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| RESEARCH ARTICLE

Identifying and Prioritizing Sustainable Supply Chain Indicators in the Petrochemical Industry

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| ABSTRACT

Sustainable development has gained global recognition, especially in industries such as petrochemicals, with profound environmental impacts. Integrating sustainability principles into supply chain management has become increasingly essential, especially in the petrochemical sector, where traditional practices significantly contribute to environmental degradation. Despite progress in sustainable supply chain literature, significant gaps remain in incorporating sustainability principles into supply chain management practices. The petrochemical industry faces unique challenges that remain unaddressed. There are also still no suitable models to address these issues. The main objective of this study is to identify and prioritize sustainable supply chain indicators in the petrochemical industry. This research employs mixed methods, starting with a qualitative meta-analysis of existing sustainability indicators using MAXQDA software for comprehensive coding. It then conducts quantitative analyses using the Delphi-Fuzzy method, DEMATEL, and the Analytic Network Process (ANP) to assess the interrelationships and significance of these indicators. The study identifies and categorizes 15 sustainability arrows for the supply chain, highlighting that environmental management and environmental pressures are the most critical for enhancing sustainability. This research has important scientific implications that will help develop sustainability assessment models in petrochemical supply chains. The results show that integrating economic, social, and environmental dimensions helps improve organizational performance and create more effective solutions to environmental challenges. Also, this research allows decision-makers to optimize their resource priorities and can be a cause for prospective study in the domain of supply chain sustainability in different industries.

| KEYWORDS

Analytic Network Process, Sustainable Supply Chain, Petrochemical Industry, Multi-Criteria Decision Making, Delphi-Fuzzy Method.

| ARTICLE INFORMATION

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1. Introduction

The topic of renewable supply chains in the petrochemical industry is emerging as a strategic imperative in today's world (Kshanh & Tanaka, 2024). With increasing concerns about climate change, environmental pollution, and depletion of natural resources, various industries, especially petrochemicals, must gravely integrate sustainability principles into their supply chain processes (Ansett, 2007). This industry is increasingly under criticism due to its profound environmental impacts, and it is necessary to take steps to reduce its adverse effects (Hernandez-Perdomo & Mun, 2017). Integrating sustainability into the petrochemical supply chain helps improve organizational performance and reduce costs while also helping to conserve natural resources and support local communities (Elavarasan et al., 2024). This issue leads to brand credibility and increased customer loyalty and also acts as a source of competitive advantage in global markets (Nasri et al., 2023). Failure to pay attention to sustainability principles in the petrochemical industry can bring grave and profound risks. These risks include (environmental pollution) leading to the destruction of ecosystems and threats to public health (Wu et al., 2021). In addition, excessive and unsustainable extraction of natural resources can lead to the depletion of these resources and the destruction of natural habitats (Seuring & Müller, 2008).

On the other hand, failure to comply with environmental standards carries legal and financial risks that can lead to heavy fines and damage to brand reputation (Carter & Rogers, 2008). Previous research has shown that while the literature on sustainable supply chains is growing, many studies have not paid sufficient attention to the specific challenges of the petrochemical industry. The issue of sustainability in the petrochemical supply chain faces ambiguous aspects that hinder the effective integration of sustainability principles into the sector (Pagell & Shevchenko, 2014). One key issue is the unclear definition and evaluation of sustainability indicators (Wittstruck & Teuteberg, 2012). While much research has examined the general concepts of sustainability, there is ambiguity in identifying applicable and measurable indicators in the petrochemical industry (Carter & Liane Easton, 2011). It is not only due to the lack of consensus on the choice of indicators but also to the implementation challenges and complex relationships between these metrics. In addition, industry-specific differences also contribute to this ambiguity, highlighting the need for more tailored and accurate models for assessing sustainability in the petrochemical supply chain (Marques et al., 2022). There has been a lot of research on sustainable supply chain management and sustainable development. However, there is a significant research gap in understanding the economic and social impacts of sustainable supply chains in the context of the petrochemical industry. This gap is crucial because it relates to the need to improve monetary and social performance while preserving the environment, as well as implications for sustainable development and increasing the competitiveness of this industry. Addressing this research gap is crucial because it offers the reasoning for developing sustainable assessment models and optimizing processes.

In the field of sustainable supply chain management and sustainable development, there is a significant gap in our understanding of the environmental impacts of the supply chain in the petrochemical industry. The new theory could focus on creating a "multidimensional sustainability assessment model" that uses big data and artificial intelligence algorithms to analyze and optimize the complex relationships between economic, social, and environmental indicators in the petrochemical industry. Therefore, this study aims to identify and prioritize indicators of sustainable supply chains in the petrochemical industry. This research seeks to provide models for improving sustainable performance and reducing negative environmental impacts in this industry.

2. Literature review

The initial discussions surrounding supply chain sustainability can be traced back to 1995 (Seuring & Müller, 2008). In the United States, the movement gained momentum in 1969 after the passage of the Clean Air Act (Carter & Rogers, 2008). define sustainability as integrating economic, environmental, and social considerations within an organization, achieved through the systematic coordination of internal business processes to enhance long-term financial performance and create value chains (Carter & Rogers, 2008). Pagell & Shevchenko (2014). An example of a sustainable supply chain is its design, coordination, control, and organization to achieve economic efficiency and minimize environmental and social harm over time (Pagell & Shevchenko, 2014). However, Wittstruck & Teuteberg (2012). expanded on this concept, defining sustainable supply chain management as a broader interpretation of traditional supply chain practices that incorporate social, economic, and environmental (Wittstruck & Teuteberg, 2012). Carter & Liane (2011). suggested a robust conceptual framework for Sustainable Supply Chain Management (SSCM) based on an extensive study of 28 international companies (Carter & Liane, 2011). Teuteberg & Wittstruck (2010). The supply chain management framework was proposed in organized research (Teuteberg &Wittstruck, 2010). Siewring & Moller (2008) explored internal and external drivers of sustainable supply chains. They emphasized the central company's significance in developing rewards for suppliers to produce sustainable products while achieving profitability (Siewring & Moller, 2008). Wuni (2024). Development of a multidimensional risk assessment model for sustainable construction projects (Wuni, 2024). Naegler et al (2021). Integrated multidimensional sustainability assessment of energy system transformation pathways has been addressed (Naegler et al., 2021). A summary of research on three-dimensional supply chain management (SCM) is in Table (1).

Table (1). Summary of research on three-dimensional SCM.

Researcher	The Title of the paper and the Industry under Sudy	Key axes examined	Research Method
Approach AHP	Environmental, Social, and Economic	A framework for assessing supply chain sustainability: A case study of Iran's machine-made carpet industry	(Alfat et al., 2014)
Qualitative interview analysis and ANP-fuzzy technique	Economic, Social, and Environmental	Choosing suppliers for a sustainable supply chain through fuzzy multicriteria decision-making methods: A case study in the parts manufacturing sector.	(Jia et al., 2015)
Qualitative meta-combination and Shannon entropy	Environmental, Social, and Economic	Applying a mixed qualitative approach to supply a holistic framework for assessing supply chain sustainability.	(Dao et al., 2011)
Qualitative content analysis	Society, Environment, and Economy	Creating a framework for sustainable development indicators in the mining industry.	(Carter & Rogers, 2008)
The focus is on developing a sustainability framework informed by conceptual theorizing that integrates resource dependence theory and the resource-based approach.	Integrating three-dimensional indicators—environmental, social, and economic—with four strategic aspects: risk management, transparency, and organizational culture, to achieve economic efficiency.	A framework for sustainable supply chain management: Advancing toward a new theory based on 28 American and German manufacturing firms.	(Carter & Liane, 2011)
A systematic review of texts and combination with an explanatory model	Society, Environment, Economic, and Risk management	Recognizing the key factors for productive, sustainable supply chain management in the electronics industry	(Wittstruck & Totberg, 2012)
A systematic review of the resource-based approach to developing a framework for supply chain sustainability	Sustainability capability, information technology, supply chain, and human resource management	From Green to Sustainable: The Role of Information Technology in Promoting Sustainability Integration.	(Tate et al., 2011)
Grounded theory	Dimensions of the environment, Economy, Ethics, and Education (education)	The role of supply chain management in promoting sustainability throughout the entire value chain: a focus on major global companies in the petrochemical, food, electronics, and retail sectors.	(Closs et al., 2011)

Statistical survey of 1500 employees (factor analysis, regression analysis)	The impact of eco-purchasing and sustainable packaging on social, economic, and environmental outcomes	A survey of sustainable supply chain management in Malaysia - 400 Malaysian manufacturing companies	(Gopalakrishnan et al., 2012)
A case study using an interpretive approach	Combining technological innovation and sustainability dimensions in the supply chain focal company	Innovation and sustainability in the supply chain case study: cosmetics companies	(Pereira de Carvalho & Barbieri, 2012)
Content analysis	Supply chain indicators + dynamic capabilities index	Sustainable supply chain management solutions and dynamic capabilities in the food industry	(Beske et al., 2014)
Structural interpretive approach (ISM)	Clustering of sustainability environmental indicators	Analysis of SSCM practices in the mining and minerals industry with a structural interpretation approach - mining industry	(Abadi et al., 2015)
The process consists of two steps: first, reviewing the articles, and second, conducting a factor analysis t-test.	Economic, Environmental, and Social	Commitment and preparation for sustainable supply chain management in the oil and gas industry - oil and gas industry	(Christopher, 2022)
Structural Equation Modeling of 146 UK managers	The role of governance in the implementation and implementation of sustainable supply chain management practices and its achievements in both economic and environmental dimensions	Government pressure and performance outcomes of sustainable supply chain management - an empirical analysis of the UK manufacturing industry	(Mathivathanan et al., 2018)
Using the combined method of Multiple criteria decision-making [1]	In this research, two environmental and economic dimensions concern the researchers.	Choosing sustainable materials in the construction industry with the construction and building industry of the UAE	(Govindan et al., 2016)

Research Gap and Novelty

A critical analysis of the literature on supply chain sustainability shows that despite significant advances in this area, significant research gaps remain. A notable gap in research is the lack of empirical studies on the operation of sustainability concepts in organizations. While much work has focused on sustainability theories and frameworks, the real challenges of applying these theories in various contexts remain underexplored. Also, long-term analyses of the actual impacts of sustainable practices on organizational performance are rare. Social and cultural aspects are missing from the research and significantly impact the success of sustainable supply chains.

There are also gaps in the role of technology and innovation in improving supply chain sustainability. Overall, these gaps provide new opportunities for future research and can lead to a better understanding of sustainability in supply chains. This study addresses this literature gap and attempts to help improve economic, social, and environmental performance by identifying and

[1] MCDM

prioritizing sustainability indicators. One of the main challenges in this area is the lack of clarity in defining and assessing sustainability indicators. For this reason, we conduct a qualitative meta-analysis of existing indicators to identify 15 key indicators and clarify this ambiguity. We also examine the relationships between these indicators and their importance using hybrid methods such as Delphi-Fuzzy, DEMATEL, and Analytic Network Process (ANP). This approach enhances our understanding of sustainability assessment complexities and aids in developing more accurate models for the petrochemical industry. In addition, addressing the specific challenges of this industry and examining the economic and social impacts of a sustainable supply chain helps to improve financial and social performance while preserving the environment. Ultimately, our research results allow decision-makers to optimize their resource priorities and achieve reduced negative environmental impacts and enhanced organizational performance. They provide a comprehensive framework for assessing sustainability in the petrochemical supply chain that can serve as the basis for future research in this area and other similar industries.

3. Methods

This investigation is employed in terms of meaning, is mixed research with an exploratory design that sequentially collected qualitative data first and then used quantitative data to generalize the findings. Figure (1) illustrates the research process.

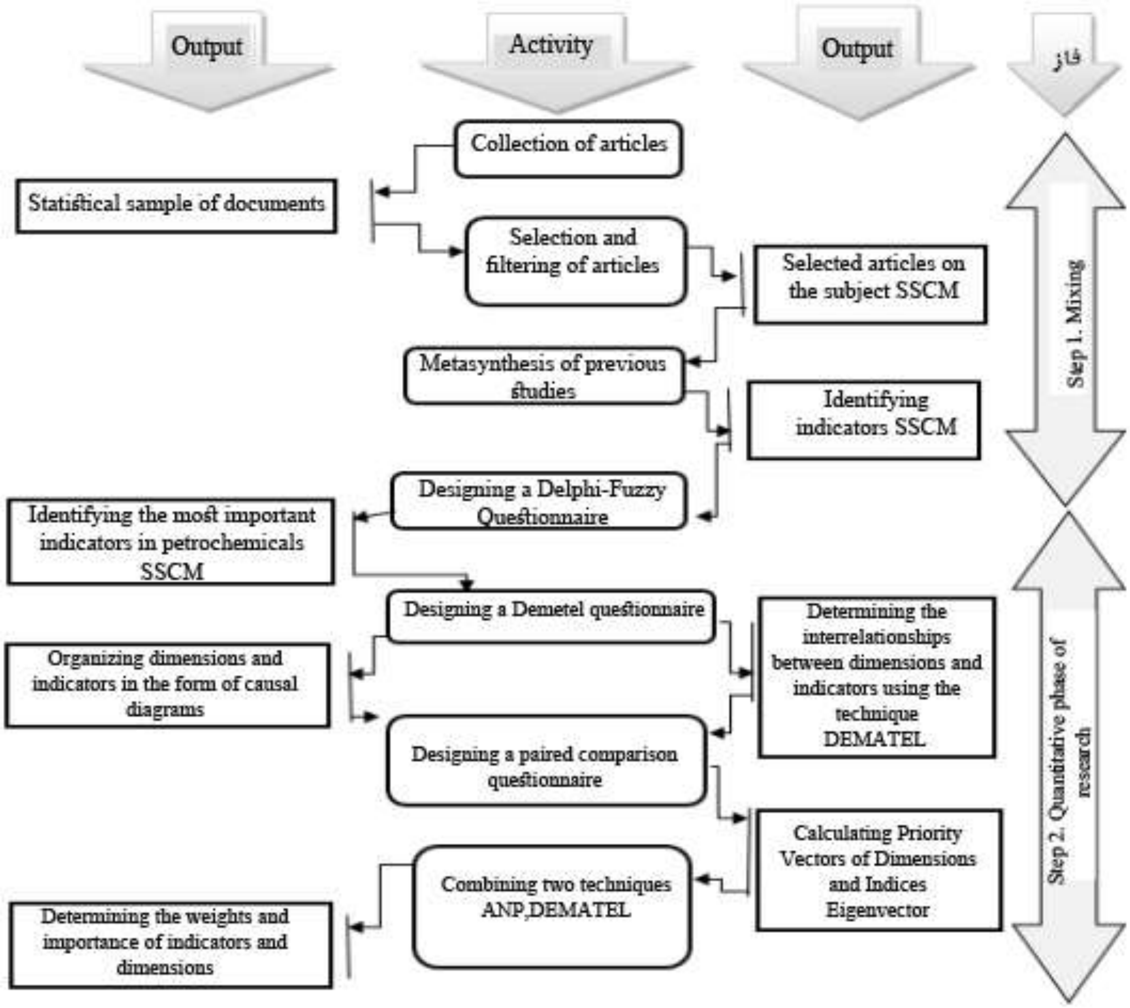

Fig (1). General diagram of the research stages

The data collection method is a descriptive survey, which does not involve a hypothesis. Considering the objectives of the analysis, the main examination questions are as follows:

What are the indicators of sustainable supply chain management in petrochemical units?

What are the causal relationships between the indicators/dimensions and their degree of importance?

The second stage of the research involves a statistical population of 73 petrochemical experts purposefully chosen to complete the DEMETEL questionnaires and the network analysis process. Table (2) summarizes the data collection method and the studied population.

Table (2). Summary of data collection method and study population

Research Steps	Statistical population		Data collection method	Data validity and reliability
Step 1: Meta-synthesis	Articles related to sustainable supply chains from 1990 to the present		Systematic studies and qualitative content analysis (emphasis on neo-objects)	Recoding and Cohen's Kappa coefficient test
Step 2: Fuzzy Delphi Technique	Academic researchers	Petrochemical experts	Delphi-fuzzy questionnaire	Content and logical validity
Step 3: Combining DEMET and Analytic Network Process	Petrochemical experts		Paired comparison questionnaire	Inconsistency rate

Data Analysis Method meta-synthesis:

Due to the growth of research and the scientific community's exposure to the explosion of information, synthetic research, which is the extract of past research, has become increasingly widespread (Rayat Pisha et al., 2016). Meta-synthesis is a variety of analyses on past research (Rayatpisha et al., 2018). Therefore, Catalano (2013). Meta-synthesis is the procedure of searching, considering, mixing, and analyzing quantitative or qualitative examinations within a typical field (Catalano, 2013).

The meta-synthesis approach in management, particularly in supply chain management, is a relatively new methodology (Esfahbodi et al., 2017). This study utilized the Sandelowski et al. (2007) model, as shown in Figure 2.

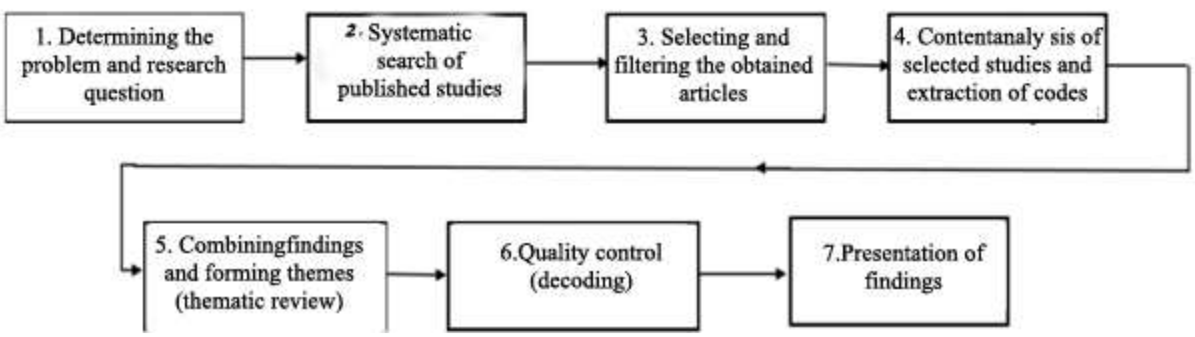

Fig (2). The Seven Steps of Meta-Synthesis (Sandelowski et al., 2007)

Fuzzy Delphi Technique:

In this research, the fuzzy Delphi approach is used to integrate the views of specialists and filter the indicators to determine the primary indicators of sustainability in high-risk industries' supply chains (Chen et al., 2008). Therefore, the opinions of experts were initially collected using triangular fuzzy numbers as follows:

Equation 1:

$W_k = (a_k, b_k, c_k)$

In the fuzzy number for indicator K, W_k represents the fuzzy number, where a_k is the minimum assessment, b_k is the average assessment, and c_k is the maximum assessment provided by the experts.

Equation 2:

$S_k = \frac{a_k + b_{k+} c_k}{3}$

Finally, based on the following criteria, the suitable indicators are selected:

- If $S_k \geq \Lambda$, indicator k is accepted
- If $S_k < \Lambda$, indicator k is not accepted

DEMATEL Technique:

The DEMATEL technique originated from the Structural Analysis Center of Geneva, planning to transform the cause-and-effect relationships of indicators into a coherent system model (Tzeng et al., 2007). Below is a brief description of the DEMATEL method: In the first step, the initial direct relationship matrix z was calculated at five levels from 0 to 4. The initial direct relationship matrix was standardized in the second step using Equations (3) and (4).

Equation 3:

X= y.Z
Equation 4:
$$y = \min_{i.j}\left[\frac{1}{\max_{1\le i\le l}\sum_{j=1}^{l} z_{ij}},\frac{1}{\max_{1\le j\le l}\sum_{i=1}^{l} z_{ij}}\right]$$

Step Three:
Computation of the total relationship matrix using Equation (5), in which the value of (I) is the identity matrix.
.
Equation 5:
$T = X\,(I-X)^{-1}$

Step Four:
Normalize the total relationship matrix V by normalizing the total relationship matrix T. This internal relationship matrix is employed to derive the supermatrix for the Analytic Network Process (ANP).
The Analytic Network Process (ANP) technique is an extension of the AHP method (Gasparatos et al., 2008) designed to address the challenges of interdependence and feedback among indicators (internal dependency) (Linton et al., 2007). However, ANP encounters difficulties in assessing the dependencies and feedback between dimensions or indicators (external dependency). The research uses the DEMATEL technique to create a network connectivity map and hypermatrix within the ANP framework.
The first step of the ANP process involves experts conducting pairwise comparisons of indicators using the 9-point scale introduced by Gulati (1999) to establish the supermatrix.
In the second step:
The initial supermatrix is grown by integrating the DEMATEL strategy with the Analytic Network Process. The third step involves creating a weighted supermatrix by normalizing the total relationship matrix. Finally, the limiting supermatrix is determined using Equation (6) based on (Mollenkopf et al., 2005).
Equation 6:
The bounded supermatrix = (balanced supermatrix)$^{2k+1}$
Existing Gaps Despite significant advances in sustainable supply chain literature, there are still gaps in integrating sustainability principles into supply chain management practices. Recent studies have often not paid attention to the specific challenges and fields of the petrochemical industry, and appropriate models for this sector have not evolved.
This research addresses these gaps by developing specific evaluation models for petrochemical supply chains. This study helps to strengthen the existing literature and provides new insights to improve sustainability in this industry.

4. Results
This analysis seeks to determine and prioritize arrows of endurable supply chains in the petrochemical enterprise. In the first stage:
Using a seven-step qualitative meta-synthesis method, it undertook an in-depth assessment of secondary data from other studies to answer its questions (Sandelowski et al., 2007).
1990 to 2016:
Systematic search for articles in reputable domestic and international journals on supply chain sustainability the initial collection of articles entitled (Sustainable Supply Chain)
Then:
Review the initial articles and identify a set of keywords and a combination of keywords from the first and second sections (supply chain, sustainability, environmental, economic, green, empowerment, social responsibility, etc.).
Next, to limit the number of articles found, the researcher reviewed the journals based on two criteria: citation rate and impact factor (using the two websites mentioned in the footnote) and finally selected (39) journals, which resulted in a total of 446 articles. With the help of the Critical Appraisal Skills Program tool and the screening method, it is possible to assess the quality of the papers, reduce the digit, and determine the minimum digit of studies with maximum importance.
In stages, we extract ninety-four article findings from the categorized articles using MAXQDA qualitative software. With the highest frequency and codes with similar meanings identified, 89 codes were categorized (topics). Sandelowski et al. referred to this method as topic analysis (Sandelowski et al., 2007).
Cohen's Kappa coefficient is applied to measure the 222 qualitative meta-analysis research.
Two or more documents are judged by referring to a specific index. Using MAXQDA software, he analyzed the relationship between documents and the binary nature of codes and used the Kappa index.
The kappa coefficient assessment is 0.603, also above the acceptable threshold of 0.6 (Viera & Garrett, 2005). This value indicates the reliability of the research. Additionally, a significance level of less than 0.05 indicates the presence of a coding relationship between the two reviewed documents (Rayat Pisha et al., 2016).

At the end of the first stage:
Identifying the most significant indicators in the petrochemical industry and compiling the findings from content analysis (meta-synthesis) as a fuzzy Delphi questionnaire.
At this stage:
Six experts from the petrochemical sector were selected using sampling to assess the importance of the indicator. The importance of these indicators was analyzed using linguistic scales and triangular fuzzy numbers related to a five-point scale defined as follows:
(0.7, 0.9, 0.9) is of great importance. (0.5, 0.7, 0.9) indicates important. (0.3, 0.5, 0.7) indicates ordinary. (0.1, 0.3, 0.5) indicates unimportant. And (0.1, 0.1, 0.3) is very unimportant.
Ultimately, indicators with a threshold value λ\lambdaλ greater than 0.6 were regarded as the most significant since the average minimum important value is 0.5 and the maximum Typical value is 0.7. Remove indicators with a score of less than (0.6).
Finally, for dimension (D) of sustainability, 18 indicators, (2) exclusion indicators, and (1) indicators based on expert opinions are combined (Tables 3, 4, and 5).
Table (3) categorizes the findings and studies used in the economic dimension (D1) and includes four main axes:
1. Business axis (i1)
This axis refers to key features of supply chain management and communication improvement. This section aims to improve internal and external communications, HR development, plus strengthening integration in the chain. Focusing on long-term relationships with customers and stakeholder management helps create competitive differentiation and improve corporate image and reputation.
2. Production axis (i2)
This axis focuses on optimizing production processes and enhancing product quality. Key objectives include efficient production planning, flexibility in responding to market changes and reducing inventory fluctuations. These measures aim to improve market position and increase the company's share in the industry.
3. Financial and cost axis (i3)
This section focuses on enhancing financial performance and transparency in monetary flows. Key strategies involve reducing costs and increasing profitability while developing financial evaluation and reporting systems to support improved decision-making and resource management.
4. Suppliers (i4)
This axis deals with the management and development of relationships with suppliers. Evaluating and selecting suppliers, establishing long-term relationships, and planning to select suitable suppliers are among the measures that help optimize the supply chain. Reducing the distance between the company plus suppliers also facilitates collaboration and improves supply chain efficiency.

Table (3). Classification of Findings and Studies Used in the Economic Dimension (D1) Research.

Theme	**Code**
Business oriented(i_1)	Improving internal and external communications Long-term vision in chain affairs Investing in employee development Strengthening integration in the chain Maintaining long-term customer engagement Stakeholder management Competitive differentiation Creating opportunities through corporate image and reputation Risk management actions in the chain Evaluating plus measuring the economic efficiency of businesses in the chain.
Production oriented (i_2)	Establishment of efficient production planning, improvement of product quality, improvement of market position, flexibility Distribution, reduction of inventory fluctuations, development Product
Financial and cost-oriented(i_3)	Improving strategic financial performance Transparency of financial flow and information

	Reducing costs and increasing profits While paying attention to two other dimensions, namely the development of financial evaluation and reporting systems
Suppliers(i_4)	Supplier development and management Supplier evaluation and selection Long-term relationship with suppliers Reducing the distance Between the central firm and providers Planning for supplier selection.

Table (4) categorizes the findings and studies used in the social dimension (D2) and includes four main axes:
1. Organizational and corporate axis (i5)
This axis addresses management and organizational structure in the supply chain. Key points include leadership commitment, knowledge sharing, and increased accountability. It also highlights the importance of an efficient organizational structure and positive culture to reduce absenteeism and enhance the work environment. Additionally, the commitment of key companies to social responsibility and charitable activities is stressed.
2. Human-centered axis (i6)
This section focuses on employee welfare and rights, covering issues like motivation, satisfaction, prevention of child labor, unemployment, and abuse. It also highlights the significance of employee well-being and security, freedom of association, plus promoting social justice. Key objectives include improving and diversifying employment opportunities and ensuring fair working conditions.
3. Social Manager Area (i7)
This area focuses on social responsibility in production and services, emphasizing transparency in production, tracking of goods, and product safety. These measures aim to build consumer trust and enhance the company's public image.
4. Goods and Services Area (i8)
Akin to the Social Manager Area emphasizes social responsibility regarding goods and services. Key points include transparency in the production process and product safety, which aid in improving the excellence and protection of products plus services within the supply chain.

Table (4). Classification of Findings and Studies Used in the Social Dimension (D2) Research.

Theme	**Code**	
Organizational and company-oriented (i_5)	Central organization	Commitment and support of leaders in the chain, sharing knowledge and information in the chain, increasing accountability in the chain, creating an efficient organizational structure, culture Appropriate organization, reducing employee absenteeism through improving the organization's environment
	The focal company of the chain	Commitment of the Core company in the chain, social responsibility of the focal company in the chain, philanthropy, ethical business, emphasis on education in the entire chain
human-centered (i_6)	Motivating and satisfying employees Preventing child labor Unemployment, abuse, and prevention Discrimination Health and safety of employees Free association activities	

	Protecting employees' rights Promoting social justice Improving and diversifying recruitment and promotion Fair working conditions.
Social manager (i_7)	Social responsibility for goods and services, transparency in the manufacturing and tracking of merchandise, plus security of products Manufacturing and services
goods and services (i_8)	Social responsibility for goods and services, transparency in production and tracking of goods, safety, and security of products Manufacturing and services

Table (5) categorizes the findings and studies used in the environmental dimension (D3) and includes five main axes:
1. Environmental pressures axis (i9)
This axis highlights the pressures on the supply chain from governments, customers, environmental associations, and shareholders. These pressures act as catalysts for companies to enhance their environmental performance and comply with standards.
2. Environmental management axis (i10)
This section focuses on the administration of the life cycle and disposal phase of products. The use of integrated environmental management systems, reducing waste generation, and developing green technologies in the supply chain are among the key issues of this axis. Assessing environmental performance in the chain and developing green suppliers also helps to improve environmental impacts.
3. Policies, Strategies, and Laws and Regulations (i11)
This axis emphasizes the importance of adhering to environmental standards and creating green policies. Adhering to environmental regulations and advancing green strategies are crucial for elevating the ecological efficiency of the supply chain.
4. Resources and Energy Axis (i12)
This section focuses on reducing resource consumption and utilizing renewable resources. Key objectives include increasing resource efficiency and minimizing the use of toxic substances in products. These measures aim to mitigate the adverse environmental effects of production and consumption.
5. Transportation and Emissions Axis (i13)
The axis emphasizes reducing greenhouse gas emissions and developing related regulations, focusing on environmentally friendly transportation and minimizing its environmental impacts as primary goals.
6. Green Activities, Innovation and Initiatives (i14)
This section covers environmental innovations and initiatives within the supply chain. Key topics include leading companies in environmental initiatives, green purchasing, and competition for ecological reputation. It also encompasses green design, green marketing, and eco-friendly internal logistics.
7. Reverse Logistics and Closed Systems (i15)
This section deals with the progression of recycling networks in the supply chain and the encouragement of innovations in the use of waste. Optimization plus closed-loop logistics systems help to reduce waste and use resources efficiently.

Table (5). Classification of Findings and Studies Used in the Environmental Dimension (D3) Research.

Theme	**Code**
Environmental pressures(i_9)	Government or governmental pressures, pressure from customers, pressure within the chain, pressure from environmentally friendly people's associations, pressure from shareholders
Environmental management (i_{10})	Managing the life cycle and end of life of products, using an integrated environmental management system (EMS), managing and reducing the production of waste and waste materials in the chain, developing green technologies in the supply chain, evaluating the environmental efficiency in the process, plus developing

	green suppliers.
Policies, strategies, and rules and regulations (i_{11})	Compliance with environmental standards, Green policies, supply chain compliance with laws and Environmental regulations, creation of strategies and sustainable practices
Resources and energy (i_{12})	Reducing the consumption of resources, using renewable resources, increasing the productivity of resources, and reducing the consumption of toxic substances in products.
Transportation and publishing (i_{13})	Reduction of greenhouse emissions, development regulations related to emissions, environmental transport
Green activities, innovation, and Initiatives (i_{14})	Pioneering the focal company of the chain in environmental initiatives, green purchasing, and competition in gaining a reputation Environmental, green marketing, green design, production, internal environmental logistics, packaging compatible with Environment, development of ideas for cooperation with the environment.
Reverse and loop logistics closed (i_{15})	Development of the recycling network in the supply chain, reproduction from waste in the production procedure, encouraging innovations related to the use of waste, design for reproduction, optimization, and effective optimization of the closed loop logistics system in the entire chain, by-products from waste

Table 6 examines the connection between the three aspects of supply chain stability using the DEMATEL technique, the total relationship matrix (T) using paired comparison questionnaires, and expert surveys showing the formation and external dependencies between the dimensions.

Table (6) .Total Relationship Matrix of the Three Main Dimensions (T1).

	(D_1)	(D_2)	(D_3)
(D_1)	0.678	1.174	1.434
(D_2)	0.841	0.787	1.297
(D_3)	0.649	0.867	0.754

Table 6 contains the overall relationship matrix between the three key dimensions (financial, sociable, plus green), which examines the interactions and mutual effects between these dimensions. The examination of the numerical outcomes shows that:

The link between the economic dimension (D1) plus the social dimension (D2) has a value of 0.678, which indicates a positive impact of financial performance on social dimensions. Also, the relationship with the environmental dimension (D3) has reached a value of 1.434, which indicates a more robust and positive impact of the economy on the environment.

The relationship between the social aspect (D2) plus the economic aspect (D1) shows a value of 0.841, which links the improvement in social facets to the improvement in financial performance. The relationship with the environmental dimension (D3) is also equal to 1.297, which indicates a beneficial effect of social responsibilities on the ecological situation.

The relationship between the environmental component (D3) plus the economic aspect (D1) with a value of (0.649) shows a positive but slightly weaker relationship. The relationship with the social dimension (D2) is equal to 0.867, indicating a positive impact of environmental efforts on social conditions.

Figure (3) shows the supply chain sustainability model plus the structure of impact networks in the form of a triangle, which includes three main dimensions: environmental, economic, and social. The ecological dimension, positioned at the top of the triangle, focuses on conserving natural resources and minimizing negative impacts on the ecosystem.

The economic dimension on the right side indicates the improvement of financial performance and profitability of companies, and the social dimension on the left side addresses social responsibilities and improving the working conditions of employees. At the center of the triangle is the word sustainability, representing the model's ultimate goal: To create an equilibrium between these elements to reach supply chain sustainability objectives. The lines of connection between the dimensions indicate their mutual influences, meaning that improvements in one dimension can affect the others. The model serves as a framework for companies to enhance supply chain performance and achieve sustainability goals.

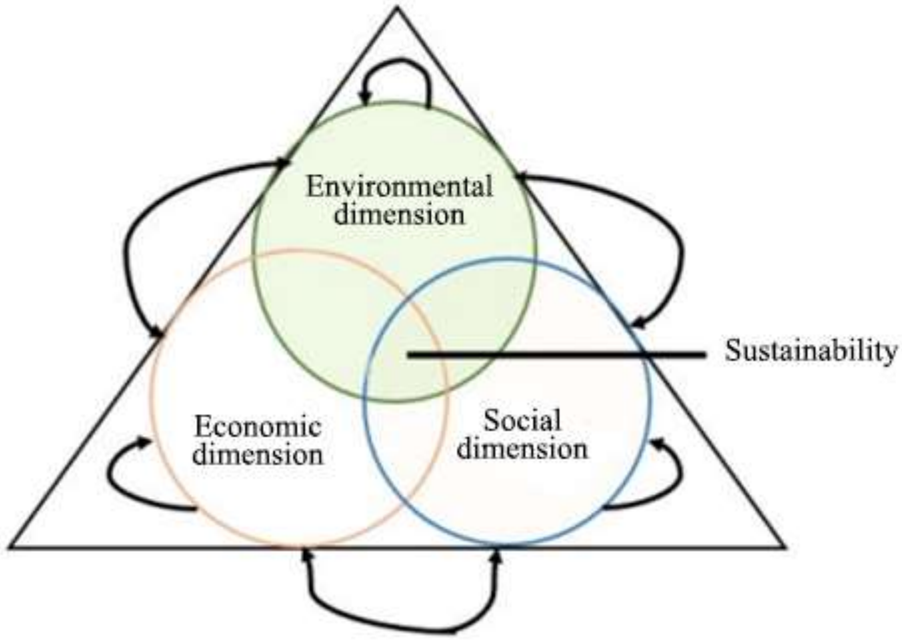

Fig (3). The Model Sustainability in Supply Chain and the Structure of Impact Networks.

After analyzing the collected data, the total relationship matrix of the indicators determines the three dimensions of SSCM, and to create internal dependency matrices, the total relationship matrix is normalized, and this matrix (internal relationship) is directly entered into the initial supermatrix (without weight). The external dependencies between the different dimensions are represented based on the network structure (Figure 3). After column normalization (multiplying each row by the inverse of its column sum), the unweighted supermatrix results in a weighted supermatrix (Table 7) not included due to paper limitations. Finally, to ensure system convergence and balance the values of the rows, the weighted supermatrix was exponentiated and defined in Equation 6. Table 8 shows the supermatrix bounds.

Table (7), known as the “ultra-primitive matrix,” analyzes the relationships and interactions between different dimensions (G, D, and L) in a system. This matrix includes weight values that indicate the relative importance of each dimension relative to the other dimensions. Values above 0.5 indicate a strong influence of that dimension on the overall assessment. Also, the values in the matrix can indicate mutual influences between dimensions, such that high values between two dimensions confirm their significant effect on each other. This analysis can help in decision-making in supply chain policies and strategies and emphasize the importance of each dimension in improving performance. Finally, Table (7), as a crucial analytical tool, helps clarify priorities and identify strengths and weaknesses in the system.

Table (7). Initial Super Matrix.

Weighted super-matrix					D1				D2				D3						
	G	D_1	D_2	D_3	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8	i_9	i_{10}	i_{11}	i_{12}	i_{13}	i_{14}	i_{15}
G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D_1	0.699	0.313	0.415	0.411	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D_2	0.198	0.388	0.278	0.372	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
D_3	0.102	0.299	0.307	0.216	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
i_1	0.000	0.504	0.000	0.000	0.060	0.087	0.089	0.083	0.084	0.094	0.092	0.093	0.071	0.077	0.081	0.085	0.067	0.086	0.069
i_2	0.000	0.272	0.000	0.000	0.072	0.050	0.080	0.073	0.067	0.068	0.069	0.085	0.064	0.063	0.065	0.074	0.062	0.06	0.059
i_3	0.000	0.161	0.000	0.000	0.061	0.061	0.040	0.056	0.054	0.057	0.057	0.053	0.049	0.048	0.048	0.049	0.047	0.051	0.054
i_4	0.000	0.063	0.000	0.000	0.071	0.065	0.074	0.050	0.072	0.068	0.070	0.063	0.072	0.071	0.065	0.076	0.076	0.067	0.070
i_5	0.000	0.000	0.449	0.000	0.086	0.089	0.092	0.086	0.066	0.100	0.105	0.098	0.081	0.092	0.084	0.093	.091	0.096	0.100
i_6	0.000	0.000	0.373	0.000	0.069	0.071	0.070	0.075	0.076	0.051	0.085	0.063	0.078	0.059	0.062	0.059	0.055	0.062	0.062
i_7	0.000	0.000	0.131	0.000	0.067	0.065	0.065	0.070	0.075	0.074	0.049	0.074	0.066	0.064	0.059	0.052	0.060	0.053	0.053
i_8	0.000	0.000	0.047	0.000	0.067	0.053	0.044	0.042	0.052	0.047	0.055	0.036	0.046	0.060	0.038	0.043	0.037	0.040	0.039
i_9	0.000	0.000	0.000	0.300	0.075	0.085	0.076	0.086	0.073	0.095	0.088	0.094	0.062	0.088	0.097	0.080	0.084	0.089	0.070
i_{10}	0.000	0.000	0.000	0.253	0.086	0.086	0.075	0.083	0.090	0.076	0.083	0.084	0.095	0.064	0.100	0.091	0.094	0.096	0.102
i_{11}	0.000	0.000	0.000	0.206	0.081	0.081	0.076	0.087	0.085	0.074	0.072	0.083	0.089	0.085	0.061	0.086	0.084	0.080	0.082
i_{12}	0.000	0.000	0.000	0.109	0.072	0.071	0.072	0.061	0.060	0.063	0.055	0.058	0.073	0.076	0.077	0.050	0.075	0.065	0.067
i_{13}	0.000	0.000	0.000	0.065	0.046	0.050	0.044	0.052	0.048	0.048	0.040	0.041	0.053	0.061	0.062	0.056	0.038	0.053	0.056
i_{14}	0.000	0.000	0.000	0.042	0.048	0.047	0.055	0.052	0.056	0.048	0.045	0.043	0.065	0.054	0.059	0.063	0.068	0.041	0.084
i_{15}	0.000	0.000	0.000	0.025	0.038	0.039	0.049	0.046	0.042	0.037	0.035	0.033	0.040	0.038	0.045	0.041	.059	0.061	0.033

The overall analysis of Table (8), known as the "super-constraint matrix," examines the ultimate impact of different dimensions (G, D, and L) in the supply chain. This matrix depicts the ultimate weights of the dimensions plus indicates their relative importance in the overall assessment of supply chain efficiency**.** The outcomes of this analysis can help clarify priorities in decision-making and allow managers to focus on the dimensions that possess the highest impact. Also, this matrix can help identify weaknesses and strengths in the relationships between different dimensions and help develop effective strategies to improve supply chain performance and sustainability. Ultimately, this analysis serves the role of a key tool to optimize management decisions and enhance overall supply chain performance.

Table(8). Limiting Super Matrix.

		G	D_1	D_2	D_3	i_1	i_2	i_3
Weighted super-matrix	G	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	D_1	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	D_2	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	D_3	0.000	0.000	0.000	0.000	0.081	0.067	0.053
D_1	i_1	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_2	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_3	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_4	0.000	0.000	0.000	0.000	0.081	0.067	0.053
D_2	i_5	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_6	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_7	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_8	0.000	0.000	0.000	0.000	0.081	0.067	0.053
D_3	i_9	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{10}	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{11}	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{12}	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{13}	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{14}	0.000	0.000	0.000	0.000	0.081	0.067	0.053
	i_{15}	0.000	0.000	0.000	0.000	0.081	0.067	0.053

i_4	i_5	i_6	i_7	i_8	i_9	i_{10}	i_{11}	i_{12}	i_{13}	i_{14}
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055
0.069	0.089	0.067	0.064	0.048	0.082	0.086	0.080	0.067	0.051	0.055

i_{15}	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042

The numerical results in Table (7), referred to as the super-primitive matrix, analyze the importance and mutual influences of dimensions G, D, and L in the supply chain. A significant weight of 0.519 for dimension G highlights its high importance. Additionally, a strong mutual influence of 0.372 between dimensions D and L indicates a close relationship and positive influence between them. These results clarify priorities, identify key dimensions, and assist decision-makers in developing effective strategies to enhance supply chain efficiency and sustainability.

The numerical analysis of Table (8), known as the super-constraint matrix, presents the final weights of dimensions G, D, and L within the supply chain. The weight values are generally lower than those in previous tables, indicating more limited effects among the dimensions. Notably, the D dimension has the highest weight at 0.067, highlighting its importance. The other values average around 0.0 to 0.1, suggesting that the additional dimensions exert less influence on one another. These findings can guide managers to focus on higher-weight dimensions and optimize resource allocation. Overall, this analysis helps identify strengths and weaknesses in the supply chain, providing a foundation for effective strategic decision-making.

Table (9) provides the essential values needed to create the effect direction map for the dimensions and indicators of sustainable supply chains. The effect direction map produced by DEMATEL (Figure 9) assists decision-makers and senior managers in the impact and accountability of different dimensions or indicators. This information helps identify causal relationships across the three dimensions and supports strategic decision-making for managers to increase performance in each area.

Equation 7:

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}$$

Equation 8:

$$r = \left[c_{ij}\right]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)_{1\times n}$$

In addition to determining the relationships between dimensions and indicators, another application of the DEMATEL technique creates the impact direction map, which depicts the causal relationships amid the indicators. To construct the graph, sum the rows and Total columns relation matrix (T) representing the vector (R) and vector (C), which are determined using equations 7 and 8. The vector (R) shows the degree of influence, and the vector (C) shows the level of correlation alongside other indicators. The worths of R + C represent the degree of connection of an indicator with other indicators, and variables with higher R + C values have a stronger connection with other indicators, and R - C indicates the degree of impact of factors in the system and a higher priority in resource allocation (Wu et al.,2021).

Table (9) clarifies the impact and importance of the various aspects of the supply chain plus shows how these dimensions can influence each other. The economic dimensions are specifically centered, emphasizing the importance of financial and cost-oriented processes. At the same time, the social dimensions indicate an emphasis on human and organizational aspects that help improve internal and external interactions. However, environmental challenges are evident in this table, highlighting the need for greater attention and management in this area. Overall, this analysis emphasizes the importance of balancing economic, social, and environmental dimensions and shows that to improve the overall performance of the supply chain, comprehensive and integrated strategies should be considered that tackle all these dimensions.

Table (9). Impact and Importance Values of Dimensions and Indicators.

Dimensions (criteria)	R_i-C_j	R_i+C_j	(R_i + C_j , R_i -C_j)
Economic (D_1)	1.119	5.454	(5.454,1.119)
Business orien) ted (i_1)	0.083	6.109	(6.109,0.083)
Production oriented(i_2)	-0.607	6.109	(6.109,0.607)
Financial and cost-oriented(i_3)	-1.085	5.079	(5.079, -1.085)
Suppliers(i_4)	-0.233	5.495	(5.495,0.233)
social(D_2)	0.096	5.752	(5.752,0.096)
organization and focal company(i_5)	0.845	6.045	(6.045,0.845)
human-centered(i_6)	0.411	4.685	(4.685,0.411)
Social management(i_7)	0.335	4.511	(4.511,0.335)

goods and services(i_8)	-0.408	4.014	(4.014, -0.408)
Environmental (D_3)	-1.215	5.755	(5.755, -1.215)
Environmental pressures (stimulus) (i_9)	0.716	5.592	(5.592, 0.716)
Environmental management(i_{10})	0.309	6.277	(6.277,0.309)
Policy, rules, and regulations (i_{11})	1.026	5.152	(5.152, 1.026)
Resources and Energy (i_{12})	-0.373	5.469	(5.469, 0.373)
Transportation and publishing(i_{13})	-0.842	4.654	(4.654, -0.842)
Green activities, innovation, and initiatives(i_{14})	-0.211	4.387	(4.387, -0.211)
Reverse logistics and closed-loop(i_{15})	0.032	3.242	(3.242, -0.032)

Table (9) presents a numerical interpretation of the effect and importance of different dimensions of the supply chain. Economic dimensions (D1) have significant positive weights, such that the values of (ri-cj) and (ri+cj) indicate the importance of this dimension in the decision-making procedure. In particular, the i1 (business-oriented) and (i2) (production-oriented) indices show high values, but i3 (financial and cost-oriented) with a negative value of (-1.085) shows serious challenges in this area.
Social dimensions (D2) also have significant positive weights. Indices such as i5 (organization and company-oriented) and i6 (human-oriented) emphasize the importance of human and organizational interactions. These dimensions indicate the need for effective human resource management and improvement of organizational processes.
In the environmental dimension (D3), the ri-cj value is -1.215, highlighting significant challenges in environmental management. Despite positive values for indicators i9 (Environmental pressures) and i10 (environmental management), greater focus is necessary in this field.

The results of this research highlight the significant importance of sustainable indicators in the supply chain of petrochemical industries and contribute to the development of new theories in the field of sustainability assessment. By identifying and prioritizing 15 sustainability indicators, this study emphasizes the creation of multidimensional assessment models that simultaneously consider economic, social, and environmental dimensions.

5. Discussion

A-Interpretation of results

In this research, the results secured from the inquiry into eco-friendly supply chain indicators within the petrochemical sector indicate the elevated importance of economic, social, and environmental dimensions. Economic dimensions (D1) significantly benefit social and ecological aspects, such that indicators related to business management and production optimization (i1 and i2) are of great significance in improving the overall efficiency of the supply chain. It indicates that financial and management strategies can help improve productivity and reduce costs. The negative monetary and cost index (i3) of -1.085 indicates significant challenges that could result in financial instability and heightened economic risks.
Social dimensions (D2) also have positive and significant weights in the results obtained. Indicators such as organizational management and focus on human well-being (i5 and i6) emphasize the importance of human interactions, social responsibility, and improving working conditions. The results show that focusing on employee well-being and fostering a positive organizational culture increases overall performance and productivity. The environmental dimension (D3) shows a negative value of -1.215, highlighting significant challenges in environmental management. Despite the positive values of the ecological pressure and environmental management indices (i9 and i10), there is a clear need for increased focus on environmental issues in the industry. These results emphasize the significance of creating an equilibrium between economic, social, plus ecological dimensions plus indicate that to enhance the overall performance of the supply chain, comprehensive plus integrated strategies should be considered that can cover all these dimensions and aid the long-term viability of the petrochemical industry.

B- Significance and Implications

The results of this research highlight the significant importance of sustainable indicators in the petrochemical industry's supply chain. By identifying and prioritizing 15 sustainability indicators, this study emphasizes the critical role of environmental management and environmental pressures as key factors for enhancing sustainability in this sector. These findings have important implications for decision-makers and managers in the industry. First, the focus on integrating economic, social, and environmental dimensions contributes to enhanced organizational performance. In particular, paying attention to social and ecological aspects helps reduce negative environmental impacts and results in heightened brand credibility and customer loyalty. Hand neglecting sustainability principles can result in serious risks, including damage to brand reputation and legal consequences. Therefore, petrochemical industries must actively utilize sustainability assessment models to enhance their performance across various areas while responding to legal requirements and social expectations. The findings of this research can serve as a guide for improving processes and strategies within the petrochemical industry and other sectors, ultimately leading to sustainable development and improved environmental conditions.

C- Limitations and Future Research

This research has focused on identifying and prioritizing sustainable indicators in the petrochemical industry's supply chain; however, it has some limitations. One of the main limitations is the insufficient attention to social and cultural dimensions in sustainability assessments. This oversight can lead to an incomplete understanding of the challenges and opportunities for improving sustainability in this industry. Additionally, the study's reliance on a limited number of petrochemical experts may affect the generalizability of the results. The findings of this research will help develop new theories in sustainability assessment. By identifying and prioritizing 15 sustainability indicators, the results show that integrating economic, social, and environmental dimensions leads to improved organizational performance and the growth of more effective solutions to environmental challenges. Future research should examine sustainability models and indicators across various industries to achieve comparable and generalizable results. Studying the impact of technology and innovation on enhancing sustainable supply chain efficiency could identify more effective solutions. In particular, this research could assist in developing a "multidimensional sustainability assessment model" that utilizes big data and artificial intelligence algorithms to analyze and optimize the complex relationships among economic, social, and environmental indicators. This approach could help decision-makers optimize their resource priorities and develop more effective strategies for sustainability. Ultimately, the findings of this research not only enhance the understanding of sustainability in the petrochemical supply chain but also serve as a guide for developing new theories in this field, paving the way for future research.

D- Comparison with previous findings

Carter and Rogers (2008) the paper underscore the incorporation of economic, societal, and environmental considerations in their findings. It indicates a common understanding of sustainability across studies. The acknowledgment of 15 sustainability indicators highlights the significance of economic, social, and environmental dimensions, aligning with previous research by Pagell and Shevchenko (2014). The strength of this paper is its focus on the unique challenges of the petrochemical industry. However, our paper focuses specifically on the unique challenges of the petrochemical industry, providing deeper insights into sustainability. The identification and prioritization of 15 sustainability indicators specifically address the needs of this industry and help decision-makers allocate their resources more optimally. Implementing mixed methods such as (qualitative meta-analysis, fuzzy Delphi technique, DEMATEL, and ANP) more accurately analyzes the relationships between indicators and provides a better understanding of their interactions.

Many studies, such as those by Christopher (2022) and Mathivathanan et al. (2018), have not been identified. This focus on detail offers valuable insights into the complexities of sustainability in the petrochemical sector. The study's research approaches, including qualitative meta-analysis and quantitative techniques such as Delphi-fuzzy and demography, are consistent with previous studies similar to the labor of Jia et al. (2015) and Govindan et al. (2016) and contribute to the validity of the paper. The application of advanced analytical techniques such as Fuzzy Delphi and DEMATEL allows us to analyze complex relationships between indicators with greater accuracy. Finally, this research establishes specific assessment models for the petrochemical supply chain and serves as a reference model for other industries. The works of Christopher (2022) and Mathivathanan et al. (2018) have examined general aspects of sustainability in supply chains but have not focused sufficiently on the specific challenges of the petrochemical industry. Previous research has usually not addressed the precise identification and prioritization of sustainability indicators. In this regard, the works of Jia et al. (2015) and Govindan et al. (2016) are limited to applying traditional analytical methods and have not paid attention to advanced techniques such as Fuzzy Delphi and DEMATEL. It has led to more superficial analyses of the relationships between indicators. Most existing studies have considered different dimensions of sustainability separately and have neglected to integrate them into their analyses. This deficiency makes the results obtained less generalizable to genuine industry conditions. Conversely, many studies lack practical assessment models tailored to the petrochemical industry. In this regard, our paper, with a special focus on the petrochemical industry and the recognition of 15 specific sustainability indicators, simultaneously examines economic, social, and environmental dimensions and uses advanced analytical methods to analyze the complex relationships between indicators. This approach enriches existing literature and offers practical suggestions for enhancing sustainability in the petrochemical industry.

The study on identifying and prioritizing sustainable supply chain indicators in the petrochemical industry has significant advantages over the works of Wuni (2024) and Naegler et al. (2021). The first advantage is the specific focus on the petrochemical industry, which faces unique challenges in sustainability. While Wuni addresses construction projects and Naegler focuses on energy systems, our research provides a deeper understanding of industrial issues by addressing the specific challenges of this sector. This study identifies and categorizes 15 sustainability indicators, particularly emphasizing the importance of environmental management and pressures. This comprehensive categorization offers a more precise framework for assessing sustainability. Implementing mixed methods (qualitative meta-analysis and quantitative approaches such as fuzzy Delphi, DEMATEL, and ANP) increases the validity of the findings and helps to understand the complexities of sustainability. It integrates economic, social, and environmental dimensions essential for developing comprehensive sustainability strategies.

In contrast, the works of Wuni and Naegler et al focus specifically on individual dimensions. The results of this research contribute to theoretical advances and provide practical recommendations for decision-makers in the petrochemical industry. The article highlights gaps in the literature by identifying challenges in the petrochemical industry and the necessity for suitable sustainability assessment models, thereby contributing to the existing knowledge in the field. Ultimately, the emphasis on the essentiality of integrating innovative technologies and advanced analytical models paves the way for future research. Overall, the article significantly contributes to sustainable supply chain management through its focused analysis of the petrochemical industry, comprehensive methodology, and practical implications.

E- Policy Implications

Environmental management in the petrochemical industry is essential for conserving natural resources, reducing environmental impacts, and increasing brand reputation and customer loyalty. In the current situation where competition in global markets is increasing, paying attention to these dimensions can give companies a significant competitive advantage. Among the implications of this research is the advancement of sustainability assessment models in the petrochemical distribution network and similar industries. These models serve as a tool for measuring and improving sustainability effectiveness in sectors and help decision-makers achieve better and measurable results. Encouraging the adoption of innovative approaches in environmental administration can result in enhanced environmental conditions and decreased negative impacts from industrial activities. Improving working conditions and increasing employee satisfaction by prioritizing welfare and social responsibility will lead to improved performance and reduced employee turnover rates, which ultimately helps to increase productivity and organizational performance.

6. Conclusion

This research seeks to recognize and prioritize sustainable supply chain indicators for the petrochemical industry**.** This research identifies and categorizes 15 sustainability indicators and emphasizes that environmental management and environmental pressures are crucial for improving sustainability in this industry. Also, integrating economic, social, and ecological dimensions helps improve organizational performance. These concepts can help decision-makers optimize their resource priorities and help develop sustainability assessment models in the petrochemical supply chain. Focusing on these dimensions can result in heightened brand credibility and customer loyalty. Future research should explore sustainability models and indicators across various industries for comparable and generalizable results**.** Also, examining the function of technology and innovation in enhancing sustainable supply chain efficiency can identify more effective solutions. One of the limitations of this study is the lack of attention to social and cultural dimensions in sustainability assessment. The study highlights the need to integrate financial, societal, and environmental aspects to enhance durability in the petrochemical industry and aids in developing field-specific assessment models. This research focuses on evolving a multidimensional sustainability assessment model that utilizes big data and artificial intelligence algorithms to analyze and optimize the complex relationships among sustainability indicators. This new model not only aids in clarifying and precisely defining sustainability indicators within the petrochemical supply chain but enriches the existing literature on sustainable supply chain management.

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