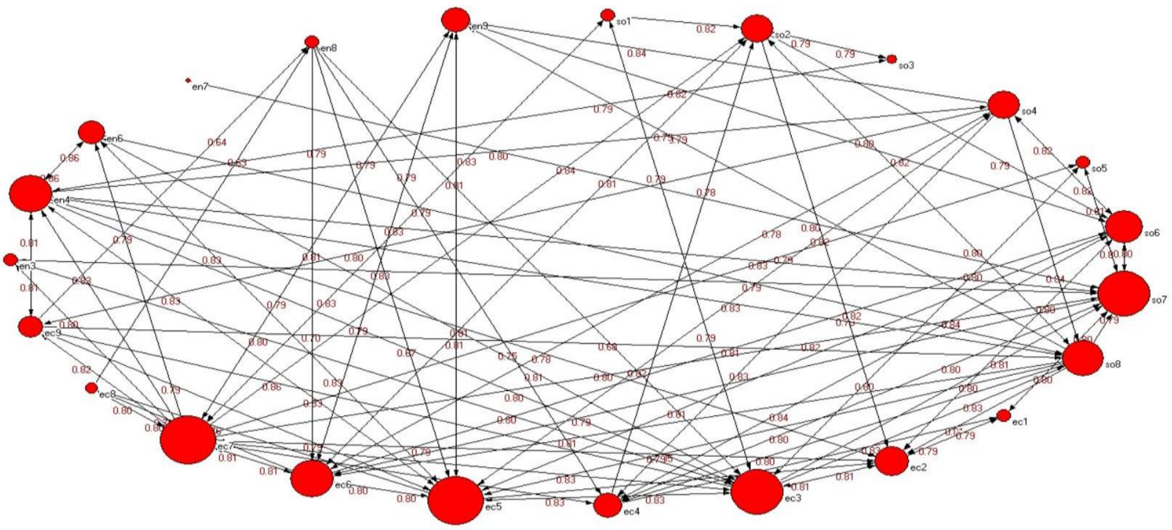

Figure 5. Fuzzy cognitive mapping of factors affecting the performance of sustainable food supply chain

In the fuzzy cognitive mapping model presented in Figure 5, negative effects (indicating an indirect relationship) are shown with dashed lines, and positive effects are shown with lines [34]. In general, in this form, all relationships are direct and there is no indirect relationship. The general information on the FCM model can be found in Table 12.

Table 12. General information on the FCM model

Density	Total Nr. Factors	Total Nr. Connections	Nr. Transmitter	Nr. Receiver	Nr. Ordinary
0.2268431	23	120	0	0	23

The model designed in this research consists of 23 main indicators, and 120 relationships are observed between them. 23 indicators from the indicators in the study have both positive Outdegree and positive Indegree and are of the ordinary type. In other words, 100% of the distribution of factors in the three groups Ordinary, Receiver, and Transmitter is shown in Figure 6.

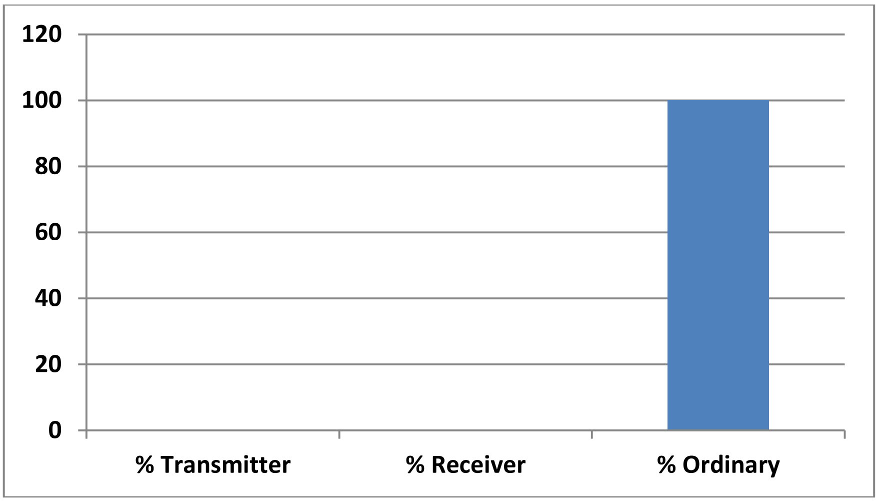

Figure 6. Bar chart of distribution of indicators

The Indegree's degree shows the Impressibility of indicators. In Figure 7, the degree of input related to the indicators is drawn. The three factors "so7", "ec5" and "ec3" have the highest Impressiveness respectively, and the three factors "en7", "so3" and "so1" have the least Impressiveness respectively.

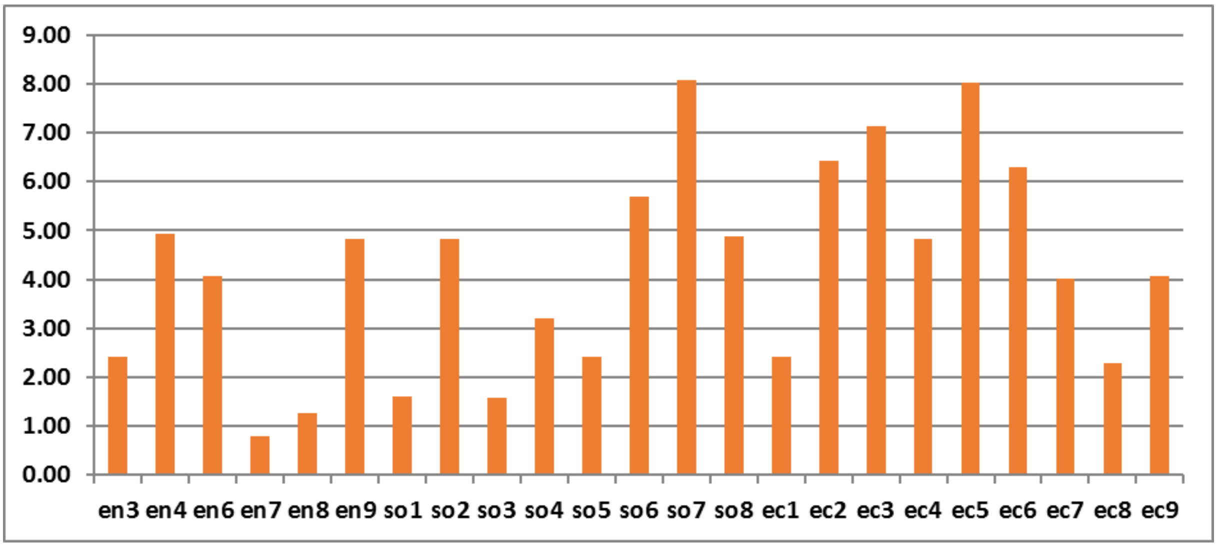

Figure 7. Degree of index input

The degree of outdegree shows the effects applied by a concept; in other words, it shows the degree of indicators' Impressiveness. The more outdegree an index has, the more significant Impressiveness of that index on the entire system is reflected.

As shown in Figure 8, three factors, "ec7", "en4", and "ec3," respectively, have the most Impressiveness, and three factors, "en7", "so2," and "ec7", respectively, have the least Impressiveness.

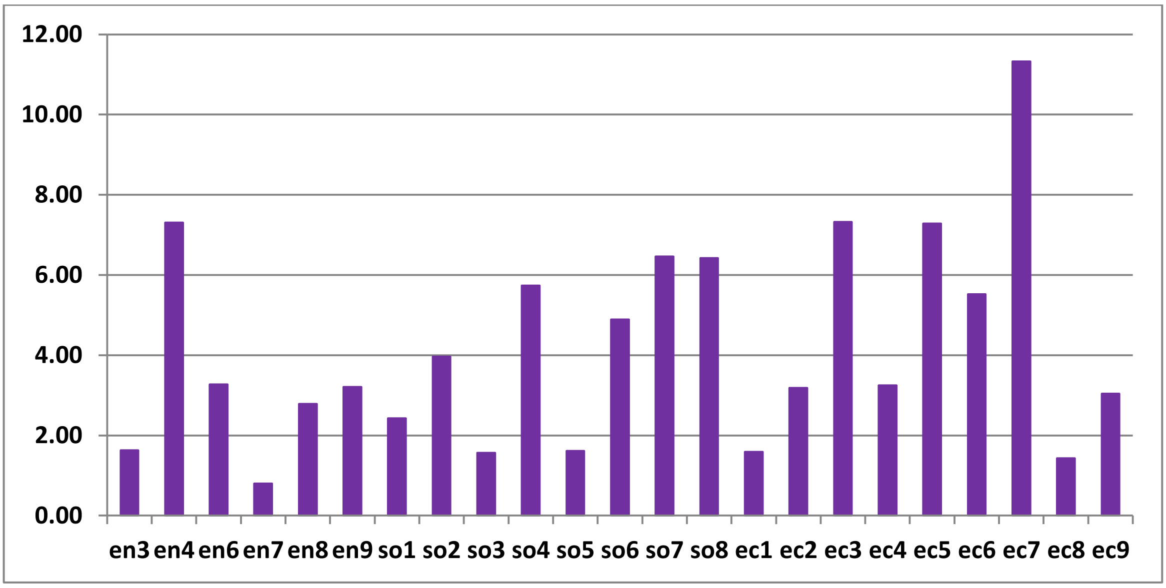

Figure 8. Output degree of indicators

The centrality degree is the sum of the previous two indicators. Each index with a higher centrality degree has a higher OD or ID than other indices. In both cases, this index is considered an important index in the system and should be considered. As you can see in Figure 9, in the desired system, the indicators "ec7", "ec5" and "so7" have the highest centrality degree, and the three indicators "en7", "so3" and "ec8" have the lowest centrality degree, respectively.

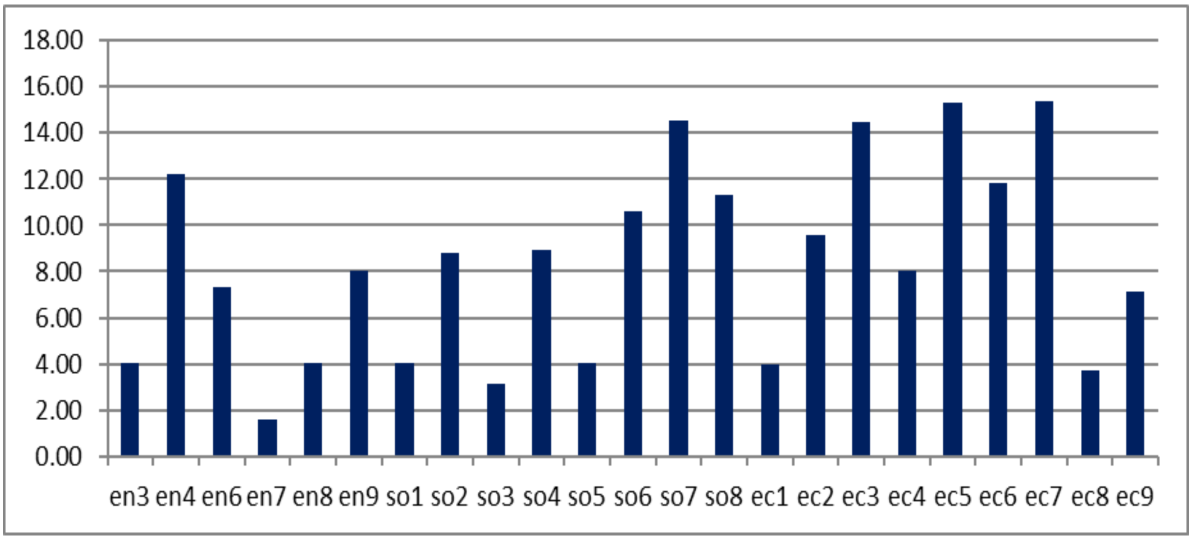

Figure 9. Centrality Degree of indicators

In Table 13, all the model indicators that were mentioned in previous figures are presented in detail with corresponding numbers.

Table 13. calculation of indicators related to the FCM model

Indicator		Outdegree	Indegree	Centrality
Energy consumption (en3)	en3	1.63	2.43	4.06
consumption of green materials (en4)	en4	7.31	4.93	12.24
Green logistics (en6)	en6	3.28	4.07	7.34
waste minimization (en7)	en7	0.80	0.80	1.60
Use of recycled materials (en8)	en8	2.79	1.27	4.05
Eco-friendly design (en9)	en9	3.21	4.84	8.04
Accountability (so1)	so1	2.43	1.61	4.04
labor productivity rate (so2)	so2	3.97	4.83	8.79
The effectiveness of the performance management system (so3)	so3	1.57	1.57	3.14
The rate of work-related injuries and illnesses (so4)	so4	5.74	3.21	8.95
noise pollution (so5)	so5	1.61	2.41	4.02
employee satisfaction (so6)	so6	4.89	5.68	10.58
The average annual training time of employees (so7)	so7	6.46	8.08	14.55
client status (so8)	so8	6.42	4.89	11.31
supply chain cost (ec1)	ec1	1.59	2.41	4.00
Supply flexibility (ec2)	ec2	3.18	6.41	9.60
profitability (ec3)	ec3	7.32	7.14	14.46
productivity (ec4)	ec4	3.25	4.82	8.06
sustainable investment (ec5)	ec5	7.29	8.03	15.31
Added value (ec6)	ec6	5.52	6.29	11.80
income distribution (ec7)	ec7	11.32	4.02	15.34
Promotion and support of new investments (ec8)	ec8	1.43	2.28	3.71
return on equity (ec9)	ec9	3.04	4.07	7.11

In Table 13, the degree of Indegree shows the Impressiveness of the indicators. The three indicators, "average time of annual training of employees, sustainable investment, profitability," have the highest Impressiveness, respectively, and the three indicators, "waste minimization, performance management system effectiveness, responsibility," have the least Impressiveness, respectively.The degree of Outdegree shows the effects the concept applies; in other words, it shows the degree of indicators' Impressiveness. The higher the OD degree of an index, the more impressive that index is in the entire system. The three indicators, "income distribution, consumption of green materials, profitability," respectively, have the most Impressiveness, and the three indicators, "waste minimization, labor productivity rate, income distribution," have the least Impressiveness. The centrality degree is the sum of the criteria of Impressiveness and Impressibility.

The value of this index for each criterion shows the interaction degree of this criterion with other investigated fuzzy cognitive mapping indices. Therefore, during the analysis of fuzzy cognitive mapping, this index should be devised at the center of decision-makers' attention. Each index with a higher centrality degree has a higher OD or ID than other indices. In both cases, this index is considered an important index in the system. Table 13 shows that the "income distribution" index ranks first and fourteenth regarding Impressiveness and Impressibility. However, it ranks first in centrality and is the chain's most critical index. A sustainable food supply is considered. The "Sustainable Investment" index ranks fourth in terms of Impressiveness and second in terms of Impressibility. However, it ranks second in terms of centrality. The "average time of annual training of employees" index is also ranked fifth in Impressiveness and first in Impressibility. This index ranks third in the centrality criterion and is the third primary index affecting the sustainable food supply chain. The "profitability" and "green material consumption" indicators are ranked second and third in Impressiveness, respectively, and third and seventh in Impressibility. According to the centrality criterion, these indicators are in the fourth and fifth positions.

Managerial Insights

In the context of sustainable food supply chain performance, managers face the challenge of balancing economic viability, environmental stewardship, and social responsibility. The following insights provide actionable guidance for managers seeking to enhance sustainability in their supply chains.

- Managers should develop a comprehensive understanding of the various indicators that affect sustainable supply chain performance. This includes economic indicators (cost efficiency, profitability), environmental indicators (carbon footprint, waste management), and social indicators (labor practices, community engagement). A balanced scorecard approach can help in evaluating these indicators collectively rather than in isolation.
- Utilizing data analytics tools can significantly enhance decision-making processes. Managers should invest in technologies that allow for real-time data collection and analysis regarding supply chain operations. This enables the identification of inefficiencies and areas for improvement, leading to more informed and timely decisions.
- Building strong relationships with suppliers, distributors, and other stakeholders is crucial. Collaborative efforts can lead to shared resources, knowledge exchange, and joint sustainability initiatives. Managers should prioritize partnerships that align with sustainability goals and consider engaging in industry coalitions to amplify their impact.
- Sustainable supply chain management requires a culture of continuous improvement. Managers should encourage innovation in processes, products, and services that reduce environmental impact. Implementing practices such as Lean and Six Sigma can help streamline operations and minimize waste.
- Engaging with stakeholders—including customers, employees, and local communities—is essential for understanding their expectations and concerns related to sustainability. Managers should actively seek feedback and involve stakeholders in decision-making processes to enhance transparency and accountability.
- Staying informed about regulations and standards related to sustainability is critical. Managers should establish compliance frameworks that not only meet legal requirements but also exceed them, positioning their organization as a leader in sustainability. Additionally, risk management strategies should be developed to mitigate potential disruptions in the supply chain due to environmental or social issues.
- Investing in employee training and development on sustainability practices is vital. Managers should foster a workforce that is knowledgeable about sustainable practices and empowered to contribute to sustainability goals. This can lead to innovative ideas and a stronger commitment to sustainability initiatives.

5. Discussion and Conclusion

Balanced growth in three economic, social, and environmental dimensions and integration between financial and physical flows guarantee the survival and development of any supply chain in the long term. On the other hand, the food industry is a complex and global network of various businesses that provide most of the food consumed by the world's people. The term "food industry" includes industrial activities in production, distribution, transformation, preparation, storage, transportation, certification, processing, and packaging. Today, the food industry has become very diverse, and its product ranges from small, traditional, and family activities, and mechanized industrial processes. Many food industries depend almost entirely on local agricultural and livestock production or fishing. This research was carried out to design a structure to improve sustainable performance in the food industry. In this research, 45 factors were classified into three general economic, social, and environmental dimensions using a background study and summarizing other research.

These factors were general factors that were used in any type of sustainable performance measurement. For this reason and to localize and personalize these factors with Iran's food industry, 45 identified factors were provided to the experts. The experts of this department comprised 25 managers and vice-presidents of Kale company. By removing irrelevant and low-related factors, these experts listed the 26 factors as highly Impressive factors in measuring the sustainable performance of the food industry. In the following, 26 confirmed factors were evaluated using the fuzzy DEMATEL technique in each dimension and separately. In fact, in this section, in each of the environmental, economic, and social dimensions, a questionnaire was designed for the relationship degree among factors, and 25 experts were asked to answer the questions. Based on the obtained results, three factors in the environmental dimension were placed in the autonomous region. These factors were excluded from further research due to the lack of correlation with other factors. Next, the remaining 23 factors in this section were examined and analyzed to design fuzzy cognitive mapping. For this purpose, a 5-point Likert scale questionnaire was given to experts that were asked to specify the current 23 factors' status in the industry. A map with 122 relations and 23 variables was formed in the following using fuzzy cognitive mapping. The density of the fuzzy cognitive map obtained in this research is equal to 0.23, according to Table 15. The density in the fuzzy cognitive mapping shows how much of the communication within the fuzzy cognitive mapping is recognized as important and essential by experts, and the high or low level of this amount is not proof of the good or badness of the fuzzy cognitive mapping [4]. Based on the map obtained in this research, the factors of the income distribution (ec7), sustainable investment (ec5), and average annual training time of employees (so7) were identified as the factors with the highest degree of centrality. This research finding is consistent with some of the findings of [33] which consider the income distribution factor as one of the most important players in the supply chain to achieve sustainability. Also, based on the research findings, the waste minimization factor (en7) has the greatest Impressiveness on the sustainable structure of the sustainable supply chain. This research finding is consistent with part of the research findings [25]. In the following, the research proposals are presented:

Based on the findings, the energy consumption factor is placed in the link area in this research. Interface or link variables have high dependence and directing power; in other words, these criteria' Impressiveness and Impressibility are very high. Any slight change in these variables causes fundamental changes in the system. Therefore, it is recommended that the managers and practitioners of the food industry focus enough on the energy consumption factor to improve the environmental conditions and the sustainable supply chain's performance.

- Also, based on the findings of this department, dangerous factors for the work environment and society (en1), environmental pollution (en2), and greenhouse gas emissions (en5) were identified as factors that are located in the autonomous region. Independent variables have a small degree of dependence and directing power. These criteria are generally separated from the system because they have weak connections with the system. A change in these variables does not cause a severe change in the system. Based on this, it is recommended that the food industry managers pay less attention to these three factors.
- Based on the findings of the research, the factors of responsibility (so1), the amount of work-related injuries and diseases (so4), and the average annual training time of employees (so7) are placed in the area of social factors. Based on this, it is recommended that the food industry's managers and employees improve the level of responsibility within their structure. Also, by compensating for the

injuries caused by the work and better training the personnel by increasing their training time, they should try to improve the social aspect of the sustainable supply chain to achieve better performance.

- Based on the results of the research, the factors of equity return (ec9), supply flexibility (ec2), productivity (ec4), supply chain cost (ec1), sustainable investment (ec5), and profitability (ec3) are in the linked area. Therefore, based on this research finding, it is recommended that the managers and decision-makers of the food industry consider the conditions of improvement in these factors and provide the necessary ground for developing and advancing the functional goals of the sustainable supply chain in the food industry.
- Creating incentives for investment in cleaner and more efficient production in terms of environment, including loans paid by the government, technical assistance, and training programs for companies and small and medium economic activities. Also, avoiding improper commercial actions contrary to the rules of the World Trade Organization is required.
- Developing and creating an efficient and effective system in the production and supply of statistics can help improve the current food supply chain situation. Making policies and plans for the country's economic, social, and environmental development is impossible without sufficient, correct, accurate, and timely statistics. In this situation, universities have a privileged position and can help executive centers in obtaining quality and reliable statistics on society and provide the basis for achieving sustainable development.
- Supporting the transition towards cleaner gaseous and liquid fossil fuels where these fuels are environmentally correct, socially acceptable, and affordable

The limitations of the research are presented below:

- Sample Size and Selection: The study relied on a limited sample of 25 experts from a specific company (Kale Company), which may not fully represent the diverse perspectives and experiences within the broader food industry. The findings might not be generalizable to other regions or companies with different operational contexts.
- Subjectivity of Expert Opinions: The evaluation of factors and their relationships was based on expert opinions, which can introduce bias. The subjective nature of the fuzzy DEMATEL and cognitive mapping methods may affect the reliability of the results.
- Dynamic Nature of the Food Industry: The food industry is subject to rapid changes due to technological advancements, market trends, and regulatory shifts. The factors identified in this research may need continuous reassessment to remain relevant over time.
- Complexity of Interrelationships: While the study attempted to map the relationships among the factors, the complexity of interactions in the food supply chain may not be fully captured. There could be additional factors or interdependencies that were not considered.
- Focus on Specific Dimensions: The research focused on economic, social, and environmental dimensions without exploring other potential dimensions, such as technological or regulatory factors, which might also significantly impact the sustainable performance of the food supply chain.

Future research can explore the role of emerging technologies such as blockchain, IoT (Internet of Things), and AI (Artificial Intelligence) in enhancing the sustainability indicators of food supply chains. Investigating how these technologies can provide real-time data and improve transparency could lead to more sustainable practices. Understanding how consumer preferences and behaviors influence sustainable food supply chains is crucial. Future studies could focus on the relationship between consumer awareness of sustainability issues and their purchasing decisions, as well as how this impacts supply chain performance. Future research could involve longitudinal studies that track the performance of sustainable food supply chains over time. This would provide valuable insights into the long-term effectiveness of various sustainability indicators and practices.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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