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Analyzing the Drivers of Fashion Supply Chain Sustainability During Pandemics (Case Study: COVID-19)

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ABSTRACT

This research aims to identify and analyze the drivers of sustainability in the fashion supply chain during periods of disruption. The importance of this study lies in providing an integrated model to understand the dynamics governing sustainability under such conditions. This research employs a three-stage mixed-method approach. First, the fuzzy Delphi method was used to screen and finalize key drivers from an initial list extracted from the literature. Next, interpretive structural modeling was applied to develop a six-level hierarchical model illustrating the causal relationships among these drivers. The results indicate that drivers such as “top management commitment” and the “existence of explicit policy” occupy the most fundamental level and serve as prerequisites for other factors. Finally, MICMAC analysis confirmed that the system is highly interconnected and that the identified fundamental drivers exert the greatest influence on the entire system.

1. Introduction

In recent years, sustainable supply chain management has garnered the attention of many researchers as a new and influential field. The global fashion industry, valued at $1.79 trillion in 2024, is not only a significant economic force but also an influential socio-cultural phenomenon. The industry relies on a complex and global network of supply chains that originate from cotton fields and synthetic fiber factories [1](Dzhengiz et al., 2023). These supply chains pass through design, production, and distribution workshops before reaching the hands of end consumers worldwide [2](Moretto et al., 2018). However, in recent decades, the industry has faced heavy criticism for its negative environmental and social consequences. These include the massive production of textile waste, excessive consumption of water resources, and inadequate working conditions in factories [3-5](Barnes & Lea-Greenwood, 2006, Turker & Altuntas, 2014, Majumdar et al., 2021).

In response to these challenges, the paradigm of "sustainable supply chain management" (SSCM) has emerged as a strategic approach. This approach urges organizations to move beyond economic

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profitability and commit to their environmental and social responsibilities [6] (Seuring & Müller, 2008). Today, considering sustainability in supply chain network management has become a crucial issue for organizations, governments, and society due to the increasing impacts of the global population and rising human activities [7] (Karadayi-Usta, 2023). However, due to the complexity of the issue, identifying and analyzing the drivers affecting supply chain sustainability, particularly in specific industries like fashion and under critical conditions such as a pandemic, poses a challenging and complex task [8](Garcia-Torres et al., 2022). The move towards sustainability faced an unprecedented stress test with the global crisis of the COVID-19 pandemic. The pandemic disrupted supply, demand, and logistics worldwide, revealing the profound vulnerability of global supply chains. The COVID-19 pandemic presented a paradoxical situation for the sustainability agenda [9](Tam et al., 2023). Economic pressures caused by the crisis, order cancellations, and reduced demand led many companies to deprioritize investments in sustainable initiatives. However, the crisis also brought temporary improvements in air quality and increased consumer awareness of ethical and environmental issues, highlighting the importance of sustainability [10-12](Zhao & Kim, 2021, Sarma et al., 2023, Shen et al., 2023).

This research aims to identify and structurally analyze the drivers influencing the sustainability of the fashion industry's supply chain during a pandemic crisis. While previous studies have listed these drivers, the interrelated, complex, and hierarchical relationships between them remain unclear. This research seeks to clarify these relationships by using a hybrid approach that includes fuzzy Delphi for driver screening and interpretive structural modeling (ISM) for relationship analysis. The resulting model will assist managers and policymakers in understanding the causal relationships among drivers and developing more effective and resilient strategies to achieve sustainable supply chains in a volatile post-COVID-19 world.

2. Literature review

The concept of sustainable supply chain management did not emerge suddenly; rather, it was the result of an evolutionary process. In the 1990s and the early 2000s, the main focus was on green supply chain management, which primarily addressed environmental issues such as pollution reduction, recycling, waste management, and reverse logistics. This approach was often reactive in nature, aiming mainly to comply with increasing environmental regulations and to avoid legal penalties [6](Seuring & Müller, 2008). Over time, with rising global awareness, it became clear that focusing solely on the environment was insufficient. Mounting pressure from consumers and non-governmental organizations pushed firms to recognize that social and economic issues are as important as environmental ones [13](Carter & Rogers, 2008). This broader understanding catalyzed the evolution from green supply chain management toward an integrated sustainable supply chain management - a comprehensive approach that simultaneously and coherently considers all three dimensions of sustainability. This shift was not merely an expansion of topics but represented a fundamental paradigmatic change from a "compliance-driven" logic to a "value-creating" logic [14] (Siems et al., 2023). Initially, firms engaged with sustainability to avoid negative consequences. Today, sustainability is increasingly recognized as a source of competitive advantage, a driver of innovation, and a strategic means to enhance resilience and long-term financial performance [15](Anner, 2020). In this trajectory, information technology and the transparency fostered by globalization - which rapidly expose social and environmental issues at the farthest points of supply chains - have played a key role in accelerating this transformation. Based on the extant literature, drivers of sustainable supply chain management can be classified into two main categories: external and internal. This framework helps to better understand the origins of pressures and motivations [16] (Saeed et al., 2017).

- External drivers: These drivers originate from the organization's external environment and are not directly controllable by the firm [17](Saeed & Kersten, 2019):
    - Regulatory pressures: Includes national and international laws and regulations on issues such as pollution control, waste management, occupational health and safety standards, and labor rights.
    - Market pressures: Encompasses customer demand for green and ethical products, competitors' pressure to gain competitive advantage through sustainability, and the need to improve brand image and reputation in the marketplace.
    - Social pressures: Includes societal expectations, NGO campaigns and activism, media coverage, and pressure from local communities.
- Internal drivers: These drivers stem from within the organization and result from managerial decisions and strategies [16](Saeed et al., 2017):
    - Corporate strategy: Involves top management commitment and support, the organization's sustainability vision and mission, and the integration of sustainability goals into core business strategies.
    - Economic and operational performance: Includes motivations to reduce costs (through lower energy, water, and material consumption), increase productivity, manage supply-chain risks, and improve product and process quality.
    - Organizational culture and learning: Covers managers' and employees' ethical values, the creation of an organizational culture that supports sustainability, and the organization's ability to learn and adapt to emerging challenges.

This shift in drivers indicates an important underlying trend: a gradual movement from a push logic to a pull logic. Initially, firms were driven toward sustainability by external pressures (regulations) [13](Carter & Rogers, 2008). Gradually, internal factors (strategy, competitive advantage) and market demand pulled firms toward sustainability [18](Brandenburg et al., 2014). This reflects the internalization and maturation of sustainability within business strategies. Among these, top-management commitment stands out as a critical internal driver and a prerequisite. An organization lacking committed leadership will likely adopt superficial or symbolic sustainability measures even under strong external pressures. Conversely, committed leadership can turn external pressures into strategic opportunities for innovation and growth [19](Haldorai et al., 2025). Finally, the general classification of sustainable supply chain management drivers includes [17](Saeed & Kersten, 2019):
External drivers [16-17, 20](Saeed et al., 2017, Saeed & Kersten, 2019, de Aguiar Hugo et al., 2021): regulatory (environmental laws and regulations, labor standards, penalties for non-compliance, institutional pressures), market (consumer demand for sustainable products, competitor pressure, brand image improvement, access to new markets) and social (pressure from NGOs, media coverage, societal expectations, pressure from responsible investors).
Internal drivers [16-17,20](Saeed et al., 2017, Saeed & Kersten, 2019, de Aguiar Hugo et al., 2021): strategic (top-management commitment and support, organizational vision and mission, integration of sustainability into business strategy), economic and operational (cost reductions - energy, materials, waste, productivity increase, risk management, product/process improvement, product

and process innovation), and cultural and learning (managers' ethical values, supportive organizational culture, employee training and development, cross-functional collaboration).

2.1. Sustainable supply chain management in the fashion and apparel industry: Specific drivers and characteristics

The fashion and apparel industry, due to its distinctive features - including long, global supply chains, short product life cycles, and direct impact on end consumers - provides a particular context for analyzing drivers and barriers of sustainable supply chain management. The dynamics of this industry have amplified some general drivers and produced new, industry-specific drivers. To understand sustainability drivers in this industry, one must first consider the fundamental tension between the two dominant business models operating within it [21](Köksal et al., 2017):

- Fast fashion: This model, which has dominated the industry in recent decades, relies on mass production of low-cost garments that follow the latest trends, extremely rapid production and supply cycles (sometimes weekly), and continuous stimulation of consumption. This business model is inherently at odds with sustainability principles because it leads to excessive resource consumption (water, energy, chemicals), produces vast amounts of textile waste, and often involves exploitation of low-cost labor in developing countries to keep prices low [3] (Barnes & Lea-Greenwood, 2006).
- Sustainable fashion: This movement emerged as a direct reaction to the negative consequences of fast fashion. Sustainable fashion emphasizes contrasting principles: producing higher-quality and more durable products (longer lifetimes), using environmentally friendly raw materials (e.g., organic cotton, linen, and recycled materials), transparency across the supply chain, and ensuring fair working conditions and wages [22] (Cerqueira-Streit et al., 2021).

This tension itself has become a powerful driver for change. The fast-fashion model, by exacerbating environmental and social crises, has provoked a strong counter-movement in the form of sustainable fashion and increasing public awareness. In other words, the crisis-producing nature of fast fashion has acted as a catalyst for the search for sustainable solutions. Based on a comprehensive review of theoretical literature and empirical background, a set of primary drivers that affect fashion supply chain sustainability during a pandemic have been identified (Table 1).

Table 1

Primary drivers of fashion supply chain sustainability during a pandemic

Category	Driver	Source
Economic sustainability	Reducing operational costs without harming sustainability	[6] Seuring & Müller, (2008), [23] Beske & Seuring, (2014)
	Considering environmental and social requirements to maintain profitability	[13]Carter et al., (2008), [24]Ashby et al., (2012)
	Aligning cost management with long-term sustainability goals	[13] Carter & Rogers (2008), [25] Ahi & Searcy (2015)
	Basing purchasing decisions on suppliers' financial sustainability indicators	[26] Pagell & Wu (2009), [27] Van Weele (2018)
Environmental sustainability	Importance of suppliers' environmental certifications	[28] Zhu et al., (2005), [29] Li et al., (2017)
	Prioritizing recycled or low-carbon-footprint raw materials	[30] Testa et al., (2011), [20]de Aguiar Hugo et al., (2021)

	Reducing production waste through process optimization	[31] Sarkis (2003), [12] Sheng et al., (2023)
	Environmental reporting across the entire supply chain	[32] Gimenez & Tachizawa (2012)
	Incorporating life-cycle environmental criteria in product design	[33] Pujawan & Bah (2022), [34] Dhiwar & Bedarkar (2025)
	Prioritizing transportation planning to reduce pollution and energy consumption	[35] Björklund (2011), [36] Fatorachian & Kazemi (2025)
Social sustainability	Transparent monitoring of workers' conditions across the supply chain	[37] Klassen & Vereecke (2012), [38] Brydges & Hanlon (2020)
	Ensuring suppliers comply with safe and fair labor standards	[39] Alghababsheh & Gallear (2022)
	Including human-rights clauses in supplier contracts	[25] Ahi & Searcy (2015)
	Supporting small and medium enterprises within the supply chain	[40] Wang et al., (2018), [41] Takeda et al., (2024)
	Mandatory professional ethics training for supply-chain staff	[42] Gold et al., (2010), [43] Khan et al., (2018)
Technology for sustainability	Using modern communication technologies for sustainability monitoring	[44] Chin et a., (2015), [45] Paliwal et al., (2020
	Employing integrated information systems to measure environmental footprints	[46] Awan et al., (2021), [47] de Camargo Fiorini et al. (2017)
	Digital technologies that increase stakeholder engagement	[48] Baryannis et al., (2019)
Collaboration and integration	Actively sharing sustainability information with suppliers	[49] Danese et al., (2018)
	Jointly setting and monitoring sustainability KPIs with stakeholders	[23] Beske & Seuring (2014), [50] Badi & Murtagh (2019)
	Collaborating with customers to improve environmental performance	[23] Beske & Seuring (2014), [51] Marques, L. (2019)
	Participating in joint sustainable development projects with supply-chain partners	[52] Srivastava (2007), [53] Pagell & Shevchenko (2014)
Sustainable supply-chain design	Demand planning with environmental and social considerations	[18]Brandenburg et al., (2014)
	Considering or implementing circular supply-chain models	[54] Genovese et al., (2017), [55] Lüdeke-Freund et al., (2019)
	Prioritizing social and environmental impacts in network design	[56] Ageron et al., (2012)
Compliance with standards	Adherence to standards such as ISO 14001	[57] Delmas & Toffel (2004), [17]Saeed & Kersten (2019)
	Evaluating suppliers' environmental and social performance	[58] Govindan et al., (2015)
	Conducting periodic sustainability audits in the supply chain	[59] Hsu et al., (2011)
Sustainable innovations	Applying sustainable innovations in product design	[60] Akyuz & Gursoy (2020), [61] Chalmeta & Santos-deLeón (2020)
	Allocating financial resources to sustainable innovation projects	[62] Carter & Liane Easton (2011)
Crisis management and business continuity	Having pre-designed plans to preserve sustainability during crises	[63] Ivanov, D. (2020), [64] Queiroz et al., (2022)
	Ability to maintain environmental sustainability indicators during crises	[63] Ivanov, D. (2020), [64] Queiroz et al., (2022)
	Requiring suppliers to comply with sustainability standards during crises	[65] Mashud et al., (2025), [66] Golan et al., (2020)

	Prioritizing the preservation of social values such as humane working conditions during crises	[33] Pujawan & Bah (2022), [64] Queiroz et al., (2022)
Risk reduction strategies	Regular assessment of social and environmental risks	[48] Baryannis et al., (2019)
	Replacing unsustainable suppliers with responsible ones	[32] Gimenez & Tachizawa (2012)
	Using tools such as life-cycle assessment to reduce risk	[67] Petti et al., (2018), [22] Cerqueira-Streit et al., (2021)
Sustainable transparency and traceability	Transparent sharing of origin data and production processes	[68] Köksal et al., (2018), [69] Dasaklis et al., (2022)
	Increasing consumer trust through traceable sustainability data	[70] Chen (2024), [71] Nguyen & Nguyen (2025)
Governance and policymaking	Existence of codes of conduct and explicit sustainability policies	[24] Ashby et al., (2012), [4]Turker & Altuntas (2014)
	Systems for monitoring performance to track sustainability policies	[72] Jia & Jiang (2018), [17]Saeed & Kersten (2019)
	Senior management involvement in sustainability decision-making	[50] Badi & Murtagh (2019), [19]Haldorai et al., (2025)
Stakeholder engagement	Considering consumers' and other stakeholders' perspectives in decisions	[14]Siems et al., (2023)
	Providing equal opportunities for small suppliers	[73] Martins et al., (2022)
	Considering the rights of future generations in decision-making	[74] Kar et al., (2022)

The literature review demonstrates that sustainability in the fashion supply chain is a multidimensional and complex concept influenced by various institutional pressures. The COVID-19 pandemic has intensified this complexity by creating new threats and opportunities. Although several studies have identified sustainability drivers, a major research gap remains: the absence of an integrated and structured model that analyzes reciprocal and hierarchical relationships among these drivers within the specific context of the fashion industry during a global crisis. To strengthen the link between theoretical foundations and methodology, it should be emphasized that prior approaches, which mostly stopped at identifying and listing factors, are inadequate for analyzing the complex conditions resulting from a global crisis such as the COVID-19 pandemic. The interwoven and hierarchical nature of drivers during crises necessitates an approach capable of modeling these complex relationships. Therefore, the use of a structural modeling approach like Interpretive Structural Modeling (ISM) is a logical next step -not an arbitrary choice- but a natural outcome of the gap in the literature and the need for a deeper system-level understanding. This study aims to fill that gap by adopting a two-stage approach. First, using a fuzzy Delphi method, drivers identified from the literature are screened and finalized by experts. Then, through structural modeling and MICMAC analysis, the internal relationships among these drivers are modeled and a hierarchical structure is presented. This framework will assist in understanding the fundamental and strategic factors.

3. Problem statement

In recent years, sustainability has become a growing priority in the fashion industry, considering the simultaneous impact of economic, social and environmental factors. This is especially important as fashion supply chains are typically global and are often accused of ignoring ethical, occupational and environmental issues. On the other hand, history has shown that under the influence of disruption and crisis conditions such as the outbreak of a pandemic, efforts focused on environmental and social sustainability in the supply chain have been affected and reduced. However, during the pandemic,

when production activities were stopped or reduced, positive side effects such as improved air quality were observed, which in turn paved the way for increased attention to sustainability in the post-COVID-19 era. The COVID-19 pandemic has also significantly changed consumer behavior. Due to restrictions, job insecurity and changes in household income, non-essential purchases have decreased and attention to sustainable criteria in purchases has increased. The fashion industry, due to its specific characteristics, was also significantly affected by these conditions. However, it is unclear whether these changes in consumer attitudes will be sustainable or are simply a temporary reaction to the crisis. On the supply side, the fashion retail landscape also witnessed significant changes; many organizations closed, reduced or changed their activities. With a sharp decrease in demand, unsold inventory increased and new garment production was stopped.
This set of changes makes it more urgent than ever to identify and analyze the drivers affecting the sustainability of the fashion industry's supply chain under pandemic disruption. Previous studies have identified several key drivers for managing supply chain sustainability in pandemic conditions, including: risk management capacity, supply chain agility, customer support, community pressure, adoption of new technologies, supply chain collaboration, development of health protocols, and government support. However, simply identifying these drivers is not enough. The main challenge is in understanding the complex and interrelated relationships between these factors and ranking them based on their degree of influence and impact. This is a complex multi-criteria decision-making problem that requires a combined and efficient analytical approach for modeling. This study is designed to fill this research gap. Sustainability in the fashion supply chain is a multifaceted concept influenced by a set of interrelated drivers. Identifying and understanding the relationships between these factors is essential for developing effective strategies, especially in crisis situations. Some of the key drivers are described below.

1. Institutional and stakeholder pressures: These drivers are external forces that push organizations to adopt sustainable approaches.
    - Consumer and societal pressure: After the COVID-19 crisis, consumer awareness of environmental and social issues increased. This change in behavior has become a powerful pressure force that requires brands to be transparent, responsible, and provide sustainable products [75-76](Schmidt et al., 2021, Haukkala et al., 2023).
    - Government and regulatory pressure: Governments play a significant role in shaping the sustainable performance of supply chains by imposing stricter environmental regulations (such as waste management and carbon reduction) and labor standards. Compliance with standards such as ISO 14001 also falls into this category [77](Sarkis et al., 2011).
    - Relationships: Stakeholder pressure, especially consumers, is a "mother driver" that activates other drivers. This pressure directly affects "corporate governance and management commitment," forcing them to allocate resources for "sustainable innovation" and "adoption of new technologies" to increase transparency.
2. Strategic and operational capabilities: These drivers refer to the organization's internal capabilities to manage and implement sustainability.
    - Supply chain agility and resilience: Crises such as the pandemic have shown that supply chains must be able to respond quickly to disruptions. Agility refers to the ability to respond to sudden changes in demand and supply, while resilience focuses on the ability to recover from a crisis. Both are essential for maintaining sustainability in the face of uncertainty [78-79](Christopher and Peck, 2004, Chang et al., 2021).

- Sustainability risk management: This driver involves identifying, assessing, and managing risks related to the three dimensions of sustainability (economic, social, and environmental) throughout the supply chain. Regular supplier assessments and the use of tools such as product life cycle analysis are components of this [80](Choudhary et al., 2023).
- Adoption of circular business models: Going beyond linear sustainability, circular models focus on recycling, reusing, and reducing waste to zero. This is a strategic capability that requires a complete redesign of products and processes [81] (Geissdoerfer et al., 2017).
- Relationships: Agility is highly dependent on supply chain collaboration" and "adoption of new technologies. An agile supply chain can better manage sustainability risks. Also, implementing circular models is almost impossible without traceability technologies and close collaboration with partners.

3. Technology and transparency: This category is a key enabling driver for realizing modern sustainability [45](Paliwal et al., 2020).
   - Adoption of new technologies (digitalization): Technologies such as blockchain, IoT, and AI allow for precise traceability of products from source to consumer. This transparency is needed to build trust with consumers and monitor compliance with social and environmental standards. Environmental responsibility by suppliers is crucial.
   - Transparency and traceability: This driver, a direct result of digitalization, allows companies and consumers to see the origin of raw materials, production conditions and the environmental footprint of products.
   - Relationships: Technology is an "enabling driver". Transparency brought about by technology helps reduce the risks associated with irresponsible suppliers and responds to consumer pressure by providing reliable data. It also provides the necessary infrastructure for effective supply chain collaboration.
4. Supply chain collaboration and governance: These drivers focus on how relationships and policies are managed in the supply chain.
   - Collaboration and information sharing: Sustainable management of a global supply chain is not possible without close collaboration between brands, suppliers, manufacturers and even competitors. This collaboration includes transparent information sharing, setting common goals and co-investing in sustainable projects [82] (Fawcett et al., 2008).
   - Corporate governance and senior management commitment: Sustainability should be defined at the highest strategic levels of the organization. Having clear policies, codes of conduct for suppliers, and direct senior management involvement ensures that resources are allocated and the issue is given importance throughout the organization [4](Turker & Altuntas, 2014).
   - Relationships: Senior management commitment is the starting point for creating a sustainable culture in the organization and leads to supplier evaluation and auditing. Effective collaboration also requires technology-based transparency, which in turn strengthens the agility and resilience of the entire chain.

4. Research method

This research is an applied research in terms of its purpose, because its results can be directly used by fashion industry managers and policymakers to improve sustainability strategies in crisis situations. In terms of the nature and method of data collection, this research is descriptive-analytical and based on a mixed approach. In the first part, expert opinions are used to identify and screen drivers (qualitative approach), and in the second part, the relationships between these drivers are analyzed structurally using modeling techniques. The process of implementing this research is designed in two main stages and five steps as follows [83-84](Hasani et al., 2025, Maddah et al., 2026):

- Stage One: Identifying and Screening Drivers
  - Step 1: Comprehensive literature review and extraction of an initial list of sustainability drivers.
  - Step 2: Designing a fuzzy Delphi questionnaire and forming an expert panel.
  - Step 3: Implementing the fuzzy Delphi technique in several rounds to achieve consensus and finalize the list of drivers.
- Second stage: Modeling and analyzing relationships
  - Step 4: Designing the structural self-interaction matrix (SSIM) and implementing the interpretive structural modeling (ISM) technique using the opinions of the expert panel to determine the relationships and leveling of the drivers.
  - Step 5: Implementing the MICMAC analysis to classify the drivers based on the power of influence and dependence.

The statistical population of this study includes experts and specialists in the field of supply chain management, sustainability, and the fashion industry in Iran. This group includes university faculty members with relevant research backgrounds and senior and middle managers of companies active in the fashion and apparel industry with practical experience in the field of supply chain and sustainability. Given the nature of the Delphi and ISM methods, which are based on expert judgments, the purposive sampling method will be used. To form the expert panel, criteria such as academic background, research background, and executive experience of more than 5 years of management experience will be considered. The number of expert panel members is 15. In this study, a three-step hybrid approach is used to identify, screen, and model key drivers of sustainability in the fashion supply chain during a crisis. These three steps include Fuzzy Delphi, Interpretive Structural Modeling (ISM), and MICMAC Analysis, which are described in detail below.

4.1 Fuzzy Delphi method

To screen and select the most important drivers from the initial list extracted from the research literature, the fuzzy Delphi method is used. The use of fuzzy logic allows us to model the verbal expressions more accurately and avoid information loss in the process of averaging the opinions. The implementation steps of this method are as follows:

- **Identifying the fuzzy spectrum and collecting opinions:** First, a questionnaire is designed and experts are asked to determine the importance of each of the initial drivers using the verbal spectrum. Then, these verbal expressions are equated to triangular fuzzy numbers, a process rooted in fuzzy set theory. A triangular fuzzy number (l,m,u) is a range of numbers where m is the most likely value, l is the lower limit, and u is the upper limit of the desired value (Table 2).

Table 2.
Fuzzy spectrum for verbal expressions

Verbal phrase	Triangular fuzzy number (l,m,u)
Not at all important	(0, 0, 0.25)
Slightly Important	(0, 0.25, 0.5)

Important	(0.25, 0.5, 0.75)
Fairly Important	(0.5, 0.75, 1)
Very Important	(0.75, 1, 1)

- **Fuzzy aggregation of opinions:** After collecting the fuzzy opinions from all experts (assuming k experts), the aggregate opinion for each driver (i) is calculated using the arithmetic mean of the fuzzy numbers. If the j^{th} expert opinion for the i^{th} driver is equal to Fij = (lij, mij, uij), the fuzzy mean (Fi) is obtained from the following formula:

$$F_i = \left(\frac{1}{k}\sum_{j=1}^{k} l_{ij}, \frac{1}{k}\sum_{j=1}^{k} m_{ij}, \frac{1}{k}\sum_{j=1}^{k} u_{ij}\right) \quad (1)$$

- **Defuzzification:** In order to be able to rank the drivers, the average fuzzy number is converted into a definite number using the center of gravity method:

$$S_i = \frac{l_i + 2m_i + u_i}{4} \quad (2)$$

- **Threshold Determination and Screening:** Finally, a threshold value (α) is determined by the research team. Drivers whose definitive score (Si) is higher than this threshold (Si ≥ α) are selected as final and confirmed drivers to enter the next stage, and other drivers are eliminated from the analysis.

4.2 Interpretive Structural Modeling

ISM is a well-known technique for analyzing the complex interrelationships between a set of variables and converting them into a hierarchical structural model. This method helps to understand the structure of a complex system and shows how variables affect each other. The implementation steps of this method are:

Formation of Structural Self-Interaction Matrix (SSIM): After the list of drivers is finalized, a square matrix is formed in which the pairwise relationships between the drivers are determined based on the opinions of experts. For each pair of drivers (i,j), experts are asked, “Does driver i influence driver j?”. Four symbols are used to represent the relationship: V (driver i influences j), A (driver j influences i), X (drivers i and j influence each other), and O (there is no relationship between i and j).

Formation of the initial access matrix: The SSIM matrix filled with symbols is converted into a binary matrix (zeros and ones). This conversion is carried out according to certain rules that are the basis for converting qualitative judgments into quantitative data for subsequent analysis.

- If the element (i,j) in the SSIM is the symbol V, then in the access matrix, the element (i,j) is equal to 1 and the element (j,i) is equal to 0.
- If the element (i,j) is the symbol A, the element (i,j) is equal to 0 and the element (j,i) is equal to 1.
- If the element (i,j) is the symbol X, both the elements (i,j) and (j,i) are equal to 1.
- If the element (i,j) is the symbol O, both the elements (i,j) and (j,i) are equal to 0.

Also, the elements on the main diagonal of the matrix (i,i) are always considered equal to 1.

Formation of the final reach matrix: The original matrix may not represent all indirect relations. This property is known as transitivity. To take these relations into account, the original matrix is multiplied by itself using the Boolean multiplication rules until we get a stable matrix; that is, M(k+1)=Mk·P. The resulting matrix is the final reach matrix, which represents all direct and indirect relations.

Leveling of drivers: In this step, drivers are placed at different levels of a hierarchical model. This process is done through an iterative algorithm in which reachability and antecedent sets are determined for each factor. For each driver (i), two sets are defined:

- Reachability Set (Ri): Contains driver i itself and all drivers that i affects (the ones in row i in the final matrix).
- Antecedent Set (Ai): Contains driver i itself and all drivers that affect i (the ones in column i in the final matrix).

Next, the common set (Ri ∩ Ai) is calculated. Drivers whose common set is equal to their reachability set (Ri ∩ Ai = Ri) are placed at the highest level of the model (level 1). After determining level 1, these drivers are removed from the overall set and the process is repeated to identify level 2 and subsequent levels until all drivers are leveled.

Drawing the ISM model: Based on the levels obtained, a directional diagram is drawn in which the lower-level (more fundamental) drivers are at the bottom and the higher-level (more dependent) drivers are at the top of the diagram, and the influence relationships are displayed with arrows.

4.3 MICMAC Analysis

MICMAC analysis is a systematic process for analyzing the direct and indirect effects among variables in a system and classifying them based on their influence and degree of dependence. The implementation and computational steps of this method are explained in detail below.

Step 1 (Identification and Definition of System Variables): This step is the most fundamental and perhaps the most important step in the entire structural analysis process, because the quality of the final results depends heavily on the comprehensiveness and accuracy of the input variables. Variables must be identified in a way that covers all-important aspects of the system under study. Common methods for identifying these variables include extensive literature reviews and expert panels. After preparing the initial list, it is very important that each variable is carefully defined so that all members of the research team and experts have the same understanding of it. This process, which leads to the creation of a “common language,” prevents ambiguities and different interpretations in subsequent stages. The number of variables should be optimal; too few may lead to oversimplification of the system, and too many may make the analysis process complex and unmanageable.

Step 2 (Formation of the direct effects matrix): After the list of variables is finalized, a square matrix of dimensions n×n is formed, where n is the number of variables. This matrix is called the direct effects matrix. In this matrix, the identified variables are placed in the same order in both rows and columns. Then, the group of experts is asked to rate in pairs the direct effect of the variable in row i on the variable in column j, based on a specific scale. The scoring scales are presented in Table 3.

Table 3
Scoring scale for the direct impact matrix

Score	Description	Definition

0	No impact	Variable i has no direct effect on variable j.
1	Weak impact	A change in variable i has a small and negligible effect on variable j.
2	Moderate impact	A change in variable i has a significant effect on variable j.
3	Strong impact	A change in variable i has a significant and very strong effect on variable j.
P	Potential impact	There is no direct effect at present, but this relationship is likely in the future.

To complete this matrix, each cell M_{ij} is filled with one of these values. The entries on the main diagonal of the matrix (M_{ii}), which represent the effect of a variable on itself, are conventionally set to zero.

Step 3 (Discovering indirect relationships by raising the matrix to exponents): The real power of MI'CMAC analysis lies in its ability to reveal the hidden structure of the system. Many system dynamics are controlled by indirect relationships and feedback loops that are invisible to analysts at first glance. The MDI matrix only shows "influence paths of length 1" (i.e., direct effects). To identify indirect effects, this matrix must be raised to successive powers 2,3,...,k. As the matrix is raised to exponents, the ranking of the variables may change. This process continues until the matrix reaches "stability." Stability is achieved when the ranking of variables in the next power (MDIk+1) no longer changes significantly. This point indicates that all important influence paths, both direct and indirect, have been identified and included in the calculations.

Step 4 (Calculate the final influence and dependence): After reaching the stable matrix (which we call M_{stable}), the final values for two key indicators are calculated for each variable:

- Influence: For each variable i, the influence is calculated by summing the values of its row elements.
- Dependency: For each variable j, the dependence is calculated by summing the values of its column elements.

These two values provide the coordinates of each variable for drawing in the final analysis map.

4.4 Interpreting the results of the MICMAC: Analysis of the Influence/Dependency Map

The results of the previous step are depicted in the form of a two-dimensional graphical map that provides a deep visual understanding of the structure and dynamics of the system. A two-dimensional Cartesian diagram is drawn in which the horizontal axis (X-axis) represents the "degree of dependence" and the vertical axis (Y-axis) represents the "strength of influence". The map is typically divided into four areas, each with a unique strategic interpretation. A detailed analysis of the four areas is as follows:

- Zone 1 - Autonomous variables (weak influence and weak dependence): These variables have weak connections with other system components and, from a strategic perspective, are usually not a high priority for intervention.

- Zone 2 - Dependent variables (weak influence and strong dependence): These variables are mainly the "results" or "outputs" of the system and are very useful as key performance indicators to assess the overall health and condition of the system.
- Zone 3 - Linked variables (strong influence and strong dependence): These variables, which are at the center of the system's feedback loops, are highly dynamic and sensitive in nature. Their inherent instability is both a source of risk and an opportunity.
- Zone 4 - Independent/influential variables (strong influence and weak dependence): These variables are known as the fundamental "key drivers" of the system and are the main leverage points for policymaking and strategic intervention.

The overall distribution of variables on the map provides information about the stability or instability of the entire system. A stable system, whose variables mainly form the shape of the letter "L", is a relatively stable, hierarchical, and controllable system. An unstable system, whose variables are scattered along the main diameter, is an unstable, reactive, and unpredictable system.

5. Results and analysis

The analysis process began with identifying and screening the drivers affecting supply chain sustainability. Based on the literature review presented in Chapter Two, an initial list of 45 potential drivers was developed. This list was provided to a panel of experts in the form of a fuzzy Delphi questionnaire. The panel members were asked to specify the importance of each driver during the pandemic crisis using a 5-point Likert scale (from 1 – very low to 5 – very high). After collecting the responses, the data analysis procedure was conducted according to the fuzzy Delphi algorithm. To select the most important drivers, a threshold value (Threshold) of $\alpha = 3$ was determined. Drivers that achieved a crisp score greater than or equal to this threshold were considered final drivers and selected for the next phase (ISM modeling). Based on the results, out of the 45 initial drivers, 39 were approved and 6 were rejected. This set of 39 finalized drivers forms the input for the next stage of the analysis.

Table 4

Complete Results of Fuzzy Delphi Screening of Strategic Drivers

ID	Description	Crisp value	Screening Result	ID	Description	Crisp value	Screening Result
1	Reducing operational costs without harming sustainability	3.653	Approved	24	Prioritizing social and environmental impacts in network design	3.158	Approved
2	Considering environmental and social requirements to maintain profitability	3.972	Approved	25	Compliance with standards such as ISO 14001	3.007	Approved

3	Aligning cost management with long-term sustainability goals	3.290	Approved	26	Assessment of suppliers' environmental and social performance	3.386	Approved
4	Dependence of purchasing decisions on suppliers' financial sustainability indices	3.138	Approved	27	.Periodic sustainability audits in the supply chain	3.439	Approved
5	Importance of suppliers' environmental certifications	1.985	Rejected	28	Allocation of financial resources to innovative sustainability projects	2.827	Rejected
6	Prioritizing recycled or low-carbon-footprint raw materials	2.404	Rejected	29	Adoption of sustainable innovations in product design	3.506	Approved
7	Reducing production waste through process optimization	3.561	Approved	30	Having pre-designed programs for maintaining sustainability during crises	3.488	Approved
8	Reducing production waste through process optimization	2.622	Rejected	31	Ability to maintain environmental sustainability indicators during crises	3.141	Approved
9	Considering environmental life-cycle criteria in product design	3.066	Approved	32	Prioritizing social values such as humane working conditions during crises	3.355	Approved
10	Transportation planning with priority for reduced pollution and energy consumption	2.843	Rejected	33	Regular assessment of social and environmental risks	3.029	Approved
11	Transparent monitoring of worker conditions in the supply chain	3.997	Approved	34	Requiring suppliers to comply with sustainability standards during crises	3.647	Approved
12	Ensuring suppliers comply with safe and fair labor standards	3.167	Approved	35	Using tools such as Life Cycle Assessment (LCA) to reduce risk	3.355	Approved
13	Inclusion of human-rights clauses in supplier contracts	3.033	Approved	36	Transparent sharing of data on product origins and production processes	3.005	Approved

14	Supporting small and medium-sized enterprises in the supply chain	3.135	Approved	37	Increasing consumer trust through sustainability data traceability	2.634	Rejected
15	Mandatory professional ethics training for supply chain staff	4.118	Approved	38	Replacing unsustainable suppliers with responsible suppliers	3.025	Approved
16	Use of modern communication technologies for sustainability monitoring	3.007	Approved	39	Existence of codes of conduct and explicit sustainability policies	3.557	Approved
17	Contribution of digital technologies to enhanced stakeholder participation	3.037	Approved	40	Existence of performance evaluation systems to track sustainability policies	3.533	Approved
18	Active sharing of sustainability information with suppliers	3.336	Approved	41	Involvement of top management in sustainability decision-making	3.040	Approved
19	Joint setting and monitoring of sustainability performance indicators with stakeholders	3.053	Approved	42	Considering consumer and stakeholder perspectives in decisions	3.528	Approved
20	Collaborating with customers to improve environmental performance	3.420	Approved	43	Providing equal opportunities for small suppliers	3.909	Approved
21	Participation in joint sustainable development projects with supply chain partners	3.407	Approved	44	Considering the rights of future generations in decision-making	3.845	Approved
22	Demand planning with environmental and social considerations	3.035	Approved	45	.Increasing consumer trust through sustainability data traceability	3.477	Approved
23	Reviewing or implementing circular supply chain models	3.015	Approved				

After finalizing the list of drivers, the next step was to analyze their interrelationships and hierarchical structure using the Interpretive Structural Modeling (ISM) method. This method is an interactive learning process that converts complex mental models into a graphical, understandable structure ().

Structural Self-Interaction Matrix (SSIM):The foundation of the ISM process is the SSIM. For constructing this matrix, the panel of experts was asked to determine the pairwise relationships among the 39 approved drivers. Expert judgments were recorded using the four standard VAXO symbols (influence from row to column, influence from column to row, mutual influence, no relation). After aggregation, the final matrix was formed.

Final Reachability Matrix: The qualitative SSIM matrix was converted into a binary matrix, known as the initial reachability matrix, using substitution rules. Then, by examining the transitivity principle, indirect relationships were identified and added to the model. This computational process resulted in the final reachability matrix, along with driving power (sum of 1s in each row) and dependence power (sum of 1s in each column) for each driver.

Level Partitioning of Drivers: After constructing the final reachability matrix, the level-partitioning process began. This process was carried out iteratively by identifying the reachability set, antecedent set, and intersection set for each driver. Drivers whose reachability and intersection sets were identical were placed at the highest hierarchical level. The complete details of these iterations are shown in Table 5.

Table 5

Complete summary of the booster leveling iterations

Level	Driver ID	Level description
Level I (Final Outcomes)	36, 14, 12, 11, 45	Observable outcomes and transparency—these represent the visible final results that directly affect stakeholders, such as transparency in working conditions and consumer trust. These drivers have the highest dependence on the system's overall performance
Level II (Operational Execution and Control)	20, 19, 18, 7, 1, 26, 24, 23, 22, 34, 32, 31, 27, 38	Daily operations and control—tactical tools for achieving the outcomes in Level I.
Level III (Technological and Process Enablers)	29, 25, 17, 16, 9, 35	Tools and innovations that enable and optimize Level II processes
Level IV (Stakeholder and Supplier Integration)	,42 ,21 ,13 ,4 43	Collaboration and external interactions—translating fundamental policies into contractual and cooperative mechanisms
Level V (Policies and Enabling Systems)	40 ,33 ,30 ,3	Managerial infrastructures—performance evaluation systems, risk planning, and other overarching governance mechanisms
Level VI (Strategic and Value-Based Foundations)	,41 ,39 ,15 ,2 44	Philosophical and governance foundations—core elements defining the strategic "why" and "how" of sustainability

Final Hierarchical Model: The final output of the level-partitioning process is a hierarchical ISM model. This model converts the complex structure of driver relationships into a multi-level, understandable diagram, where lower-level drivers form the prerequisites and foundations of higher-level drivers. The six-level model depicts a logical cause-and-effect structure. In the directed graph (digraph), Level VI drivers appear at the bottom as the system's roots, including top-management commitment (41), long-term vision (44), integration of sustainability into the business model (2), explicit policy-making (39), and ethical culture (15). These are fundamental prerequisites without which any sustainability effort becomes unstable and short-lived. These strategic foundations enable Level V managerial infrastructures such as performance evaluation systems (40) and risk management (33). These systems, in turn, prepare the ground for Level IV stakeholder integration-where policies manifest in contracts (13) and joint collaborations (21). Next, Level III introduces technological and process enablers-digital technologies (16), product innovation (29), etc.-which enable optimization based on established collaborations. These tools directly lead to Level II operational implementation, including waste reduction (7), supplier audits (27), and replacement of unsustainable suppliers (38). Ultimately, success in all lower levels results in the observable outcomes in Level I: transparent worker monitoring (11), ensuring labor standards (12), and enhanced consumer trust (45). The model shows that achieving these highest-priority outcomes is not accidental—it is the result of a logical chain originating from deep, strategic commitments within the organization.

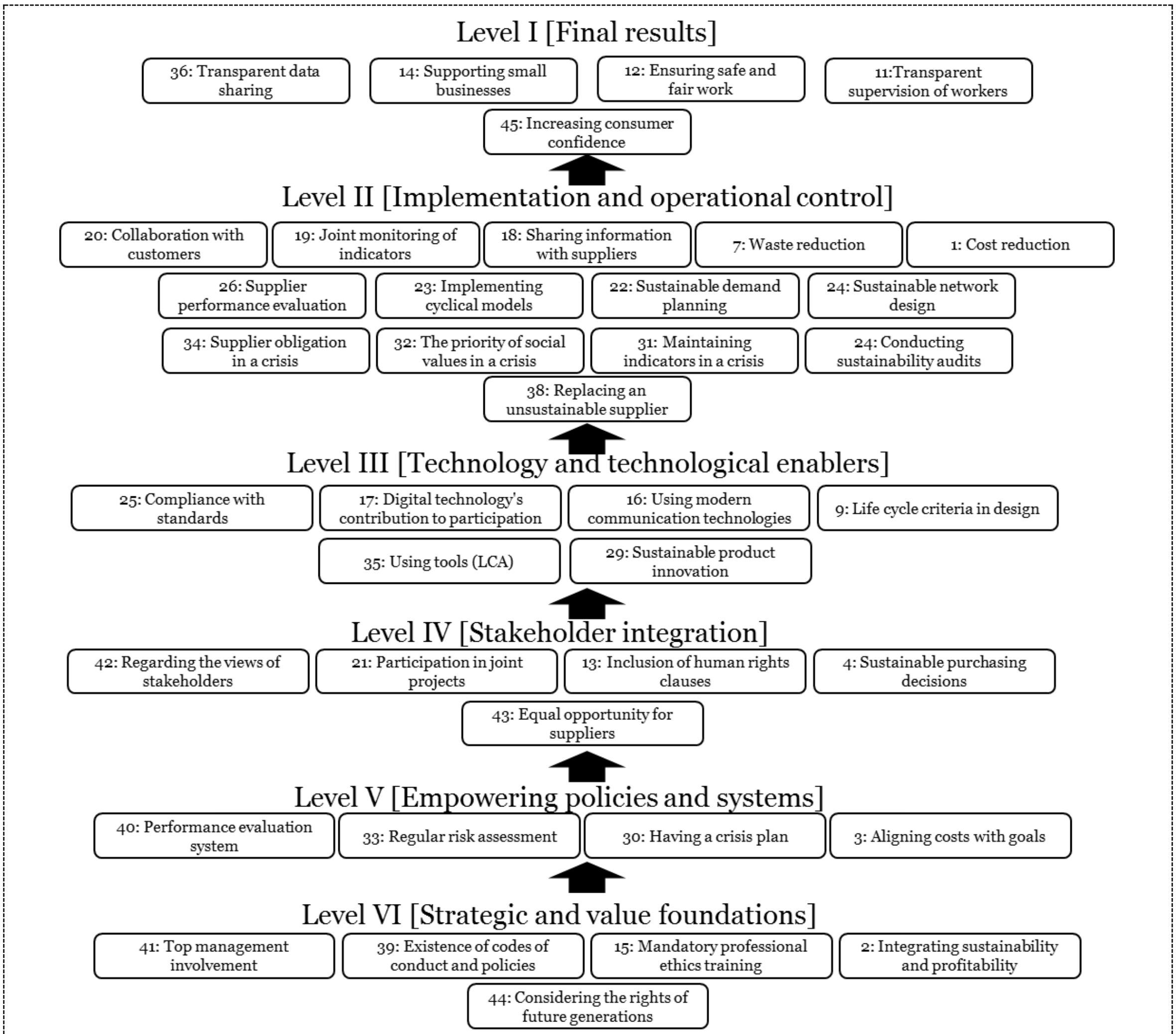

Fig. 1. Structural-Interpretive Model of Drivers of Fashion Supply Chain Sustainability

In the final step, MICMAC analysis was used to categorize drivers based on two key criteria: driving power and dependence power. These values were extracted from the final reachability matrix. By plotting these two measures on a two-dimensional graph, drivers are classified into four strategic zones.

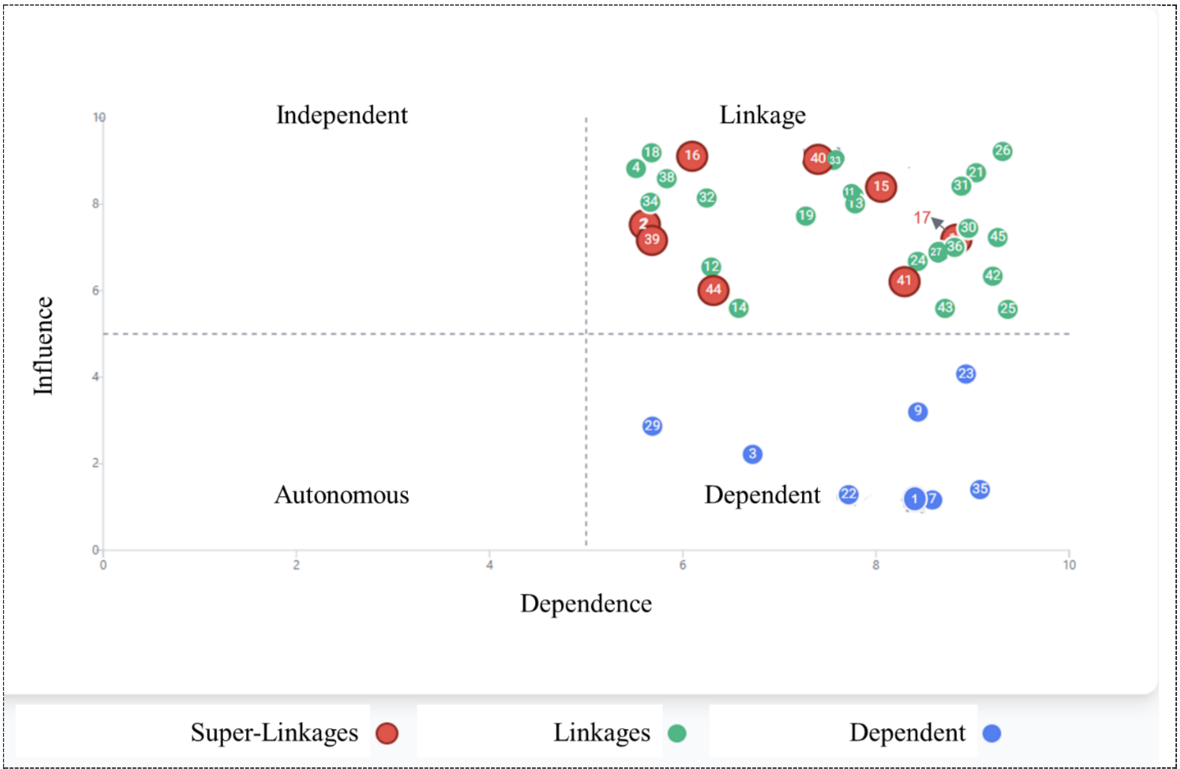

Fig. 2. MICMAC Diagram

The diagram is a four-quadrant scatter plot. The horizontal axis represents dependence level, and the vertical axis represents driving power. All 39 drivers appear as points distributed across the quadrants: independent, linkage, dependent, and autonomous. Drivers in the Dependent Zone include those with low driving power but high dependence: (1), (3), (7), (9), (22), (23), (29), and (35). These drivers are final outcomes of the system. They possess low influence but are strongly affected by other factors—desirable targets but not key levers of change. Attempting to improve them directly, without addressing their root causes, is like treating symptoms instead of the underlying condition. Drivers in the Linkage Zone include those with both high driving power and high dependence: (2), (4), (11), (12), (13), (14), (15), (16), (17), (18), (20), (24), (26), (30), (32), (34), (38), (40), (42), (43), (44), and (45). These form the backbone of the system—highly influential yet highly sensitive. They are unstable, dynamic, and strategically significant. Interventions in this zone create the strongest chain reactions across the system. Among them, drivers with the highest driving power are recognized as super-linkage drivers, including environmental/social requirements for profitability, mandatory ethics training, modern communication technologies, digital participation tools, explicit sustainability policies, performance evaluation systems, top-management involvement, and consideration for future generations. No drivers appeared in the Independent or Autonomous Zones, indicating that the sustainable supply chain system is fully interconnected, with no isolated or irrelevant drivers. MICMAC analysis clearly shows that the path to achieving final desired outcomes (dependent drivers) is through investment in linkage drivers—the true leverage points.

6. Conclusion

This study aims to identify and structurally model the strategic drivers of sustainable supply chain management in the Iranian industry. Using a hybrid methodology, a wide range of initial drivers was screened through the fuzzy Delphi method and reduced to 39 key drivers. Then, the ISM technique was applied to analyze their complex interdependencies and extract a six-level hierarchical structure. Finally, MICMAC analysis was used to determine the strategic role of each driver based on its influence and dependence. The resulting six-level model illustrates a clear cause-and-effect pathway toward supply chain sustainability. Rather than presenting isolated factors, it provides a roadmap showing how sustainability outcomes emerge from a sequence of interconnected strategic, managerial, and operational efforts. Level 6 (Strategic and Value Foundations) forms the deepest layer, encompassing drivers such as top management commitment, clear codes of conduct, mandatory ethics training, attention to the rights of future generations, and alignment of sustainability with profitability. This level serves as the foundation for all subsequent actions. Consistent with strategic management theory, the findings reinforce that sustainable transformation requires long-term vision, leadership commitment, and institutionalized values. Without these foundations, efforts at other levels remain fragmented and ineffective. Moving upward, Level 5 encompasses management infrastructure, such as performance evaluation systems and crisis management programs. These are activated by the strategic drivers at Level 6 and, in turn, enable Level 4, which focuses on stakeholder integration through mechanisms like human rights clauses in contracts and collaborations. These collaborative foundations support Level 3, which includes tools and innovations such as new communication technologies and life-cycle analysis. These capabilities lead to the execution of Level 2 operational practices, including waste reduction and supplier performance evaluation. At the top, Level 1 represents outcomes such as transparent monitoring of worker conditions and increased consumer trust. Their placement at the highest level indicates that they are results, not starting points of sustainability efforts. This underscores that managers seeking transparency and trust must strengthen deeper structural and strategic layers rather than focusing solely on visible end outcomes. The main results obtained are confirmed by other related studies [85]. MICMAC analysis further clarified the system's internal dynamics by classifying drivers according to their influence and dependence. Most drivers were located in the dependent and linkage zones, while the independent and autonomous zones were empty. This reveals the highly interconnected nature of sustainable supply chain systems and indicates that isolated or ad hoc actions are unlikely to succeed; instead, systemic and coordinated approaches are essential. Linkage drivers, which both influence and are influenced by others, emerged as the system's core dynamic elements. Among them, eight super-link drivers acted as the primary levers of change. Notably, the key drivers positioned at Level 6 of the ISM model were the same ones identified as the most influential in the MICMAC analysis. This strong alignment significantly enhances the robustness and credibility of the findings. It also shows that the ISM hierarchy is not just logical but also power-driven: the most influential drivers anchor the foundational strategic layer. Although the study did not examine feedback loops or temporal dynamics among drivers, future research could employ a dynamic systems approach to capture the evolution of these relationships over time and enhance decision-making effectiveness.

7. Declarations

AI generative: The authors declare that they use Grammarly as an AI writing assistance tool to improve their English writing.

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Data Availability: Data available on request due to the privacy/ethical restriction.

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