

Fostering Industrial Symbiosis Through Sustainable Procurement Practices in the Turkish Textile Industry

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Abstract

This study's primary aim is to understand the role and interaction of various sustainability criteria within industrial symbiosis networks, and it embarks upon this task by way of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method. This study seeks to establish the main driving forces and dependent factors that could affect the success and resiliency of these networks, enhancing sustainable industrial practices. A strong decision-making tool, DEMATEL is used in this study to visualize complex cause-and-effect relationships between sustainability criteria through a systematic matrix approach. Data was collected from experts around industrial symbiosis, covering diverse sectors for comprehensive sustainability criteria. The analysis quantitatively assesses influence and dependency among identified criteria, clearly depicting systemic interactions. It illustrates that the criteria mentioned, resilience in IS networks, adoption of innovative technologies, and optimization of material exchanges are important driving forces in the system that can put considerable influence on other criteria. Conversely, the criteria of waste reduction and environmental impact reduction are highly dependent and are greatly changed by the actions of these drivers. This study thus emphasizes the crucial balance between the influential and dependent criteria, which offers insights for designing targeted strategies to strengthen the weaker areas and weaken the strong drivers to boost overall system sustainability. This manuscript presents a unique application of the DEMATEL methodology in the Turkish textile sector; an application not previously explored in the country's industry. Hence, mapping the complex cause-and-effect relationships connecting sustainability criteria in industrial symbiosis answers a great concern in the existing literature.

Keywords- Sustainable procurement, Industrial symbiosis, Supply chain management, Textile industry, Fuzzy logic.

1. Introduction

Despite the fact that a growing number of people rely on finite resources for their well-being, global production chains, commerce, and the environmental effects of production and consumption have all expanded (Lehtoranta et al., 2011). Detrimental effects on the environment caused by these factors, such as resource-intensive usage, growing industrialization and urbanization, contemporary lifestyles, energy-

intensive use, and land use patterns, have all contributed to an increase in greenhouse gas emissions in recent years (IPCC Climate Change, 2014; Dong et al., 2019; Zheng et al., 2019). These jeopardising environmental effects underscore the urgent need for sustainability-focused approaches that guarantee the prudent use of natural resources while simultaneously reducing environmental deterioration in procurement practices. With the effects of strong stakeholder pressure, environmental restrictions, and international laws, organizations all over the world have come to understand the significance of sustainability in their operations (Lalwani et al., 2018; Shashi et al., 2018; Mani et al., 2020; Rahman et al., 2020). Given the dynamic and uncertain nature of the business environment, which led businesses have immediately increase the efficacy of their sustainability initiatives in order to gain further competitive advantages (Tseng et al., 2022). In this context, procurement has become essential to promoting the company's sustainability strategy because of its position and ability to influence external enterprises in the supply chain (Green et al., 1998; Seuring, 2004).

Since sustainable procurement is seen as a key component of attaining sustainability throughout a supply chain, many top companies have begun investing in sustainable supply chain strategies (Kannan, 2021). The process of securing the purchase of goods and services (or "products") in a way that guarantees the least amount of impact on society and the environment over the course of the product's entire life cycle is known as sustainable procurement (Meehan & Bryde, 2011).

The textile sector in Turkey has considerable significance to the economy of the country and even of the international markets, especially in the Aegean region (Günaydin et al., 2019; Kanat, 2019; Kazancoglu et al., 2024; Sagnak et al., 2024). The textile sector employs 300 million people worldwide and has a market value of over 1.5 trillion USD (Platform for Accelerating the Circular Economy, 2021; Papamichael et al., 2023). According to Yadav & Majumdar (2024), the sector has been forced to adopt sustainable practices through whatever possible means due to an increase in environmental concerns and restrictions on the availability of resources. By promoting resource sharing and reuse across industries, industrial symbiosis (IS) can be extremely helpful in this regard and assist the textile industry in implementing sustainable buying practices.

IS has also emerged as one of the ways to combat these flaws by permitting sharing and reusing between two or more industries those particular goods, such as waste (Nyakudya et al., 2023; Mirata et al., 2024). IS, a subfield of industrial ecology that is sometimes described as a cooperative strategy in which one firm's waste is utilized as raw material by another company (Lowe & Evans, 1995), can assist in resolving these issues without jeopardizing economic growth (Neves et al., 2019). Also, IS can be seen as a system that maximizes the use of materials and energy, minimizes waste production, and uses waste streams from one industry as raw materials for another (Neves et al., 2019). Additionally, the idea of IS has been receiving more attention lately as a result of the realization of its value in accomplishing both economic and environmental objectives (Tseng & Bui, 2017).

Despite the fact that sustainable procurement is becoming more and more prominent in international policy circles, little is known about how deeply ingrained sustainable procurement practices (Walker & Brammer, 2012). On the other hand, the majority of the publications in the existing literature offer in-depth studies carried out in real contexts, that is, in a specific region, with a holistic analysis of those industries, wastes, and products with potential for developing IS (Mathews & Tan, 2011; Walls & Paquin, 2015; Dong et al., 2017; Leurent et al., 2018; Marchi et al., 2018; Park et al., 2018; Mortensen & Kørnøv, 2019). Even though it has been demonstrated that the collaboration benefits the environment, the participating businesses, and the local population, IS's potential is also still unrealized, and there is still a research gap for application in both developed and developing countries (Neves et al., 2019). Furthermore, related studies in the current

literature indicate that gathering environmental data from suppliers does not always result in an assessment of that data (Preuss, 2007); instead, it acts as a stand-in control mechanism for supplier evaluation and selection (Koplin et al., 2007), shifting procurement's role from development to policing (Meehan & Bryde, 2011).

In light of this information, this study analyzes the Aegean textile industry's procurement capacities and environmental challenges using a conceptual framework as a basis. Through case study scenarios, this study mainly tries to illustrate the advantages of IS and sustainable procurement as well as the criteria considered in their adoption. This study offers procurement managers, supply chain strategists, and policymakers' useful insights to maximize resource efficiency, reduce supply chain risks, and improve resilience by putting forward workable mitigation options. This study develops the following research questions (RQs) to methodically examine the function of IS and sustainable procurement in the textile sector within an emerging economy setting, building upon the stated research gaps, motivations, and objectives:

RQ1: Within the scope of industrial symbiosis processes, which sustainability criteria affecting supply activities are the strongest drivers and which are the dependent criteria in the system?

RQ2: How can environmental, social, and economic sustainability criteria be integrated into sustainable supply strategies based on industrial symbiosis, considering their interrelationships and cause-and-effect relationships?

RQ3: How can an integrated analytical approach based on DEMATEL contribute to understanding the relationships between criteria in supporting the development of industrial symbiosis practices in developing economies like Turkey?

This study's uniqueness comes from its integrated methodology, which connects theoretical developments in decision-making techniques, Decision-Making Trial and Evaluation Laboratory (DEMATEL), with their real-world implementation in a fast-paced industrial environment. This research aims to extend existing studies on industrial symbiosis and sustainable procurement by offering a context-specific and integrated analytical perspective. Although DEMATEL and related multi-criteria decision-making techniques have been applied to sustainability and procurement issues in earlier research, these studies have mostly concentrated on isolated dimensions, particular firm-level practices, or developed economy contexts. As a result, this study tries to make three primary contributions to the existing literature. Initially, it tries to offer a comprehensive viewpoint on resource exchanges amidst firms by integrating environmental, social, and economic sustainability criteria into a procurement framework that is focused on industrial symbiosis context. The Turkish textile industry, an emerging economy setting that is still underrepresented in current IS-procurement research, is the second empirical setting in which DEMATEL method is applied. Third, the study tries to connect policy-oriented sustainability goals with operational practices by fusing causal relationship analysis with case-based insights. By providing useful advice for decision-makers working in resource-intensive industrial ecosystems, this research advances the knowledge of how industrial symbiosis can be strategically integrated into sustainable procurement systems.

2. Literature Review

IS has gained increasing popularity as an active strategy of sustainability by enhancing resource efficiency, reducing waste, and minimizing environmental impacts. Potential benefits of IS have been noted in some studies to include real resource "waste-to-resource" alleviations as well as optimizations on resources in various other sectors (Huang et al., 2020; Suzanne et al., 2021). The review is a compilation of key studies concerning IS with special reference to various aspects of procurement criteria (Fraccascia et al., 2017; Herczeg et al., 2018), environmental and social integration (Lehtoranta et al., 2011; Turken & Geda, 2020),

and, lastly, the role of policy frameworks in providing IS facilitation (Lehtoranta et al., 2011; Pajunen et al., 2013).

One of the major advantages of IS would be the efficiency of resource utilization that it can bring about, and it can also minimize waste. Such studies highlighted the role of IS as being largely productive in reducing waste and emissions through their support in optimizing material and energy flows by industrial collaboration (Mathur et al., 2020; Huang et al., 2020; Suzanne et al., 2021). Fraccascia et al. (2017) and Turken & Geda (2020) emphasize this waste-to-resource transformation as the procurement criterion in developing networks of IS. Hence, one of the prominent issues in IS research is the reduction of environmental effects. Hashimoto et al. (2010), Kundu et al. (2021), and Fallahi et al. (2024) have shown how IS could contribute to CO₂ and water footprint reductions through collaborative waste recycling and resource recovery. These studies also underscore the ways IS could engage procurement practices to be consequent with environmental sustainability goals.

It also needs to integrate environmental, social, and economic criteria for IS to realize its full potential. Similarly, Lehtoranta et al. (2011), Turken & Geda (2020), and Lawal et al. (2021) added that for IS to be sustainable, there is a need for multi-dimensional approaches beyond mere environmental objectives, including economic viability and social benefits such as job creation and community engagement. The IS networks optimizing resource flow and at the same time, being economically competitive and socially inclusive would be most successful in the long run.

In light of this, it is crucial to integrate IS into SSCM in order to enhance resource utility while minimizing the associated environmental impact. Pajunen et al. (2013), Herczeg et al. (2018), and Lawal et al. (2021) note that the collaboration of supply chain partners, either on the supplying or buying end, forms an important step in effectively implementing IS. Effective collaboration facilitates better coordination of resource exchange, thereby minimizing waste while making the supply chain resilient.

IS networks should also be resilient to disturbances, especially environmental and economic changes. Chopra & Khanna (2014) and Yu et al. (2023) discuss how to enhance resilience in IS networks by encouraging diversity and redundancy in material flows. This will ensure that the IS network remains operational even if there are external shocks or disruptions, hence flexibility is a key criterion for procurement.

Effective policies are crucial in surmounting institutional hurdles to IS development. Lehtoranta et al. (2011) and Pajunen et al. (2013) postulated that government support through waste regulations, tax incentives, and infrastructural development provides much-needed assistance for the blossoming of IS networks. Supporting the IS by policy frameworks regarding the promotion of collaboration and by-product utilization is the key to long-term sustainability of industrial ecosystems.

Other related aspects of IS include the consideration of water footprint reduction. Yu et al. (2023) and Fallahi et al. (2024) assess how much IS can contribute to water reuse and resource recovery. Valorization of the waste materials, including water recovery and energy generation, is seen as a very relevant opportunity for IS contribution in the circular economy framework, according to Gonela et al. (2015) and Kundu et al. (2021). The literature about the application of IS can be seen in **Table 1**.

IS has the potential to significantly contribute to sustainability objectives by enhancing resource efficiency, reducing waste, and mitigating environmental impacts. The effective implementation of IS requires the integration of environmental, social, and economic criteria into procurement decisions, supply chain

collaboration, and supportive policy frameworks. By addressing these factors, IS networks can play a crucial role in transitioning to a circular economy, providing economic, environmental, and social benefits.

Table 1. Literature review on industrial symbiosis practices.

Author	Objective	Country	Industry	Method
Phillips et al. (2006)	To promote sustainable waste management practices in Northamptonshire through waste minimization clubs.	United Kingdom	Waste management	
Illsley et al. (2007)	To address rural fuel poverty in Scotland through the development of a regional IS strategy utilizing wood biomass from the forest industries.	Scotland	Forest and Energy	Regional analysis and market development strategy
Hashimoto et al. (2010)	To evaluate CO2 emission reductions in Eco-towns using life cycle analysis and alternative IS scenarios.	Japan	Cement and urban industries	Life cycle analysis
Lehtoranta et al. (2011)	To analyze how SCP policies influence IS and evaluate the role of policy instruments in advancing EIPs and IS.	Finland	Forest Industry	Literature review, policy analysis, case study
Pajunen et al. (2013)	To identify and address institutional barriers in developing IS residue-based products.	Finland	Process industries	Legal and policy analysis, case studies
Gonela & Zhang (2014)	To design an optimal IS system for improving bioethanol production efficiency and profitability.	Global	Bioenergy	Linear and Mixed Integer Linear Programming
Chopra & Khanna (2014)	To assess resilience in IS networks using network analysis and propose strategies for improvement.	Denmark	Multiple Industry	Network analysis, case study
Yu et al. (2015)	To explore the evolution of IS in an eco-industrial park and identify drivers and characteristics of IS development.	China	Multiple Industry	Case study with qualitative and quantitative analysis
Leigh and Li (2015)	To integrate IE and IS principles into SSCM for enhanced environmental sustainability in a supply chain network.	United Kingdom	Distribution	Conceptual framework development, case study analysis
Albino et al. (2015)	To develop a conceptual model for urban IS that uses organic waste to produce electricity and reduce landfill reliance.	Italy	Urban sustainability	Conceptual model, input-output analysis
Gonela et al. (2015)	To design sustainable bioethanol supply chains integrating IS, addressing uncertainties and sustainability standards.	USA	Bioethanol supply chain	Stochastic MILP, case study
Witjes & Lozano (2016)	To link public procurement with sustainable business models for advancing the circular economy.	Netherlands	Public procurement	Framework development, literature review
Fraccascia et al. (2017)	To measure technical exchange efficiency in IS networks and guide IS network development.	Italy	Multiple Industry	Enterprise input-output analysis
Herczeg et al. (2018)	To explore supply chain collaboration in IS networks and its impact on sustainability.	Denmark, Germany	Multiple Industry	Theoretical framework, case studies
Zhang et al. (2018)	To develop an optimal model for carbon emission reduction in IS, focusing on sustainable consumption of waste resources.	China	Iron and Steel	Environmental input-output analysis, fuzzy goals programming
Fraccascia and Yazan (2018)	To evaluate the role of online platforms in improving IS networks' efficiency and collaboration.	Netherlands	Multiple Industry	Agent-based modeling, case study
Shi and Li (2019)	To establish a management framework that incorporates symbiotic and life cycle approaches for sustainable resource management in industrial ecosystems.	Global	Multiple Industry	LCA, LCC
Mathur et al. (2019)	To assess the environmental benefits of applying IS practices to EoL EV batteries through reuse and recycling strategies.	United States	Electric vehicles and Renewable Energy	LCA, Waste hierarchy framework
Ali et al. (2019)	To evaluate the reuse of galvanized steel scrap from the automobile industry for developing building facade systems and achieving circular economy goals.	United States	Automobile and construction	Material flow analysis, quantitative cost and energy assessment, case study analysis
Mathur et al. (2020)	To establish a circular economy in the photovoltaic industry using Life Cycle Symbiosis for EoL panels.	USA	Photovoltaics	LCS modeling, environmental impact analysis
Turken & Geda (2020)	To review IS research in supply chains and propose future research directions.	Global	Multiple Industry	Literature review, conceptual analysis

Table 1 continued...

Huang et al. (2020)	To optimize IS networks by balancing sustainability pillars through multi-objective decision-making.	China	Multi-sectoral manufacturing	Mixed-Integer Programming, epsilon-constraint method
Wadström et al. (2021)	Develop a comprehensive framework to analyze the outcomes of IS, incorporating economic, environmental, and social dimensions.	Global	Multiple Industry	Analytical framework
Lybæk et al. (2021)	To analyze the role of policies in supporting IS and propose a framework for addressing barriers and enhancing drivers.	Denmark	Multiple Industry	Policy framework analysis, case study, qualitative interviews
Lawal et al. (2021)	To review and analyze tools for IS and resource optimization, focusing on enhancing the design and sustainability of Eco-Industrial Parks.	Global	Multiple Industry	Literature review, mathematical optimization tools
Suzanne et al. (2021)	To address lot-sizing problems in IS and analyze collaboration policies between production units.	France	Multiple Industry	Two-level lot-sizing, Lagrangian decomposition
Tang et al. (2021)	To develop optimal pricing and production strategies for manufacturers in IS under tax and demand considerations.	China	Manufacturing	Game theory, numerical modeling
Södergren & Palm (2021)	To identify how local governments can reduce barriers to IS implementation through governance.	Sweden	Multiple Industry	Theoretical framework, qualitative analysis
Kundu et al. (2021)	To valorize citrus lemon waste into bioethanol using a biorefinery approach.	India	Agro-industrial	Experimental study, process optimization
Zhang et al. (2022)	To evaluate the resource efficiency of chlorine metabolism in IS within Shanghai's chlor-alkali sector.	China	Chemical Industry	SFA, LCA, LCC, DEA
Qazi & Appolloni (2022)	To identify and analyze barriers and enablers for circular procurement to aid the transition towards a more circular economy.	Global	Multiple Industry	Systematic literature review
Filimonau & Ermolaev (2022)	To explore the opportunities and challenges of adopting IS principles for FW recovery in the foodservice sector.	Russia	Food	Semi-structured interviews, thematic analysis
Isafiade et al. (2022)	To integrate utility supply chain networks with IS for heat integration in process plants.	South Africa	Co-located process plants	Multi-period optimization, superstructure modeling
Khan et al. (2023)	To analyze the implementation of IS in Saudi Arabia and propose a framework to enhance its adoption across major industries.	Saudi Arabia	Multiple Industry	Case Study
Yu et al. (2023)	To optimize material exchanges in Eco-Industrial Parks by balancing environmental, economic, and social objectives.	China	Agricultural-industrial systems	MILP
Sajid et al. (2024)	To identify the barriers to circular procurement in the construction industry and propose a way forward to overcome these challenges.	Global	Construction	Systematic literature review
Behzad et al. (2024)	To quantify and rank regional IS synergies using a decision-making framework, focusing on waste-to-resource transformations.	Chile	Multiple Industry	Waste-to-resource algorithm, (MCDM)
Duflou et al. (2024)	To enhance material efficiency and reduce environmental impacts through IS in discrete manufacturing.	Europe	Metal Industry	Environmental impact assessment
Ullah et al. (2024)	To explore the role of GPP and ecolabels in fostering sustainable consumption and production, with a focus on overcoming barriers in developing nations.	Global	Multiple Industry	Policy analysis, case studies
Heck et al. (2024)	To analyze the dual role of IS as a facilitator and obstacle in transitioning an industrial park toward defossilization.	Germany	Chemical and process industries	Case study, qualitative system dynamics, causal loop diagrams
Fallahi et al. (2024)	To assess water footprints in IS and propose strategies for sustainability using integrated indices.	Iran	Steel, coal, and power generation	Linear programming, water footprint analysis
Laatsit & Johansson (2025)	To evaluate the impact of innovation policy instruments on the formation and development of IS in process industries.	Sweden	Process industries	Conceptual analysis

3. Methodology

The problem structure addressed in this study is a multi-criterion, interconnected, and nonlinear system. In the context of industrial symbiosis and sustainable supply, environmental, economic, and social criteria interact simultaneously; classical statistical methods cannot clearly explain which of these criteria drive the system and which are the consequences. Therefore, this study requires a decision-making framework that can both account for expert judgments containing uncertainty and make visible the cause-and-effect relationships between the criteria. Integrated methodology was chosen to meet this need because it allows for the simultaneous consideration of theoretical (criterion setting, sustainability dimensions) and practical (sectoral application, policy, and management implications) elements that cannot be explained by a single method. Thus, the reader is convincingly shown that the results obtained are both analytically sound and application-oriented. The integrated methodology in this study is based on the systematic combination of three main components:

- (i) conceptual framework and criteria definition,
- (ii) expert-based fuzzy DEMATEL analysis,
- (iii) interpretation and application in a sectoral context.

In the first stage, procurement criteria were determined using a literature review and the literature on sustainable supply-industrial symbiosis. This stage constitutes the theoretical dimension of the methodology and defines which criteria will be included in the analysis. In this study, some procurement criteria were determined as a result of a detailed literature review. These procurement criteria can be seen in **Table 2**. In this study, the procurement criteria, although they have different conceptual roles in the literature (preconditions/enablers, process-oriented criteria, and outcomes), were evaluated within a single integrated network, in accordance with the DEMATEL method's structure for revealing cause-and-effect relationships within the system. Instead of classifying criteria as dependent or independent beforehand, the DEMATEL approach aims to analytically reveal these relationships. Thus, the analysis results determined that some criteria play a more driving role in the system, while others play a more dependent role.

An extensive screening process based on a systematic review of the literature on sustainable procurement and industrial symbiosis was carried out before the procurement criteria were finalized. First, a wide range of possible criteria were found in sectoral analyses, policy reports, and peer-reviewed studies. Overlapping, context-specific, and conceptually similar indicators were included in this initial list. The criteria were improved through an iterative elimination process to guarantee analytical relevance and practical applicability. Highly context-dependent variables were eliminated, redundant indicators were combined, and criteria that had little bearing on inter-firm symbiotic interactions were eliminated. Expert judgment and theoretical consistency served as the guiding principles for this refinement process. The final selection was reached when thematic saturation was achieved, meaning that additional literature sources did not introduce substantively new procurement-related dimensions. As a result, a balanced and representative set of 14 criteria was established, capturing sustainability outcomes, procurement decision factors, and industrial symbiosis capabilities.

Each indicator was defined in quantifiable, practice-oriented terms and assessed in light of the structural features of the Turkish textile industry in order to address the operational relevance of the chosen criteria. In addition to their theoretical prominence in the literature, the criteria were chosen for their applicability to production systems that are water-intensive, export-oriented, and dominated by SMEs. The procurements criteria found and their conceptual role for each criterion are compiled in **Table 2**.

The system uses a unified DEMATEL network for the evaluation of all criteria, but each criterion functions as a separate component that serves different system functions. Some criteria assess procurement decision

factors, while other criteria assess industrial symbiosis capabilities and sustainability outcomes. The roles of the elements are explained through **Table 2**. The method enables DEMATEL to function without special criteria pre-identification because it operates through its causal analysis process to identify which criteria function as causes and which function as effects.

Table 2. Procurement criteria set.

Criteria	Procurement criteria	Conceptual role	References
C1	Resource efficiency	Sustainability outcome	Huang et al. (2020), Mathur et al. (2020), Suzanne et al. (2021), Tang et al. (2021), Fallahi et al. (2024)
C2	Waste reduction	Sustainability outcome	Fraccascia et al. (2017), Herczeg et al. (2018), Huang et al. (2020), Suzanne et al. (2021)
C3	Environmental impact reduction	Sustainability outcome	Hashimoto et al. (2010), Mathur et al. (2020), Tang et al. (2021), Fallahi et al. (2024)
C4	Circular resource flows	IS capability	Albino et al. (2015), Witjes & Lozano (2016), Mathur et al. (2020)
C5	Integration of environmental, social, and economic criteria	Procurement decision factor	Herczeg et al. (2018), Turken & Geda (2020), Södergren & Palm (2021)
C6	Sustainable supply chain management	Procurement decision factor	Pajunen et al. (2013), Fraccascia et al. (2017), Suzanne et al. (2021)
C7	Collaboration and governance	IS enabler	Fraccascia & Yazan (2018), Södergren & Palm (2021), Yu et al. (2023)
C8	Optimization of material exchanges	IS capability	Huang et al. (2020), Isafiade et al. (2022), Yu et al. (2023)
C9	Adoption of innovative technologies	IS enabler	Gonela et al. (2015), Kundu et al. (2021), Isafiade et al. (2022)
C10	Development of IS frameworks	IS enabler	Herczeg et al. (2018), Lawal et al. (2021), Laatsit & Johansson (2025)
C11	Resilience in IS networks	IS capability	Pajunen et al. (2013), Chopra & Khanna (2014), Södergren & Palm (2021)
C12	Policy integration and support	IS enabler	Lehtoranta et al. (2011), Pajunen et al. (2013), Södergren & Palm (2021)
C13	Utilization of by-products	IS capability	Hashimoto et al. (2010), Albino et al. (2015), Kundu et al. (2021)
C14	Water footprint reduction	Sustainability outcome	Fraccascia & Yazan (2018), Fallahi et al. (2024)

In the second stage, the DEMATEL method was used. DEMATEL reveals cause-and-effect relationships by calculating the direct and indirect effects between criteria using a matrix-based approach. Expert opinions were used in the study, and these opinions from different sectors were expressed using fuzzy logic, integrating uncertainty and subjective judgments into the model. In this way, both the impact strength and the dependency level of the criteria were calculated quantitatively. As a result, the criteria were separated into driving and dependent factors. The analytical outputs obtained in the third stage were interpreted specifically for the Turkish textile sector and the Aegean region. Here, the methodology went beyond simply producing a mathematical result, transforming it into managerial and political implications on how industrial symbiosis can be strengthened in practice.

These integrated methods are used complementarily, not sequentially. The conceptual framework guides the analysis, DEMATEL quantifies this framework, and the sectoral application connects the results to a real-world context. The methodology comprehensively reveals not only the order of importance of sustainability criteria but also their roles and interactions within the system.

3.1 Fuzzy DEMATEL

DEMATEL is a method used to analyze complex systems and evaluate the relationships and interactions between their elements (Dicks & Molenaar, 2024). It is especially suited for determining causal relationships and the influence strength among factors in a system (Nicula & Constantinescu, 2023).

Decision-makers can use DEMATEL to build the structure of the problem, prioritize factors, and understand the cause-and-effect relationships within a network. DEMATEL has the following six steps (Kazancoglu et al., 2023):

Step 1: Assessment of the initial Z matrix of direct relationships requires the appraisal of the first direct relation matrix with a pairwise comparison process. To see how any two elements interact, respondents are asked to define the direct relations on an integer scale divided into four levels. The fuzzy DEMATEL comparison scale includes "No influence (0), Low impact (1), Medium influence (2), High influence (3), Very high influence (4)." The fuzzy scale can be seen in **Table 3**.

Table 3. Fuzzy scale.

Linguistic term	Crisp scale	(l, m, u)
No influence	0	(0.00, 0.00, 0.25)
Low influence	1	(0.00, 0.25, 0.50)
Medium influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1.00)
Very high influence	4	(0.75, 1.00, 1.00)

Step 2: Through pair-wise comparison, we obtain the initial total relation matrix Z , which is an $a[n \times n]$ matrix. Respondents were able to rank how much the criterion Di affected the criterion Dj in terms of effect and direction, where z_{ij} , j denotes the decision maker's judgments. The information collected has been put into a matrix with principal diagonal members equal to zero.

$$z_{ij} = \frac{1}{l} \sum_{k=1}^l z_{ij}^k, \quad i, j = 1, 2, \dots, n,$$

$$D_1 D_2 \dots D_n,$$

$$Z = D_1 D_2 \dots D_n \begin{bmatrix} 0 & z_{12} & \dots & z_{1n} \\ z_{21} & 0 & \dots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_{n1} & z_{n2} & \dots & 0 \end{bmatrix}.$$

Step 3: Aggregation of expert judgments. The individual fuzzy direct-relation matrices obtained from the 15 experts were aggregated by calculating the arithmetic mean of the corresponding fuzzy values for each cell. This process resulted in a single aggregated fuzzy direct-relation matrix representing the collective expert perception. Using the formula denoted below, the normalized direct relation matrix X can be computed and established:

$$X = \frac{Z}{s},$$

$$s = \left(\sum_{j=1}^n z_{ij}, \sum_{i=1}^n z_{ij} \right).$$

All matrix X components are such that:

$$0 \leq x_{ij} < 1,$$

$$0 \leq a,$$

$$\sum n_j = 1,$$

$$x_{ij} \leq 1,$$

and at least go one of such i 's having, $\sum n_j = 1 \quad z_{ij} \leq s$.

Step 4: When considering $h \rightarrow \infty$, we compute the total relation matrix T , which gets defined as

$$T = X + X^2 + X^3 + \dots + X^h = X(1 - X)^{-1},$$

where, I is an identity matrix.

Step 5: Generating Innovative Relation Maps IRM. The addition of the values in rows and columns is done independently in this phase and is designated as C and R in the matrix of total relation.

$$R = [r_i]_{n \times 1} = [\sum_{j=1}^n t_{ij}]_{n \times 1}, \quad C = [c_j]_{1 \times n} = [\sum_{i=1}^n t_{ij}]_{1 \times n}^T.$$

Step 6: Another way is to induce a causal diagram. This is done when we link datasets and adjust a C from an R . The horizontal axis is denoted by $(R + C)$ and is called the Cause. The size of the ratio $(R + C)$ says how strongly the criterion affects the system at large. Conversely, the vertical axis is denoted by $(R - C)$ and is called the Effect. If $(R - C) > 0$, then there is some net causation, conversely, if $(R - C) < 0$, then there is some net reception or effect.

All aggregation, defuzzification, normalization, and matrix operations were performed using Microsoft Excel.

3.2 Defuzzification Method

In this paper, the CFCS method is selected as the method for defuzzifying the fuzzy data into crisp scores. It was developed by Opricovic and Tzeng (2003). The approach uses fuzzy maximum and minimum values in deciding the left and right scores. With the membership functions, the overall score is determined by using a weighted average (Berberoglu et al., 2023).

The fuzzy judgments:

$$\tilde{z}_{ij}^k = (l_{ij}^k, m_{ij}^k, r_{ij}^k), \quad (k = 1, 2, \dots, \rho).$$

Normalization:

$$xl_{ij}^k = (l_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max},$$

$$xm_{ij}^k = (m_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max},$$

$$xr_{ij}^k = (r_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max}.$$

$$\text{where, } \Delta_{min}^{max} = \max r_{ij}^k - \min l_{ij}^k.$$

Right and left values:

$$xls_{ij}^k = xm_{ij}^k / (1 + xm_{ij}^k - xl_{ij}^k),$$

$$xrs_{ij}^k = xr_{ij}^k / (1 + xr_{ij}^k - xm_{ij}^k).$$

Total crisps value:

$$x_{ij}^k = [xls_{ij}^k(1 - xls_{ij}^k) + xrs_{ij}^k xrs_{ij}^k] / [1 - xls_{ij}^k + xrs_{ij}^k].$$

Calculation of crisp values:

$$z_{ij}^k = \min l_{ij}^k + x_{ij}^k \Delta_{min}^{max}.$$

The final integrated crisps values:

$$z_{ij}^k = \frac{1}{\rho} (z_{ij}^1 + z_{ij}^2 + \dots + z_{ij}^\rho).$$

3.3 Case Study

The fuzzy DEMATEL method was applied in a case study with key stakeholders in the Turkish textile industry. This study aimed to evaluate how sustainable procurement practices are put into practice in IS. A panel of experts with diverse backgrounds in the textile sector was formed to assess the procurement criteria identified in the literature review. The expert panel was established through selection methods that are typically used in expert-based multi-criteria decision-making research. Experts were selected based on three main criteria: (i) direct professional involvement in the textile supply chain or industrial symbiosis-related activities, (ii) a minimum of five years of sectoral experience, and (iii) practical or academic expertise in sustainability, circular economy, or logistics management. The final panel consisted of 15 experts who represented various organizations that included textile manufacturing firms and recycling companies, logistics providers, consultancy firms, and academic institutions. The panel members worked in the Aegean textile ecosystem as their main research area, but they also had professional work experience in other Turkish regions, which enabled the panel to show both regional specificities and general industry trends. The expertise and practical roles of panel members are detailed in **Table 4**.

Table 4. Expert information.

Expert number	Profession	Years of experience
1	Production Manager	12
2	Sustainable Procurement Specialist	8
3	Environmental Impact Analyst	10
4	Supply Chain Manager	15
5	Circular Economy Researcher	7
6	Waste Management Expert	11
7	Logistics and Transportation Specialist	13
8	Assistant Professor	14
9	Professor	20
10	Recycling Specialist	9
11	Water Footprint Analyst	10
12	Energy Efficiency Consultant	12
13	Academic Researcher	8
14	Sustainability Expert	9
15	Industrial Ecology Expert	15

3.4 Data Collection

Data were collected using structured questionnaires whereby experts rated the influence of one criterion over another on a scale of 0 (no influence) to 4 (very high influence). The data were thereafter transformed into a fuzzy direct relationship matrix, which underwent normalization to bring about consistency and handle ambiguity due to human judgments.

The normalized direct relation matrices were then used to calculate the total relation matrix, which aids in the description of the cause-and-effect relationship among the criteria. These relationships, sometimes shown in causal diagrams, help in visualizing the influence dynamics between the said criteria.

3.5 Results

In this portion of the research, a case study is undertaken to evaluate the implementation of sustainable sourcing practices by key stakeholders within the context of the Turkish textile industry. The expert panel with regards to this study consisted of various stakeholders experienced in a multitude of fields within the textile industry. This panel evaluated the sourcing criteria derived by way of literature review. Fuzzy DEMATEL was used in this study to visualize the impact dynamics of these criteria.

The DEMATEL research revealed a precise categorization of cause-and-effect aspects and offered a systematic evaluation of the interdependencies among procurement criteria in promoting Industrial Symbiosis within the Turkish textile sector. A comprehensive insight of the most important enablers and dependent outcomes in the adoption of sustainable procurement procedures is made possible by this difference. First, as can be seen in **Table 5**, the arithmetic means of the experts' assessments and the regions they considered appropriate were obtained during the creation of the initial direct relation matrix (see **Table 5**).

Table 5. Initial direct relation matrix.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	Total
C1	0,033	0,585	0,967	0,967	0,733	0,396	0,313	0,191	0,967	0,733	0,967	0,191	0,967	0,967	8,976
C2	0,313	0,033	0,313	0,313	0,547	0,775	0,547	0,547	0,733	0,313	0,500	0,547	0,733	0,914	7,129
C3	0,396	0,775	0,033	0,733	0,139	0,775	0,313	0,232	0,967	0,967	0,914	0,547	0,232	0,967	7,990
C4	0,547	0,360	0,733	0,033	0,191	0,914	0,547	0,967	0,585	0,733	0,775	0,313	0,914	0,914	8,525
C5	0,914	0,914	0,687	0,914	0,033	0,232	0,360	0,232	0,547	0,585	0,585	0,914	0,585	0,547	8,047
C6	0,865	0,664	0,819	0,587	0,819	0,033	0,967	0,547	0,587	0,967	0,967	0,819	0,967	0,587	10,193
C7	0,640	0,547	0,967	0,865	0,640	0,587	0,033	0,640	0,640	0,967	0,865	0,819	0,733	0,547	9,488
C8	0,967	0,967	0,914	0,967	0,733	0,914	0,861	0,033	0,604	0,809	0,768	0,733	0,861	0,914	11,044
C9	0,775	0,809	0,861	0,967	0,809	0,768	0,861	0,809	0,033	0,967	0,967	0,914	0,967	0,967	11,472
C10	0,640	0,775	0,914	0,967	0,967	0,861	0,809	0,809	0,033	0,033	0,775	0,967	0,604	0,914	10,895
C11	0,861	0,640	0,809	0,861	0,967	0,861	0,914	0,967	0,861	0,967	0,033	0,967	0,861	0,914	11,482
C12	0,640	0,640	0,472	0,733	0,733	0,587	0,640	0,967	0,664	0,547	0,865	0,033	0,819	0,664	9,004
C13	0,967	0,967	0,664	0,967	0,764	0,865	0,865	0,865	0,587	0,967	0,764	0,547	0,033	0,587	10,406
C14	0,865	0,819	0,587	0,733	0,547	0,865	0,547	0,967	0,764	0,967	0,664	0,640	0,664	0,033	9,660
														Max	11,482

The degrees of C and R values in **Table 5** were later multiplied to create the total relation matrix (see **Table 6**).

Table 6. Total relation matrix.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0,003	0,051	0,084	0,084	0,064	0,035	0,027	0,017	0,084	0,064	0,084	0,017	0,084	0,084
C2	0,027	0,003	0,027	0,027	0,048	0,067	0,048	0,048	0,064	0,027	0,044	0,048	0,064	0,080
C3	0,035	0,067	0,003	0,064	0,012	0,067	0,027	0,020	0,084	0,084	0,080	0,048	0,020	0,084
C4	0,048	0,031	0,064	0,003	0,017	0,080	0,048	0,084	0,051	0,064	0,067	0,027	0,080	0,080
C5	0,080	0,080	0,060	0,080	0,003	0,020	0,031	0,020	0,048	0,051	0,051	0,080	0,051	0,048
C6	0,075	0,058	0,071	0,051	0,071	0,003	0,084	0,048	0,051	0,084	0,084	0,071	0,084	0,051
C7	0,056	0,048	0,084	0,075	0,056	0,051	0,003	0,056	0,056	0,084	0,075	0,071	0,064	0,048
C8	0,084	0,084	0,080	0,084	0,064	0,080	0,075	0,003	0,053	0,070	0,067	0,064	0,075	0,080
C9	0,067	0,070	0,075	0,084	0,070	0,067	0,075	0,070	0,003	0,084	0,084	0,080	0,084	0,084
C10	0,056	0,067	0,080	0,084	0,084	0,075	0,070	0,070	0,075	0,003	0,067	0,084	0,053	0,080
C11	0,075	0,056	0,070	0,075	0,084	0,075	0,080	0,084	0,075	0,084	0,003	0,084	0,075	0,080
C12	0,056	0,056	0,041	0,064	0,064	0,051	0,056	0,084	0,058	0,048	0,075	0,003	0,071	0,058
C13	0,084	0,084	0,058	0,084	0,067	0,075	0,075	0,075	0,051	0,084	0,067	0,048	0,003	0,051
C14	0,075	0,071	0,051	0,064	0,048	0,075	0,048	0,084	0,067	0,084	0,058	0,056	0,058	0,003

At this stage, RQ1 can be answered by identifying the sustainability criteria that act as driving factors and those that function as dependent factors within industrial symbiosis-based supply activities, based on the DEMATEL results. The Fuzzy DEMATEL results are shown in **Table 7**. The ranks of each criterion come from the column indicated by D+R. The larger the D+R, the more effective it is against the others. D-R values are also important to understand whether each criterion is cause or effect. For D-R, negative ones are “Effect”, positive ones are “Cause”.

Resilience in IS networks (C11) is reported to garner the highest D+R value of all the criteria. This means that it is an important causal factor within the system that defines the flexibility and resilience of IS networks in the face of various external forces. Resilience provides defense for IS networks against the shocks of the

economy or environment, supporting the continuance of sustainable business practices. This criterion assumes a critical place in determining the success of IS applications, especially in complex and volatile market conditions. The high D+R rating of Development of IS frameworks (C10) indicates that the criterion is very important for the system. The development of IS frameworks lays the building blocks for standardization and extension of IS applications, hence optimizing the resource-sharing process across different industries. This is a strategic scenario in achieving sustainability targets and in minimizing environmental impact. Adoption of innovative technologies (C9) is related to the adoption of innovative technologies and has a very high D+R magnitude. Innovative technologies support IS practices, optimizing resource usage and encouraging waste reduction, they also provide cost savings through process efficiencies. This criterion is important for the modernization of IS networks and compatibility with industry 4.0 technologies. These three criteria are strategically important for the development of IS networks and the sustainability goals of enterprises. Resilience, development of frameworks, and acceptance of innovative technologies will provide environment-related and economy-related benefits, but also serve to boost the resilience and competitiveness of the complete supply chain system.

Table 7. Fuzzy DEMATEL results.

Criteria	D	R	D+R	D-R	Rank	Dependence
C1	4.82918	5.034102	9.86	-0.20	9	Effect
C2	3.908544	5.064071	8.97	-1.16	13	Effect
C3	4.376691	5.198202	9.57	-0.82	12	Effect
C4	4.697772	5.633751	10.33	-0.94	8	Effect
C5	4.240235	4.627491	8.87	-0.39	14	Effect
C6	5.439239	5.098118	10.54	0.34	7	Cause
C7	5.08685	4.62674	9.71	0.46	10	Cause
C8	5.814699	4.765254	10.58	1.05	6	Cause
C9	6.082965	5.049817	11.13	1.03	3	Cause
C10	5.756543	5.614722	11.37	0.14	2	Cause
C11	6.09572	5.532634	11.63	0.56	1	Cause
C12	4.866564	4.788869	9.66	0.08	11	Cause
C13	5.517942	5.298971	10.82	0.22	4	Cause
C14	5.198189	5.578389	10.78	-0.38	5	Effect

The dominant drivers and dependent outcomes are highlighted in **Figure 1**, which depicts the criteria's causal structure. Although the most important factors are resilience in IS networks (C11), adoption of new technologies (C9), and optimization of material exchanges (C8), their importance becomes clearer when considered in the context of the Turkish textile industry. Network resilience is a crucial strategic priority in Turkey due to the country's frequent market fluctuations, reliance on exports, and susceptibility to supply disruptions. The strong driving force behind technological adoption can also be explained by the growing pressure for digital traceability, environmental reporting, and adherence to international standards. Furthermore, the practical need for waste valorization and cost reduction in resource-intensive textile production clusters is reflected in the optimization of material exchanges. Therefore, it appears that systemic capabilities rather than discrete operational interventions are needed to improve sustainability performance, as these structural drivers have a significant impact on dependent criteria like waste reduction and environmental impact mitigation. **Figure 1** indicates the causal diagram for each criterion of the system.

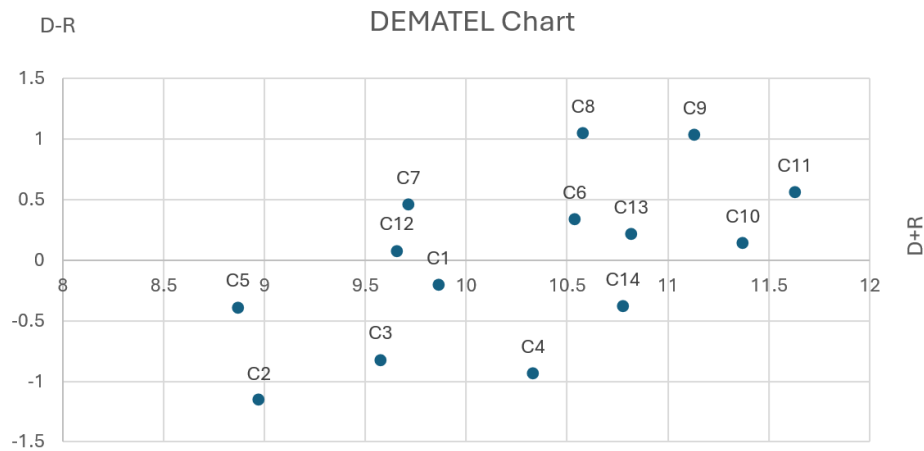


Figure 1. The causal diagram.

Highly influential and independent: Criteria C11 (Resilience in IS networks), C9 (Adoption of innovative technologies), and C8 (Optimization of material exchanges) stand out for being far right and high up on the D-R axis. Their position here suggests that they are yet significant drivers themselves in the system, capable of affecting other criteria to a greater degree than they are affected. Thus, these criteria would essentially drive change and, consequently ought to be considered strategic leverage points to maximize their impact. C6 (Sustainable supply chain management), C10 (Development of IS frameworks), and C13 (Utilization of by-products) also cause criteria, but are not as strongly positioned as the highly influential criteria. Their position indicates a solid but slightly less than dominant influence, meaning that, while they may drive changes, they do so with less strength as compared to the top-tier drivers. In the cause region but near the horizontal axis are C7 (Collaboration and governance) and C12 (Policy integration and support), clearly emerging influencers. With the right strategic focus and resources, these criteria could divert considerable impact towards themselves.

C2 (Waste reduction) and C3 (Environmental impact reduction) are the major dependent elements of the system, lying very much below the horizontal axis. They are more dependent on other criteria rather than being able to influence others. Accordingly, these are the responsive variables in the system. They might require a focused intervention or programmatic support to enhance their ability to contribute toward system-based objectives. C4 (Circular resource flows), C5 (Integration of environmental, social, and economic criteria), and C14 (Water footprint reduction) are all able to be considered lesser dependencies. Strategic work should improve their role in the system.

Heavy focus on strengthening the high D-R drivers (especially C11, C9, and C8) will make a major leverage for systemic changes. Making sure these criteria bolster their influence throughout the system is important. The ability to intervene with policy or resources would take care of highly dependent criteria, such as C2 and C3, in enabling them to act proactively for the system's goals. Emergent supporters like C7 and C12 should also be maintained for a balanced system to counteract functionality and sustainability.

4. Discussion and Implications

The DEMATEL application to the analysis in this study provides considerable insights into the dynamics of the IS network concerning the influence and dependence of sustainability criteria on one another. Understanding these dynamics is necessary for improving decision-making and implementing effective sustainability practices in the industry. Thus, the DEMATEL diagram shows that Resilience in IS Networks

(C11), Adoption of Innovative Technologies (C9), and Optimization of Material Exchanges (C8) are some criteria that exert a high influence on the system. These criteria have great cause-oriented roles and bring about systemic change. Their high placement on both the D-R and D+R axes makes them ideal catalysts to advance IS practices. In contrast, the lower placement of Waste Reduction (C2) and Environmental Impact Reduction (C3) on the D-R axis shows that they are likely to be more influenced by other elements and interventions within the system. This implies a greater level of dependency, thus highlighting these as perspectives where focused interventions are required to enhance their ability to positively influence and drive the system.

By optimizing the performance and impacts of key drivers such as C11, C9, and C8, notable improvements can arise from within the system. For instance, enhancing resilience in IS networks will afford the industries to withstand and adjust to environmental and economic pressures better. Similarly, enabling emerging technologies will fast-track the adoption of sustainable and efficient practices. Strategic planning and resource allocations directed toward these areas will yield the most impact for IS projects. Furthermore, the analysis elaborates upon the need to strengthen the more dependent criteria, such as C2 and C3. Although they have a low influence rating compared to others, their influence is pivotal in realizing the broader environmental sustainability agenda. In a more immediate sense, fostering a culture of waste reduction and environmental impacts involves more than direct interventions. It entails the integration of such interventions into the firms' main practices and the national policy landscape. This can take the form of creating sounder policies to promote waste minimization and enhance compliance requirements on environmental issues across industries. A balance between influential and dependent criteria ought to be maintained for the sustainability of IS networks.

The DEMATEL causal diagram clearly reveals not only the importance levels of criteria in a sustainable supply and industrial symbiosis system, but also their functional roles within the system. Criteria located in the upper right region of the diagram and having positive D-R values (e.g., adoption of innovative technologies, optimization of material changes, and resilience of industrial symbiosis networks) are key lever points that drive other criteria with high impact. The position of these criteria indicates that they are elements that trigger structural transformation in the system and create a chain reaction on multiple sustainability outcomes. In contrast, criteria located in the lower region of the diagram with negative D-R values (such as waste reduction, environmental impact reduction, and water footprint reduction) are more outcome-oriented and dependent in nature within the system. The low impact-high dependency structure of these criteria shows that improvements through direct interventions will have limited impact, instead, they are shaped indirectly depending on improvements in the driving criteria. This suggests that environmental performance indicators should be considered primarily for monitoring and evaluation purposes, rather than strategically. Criteria with D-R and D+R values near or in the middle of the diagram's center (e.g., sustainable supply chain management and criteria integration) play a balancing and connecting role in the system. These criteria are both influenced by driving factors and provide a transition mechanism for dependent criteria. Therefore, this position indicates that these criteria should be managed through gradual improvement and coordination mechanisms rather than sudden policy interventions. Overall, the diagram allows managers to clearly distinguish which criteria are strategic investment areas, which are operational monitoring indicators, and which are transition elements that need to be carefully managed in terms of system stability. In this respect, the DEMATEL causal diagram is not only an analytical output but also a prescriptive tool that guides multi-criteria sustainability decisions.

At this stage, RQ2 can be addressed by synthesizing the identified environmental, social, and economic criteria within the causal structure revealed by the DEMATEL analysis. DEMATEL findings demonstrate that the integration of environmental, social, and economic sustainability criteria into strategy should be

structured with a focus on "managing the causes" rather than "targeting the results." In this context, three rules are proposed for integration: (i) strengthening the system's leverage points by first investing in cause criteria (especially C11 resilience, C9 innovative technologies, C8 material change optimization, C10 IS frameworks, and C6 sustainable supply chain management), (ii) positioning bridging criteria (C7 collaboration-governance, C12 policy support, C13 byproduct use) as implementation mechanisms that ensure corporate coordination and establishing standard processes and common governance structures in these areas, (iii) monitoring dependent criteria (C2 waste reduction, C3 environmental impact reduction, C14 water footprint reduction), which are environmental performance outputs, not as targets to be directly suppressed, but as KPIs that measure the outcome of improvements in cause criteria. Thus, three-dimensional sustainability (environmental-social-economic) is integrated into the system not through individual projects, but through an integrated strategy design that starts with driving criteria and is reflected in the outcomes.

At this stage, RQ3 can be answered by explaining how the DEMATEL-based integrated analytical approach clarifies the causal relationships among sustainability criteria to support the development of industrial symbiosis practices in developing economies. One of the main challenges in implementing industrial symbiosis in developing economies like Turkey is the limited data on inter-firm flows and the low level of standardization in measuring sustainability criteria. Therefore, the fuzzy DEMATEL approach, which systematically incorporates expert judgments into the model, is applicable in data scarcity conditions and offers a practical analytical framework for decision-makers. Furthermore, the method clarifies which leverage points should be focused on for scaling IS in developing economies by highlighting the "driving role" of institutional capacity elements such as policy support (C12), governance/collaboration (C7), and framework development (C10).

Managers involved in or poised to develop IS networks can greatly benefit from understanding the criteria that are identified in this study as influential or dependent. Targeting the strengthening of key drivers such as IS networks' resilience, innovative technologies adoption, and material exchange optimization will help managers drive operational efficiency and sustainability. This includes investing in the resilient infrastructure and technologies that contribute to the better reuse and recycling of materials. Moreover, managers should consider initiating training programs for their staff to raise awareness and competence in the efficient management of such systems. Such strategic emphasis not only enhances the sustainability profile of the corporation but also gives the firm a competitive edge in constantly evolving markets with increasing environmentally conscious purchasing behaviors. Thus, from a managerial perspective, the criteria located in the driving quadrant of the causal diagram are primary intervention points for strategic decision-making, and resource allocation should be directed to these areas. Dependent criteria, on the other hand, should be treated as target outcomes in policy and strategy development processes, and direct operational pressure on these criteria should be avoided. Criteria located at the center or near equilibrium in the diagram should be monitored for system stability, and abrupt interventions should be avoided. Thanks to these decision rules, the DEMATEL diagram can be used not only as an analytical visualization but also as a systematic management tool.

Adding to the literature, this paper develops a DEMATEL application in IS, thereby contributing a novel insight into how different sustainability criteria interact within such networks. Scholars can utilize the findings as a springboard for investigating the interactions between these criteria further in various industrial contexts or geographical settings. In addition, this study provides some scope for examining how different interventions aimed at improving the driving criteria or supporting dependent criteria might play a role in IS networks. Furthermore, the long-term effects of these strategic focuses on the industrial systems' health and sustainability could be assessed.

The role of governments becomes important in defining how effective IS networks are, and therefore affects the conditions under which IS may operate. This research strongly suggests that policies promoting the resilient development of IS networks and integration of innovative technologies could strongly sustain industrial practice. Governments might also begin to think likely of offering incentives to firms investing in advanced recycling technologies or firms that achieve substantial reductions in waste and emissions. Additionally, the policy framework might be amended with the consideration of supporting the dependent criterion in a much swifter way, whereby environmental regulations are both firm and facilitating, so as to provide an explicit route for industries to adhere to in their sustainability journey.

Social implications also have profound significance, as this study emphasizes the importance of adopting sustainable practices within industrial operations. By supporting the adoption of innovative technologies and higher material and resource efficiency, industries decrease their environmental footprint, which in turn benefits the communities directly through lower pollution and more conserved resources. In addition, circular resource flows and waste reduction can create jobs in novel areas of recycling and sustainable management, thereby contributing to social welfare. Communities might, in fact, make more progress with industry players that have declared their commitment to sustainable practices, which resolve mutual community-industry involvement.

To sum up, this DEMATEL analysis both elaborates on the interactions between different sustainability criteria and suggests some of the important strategies for the enhancement of IS networks. By considering both drivers and dependent criteria, an industry may initiate the process of setting up a much more resilient, efficient, and sustainable ecosystem in accordance with white environmental, social, and economic goals.

5. Conclusion

Pressing environmental issues, such as the growing greenhouse gas emissions, resource shortages, and ecological deterioration, brought on by resource-intensive consumerism, urbanization, and global industrialization, highlight the urgent need for sustainability-oriented methods across businesses. Because of its strategic role in influencing supply chain processes and fostering resource efficiency, procurement is seen as a crucial component in this context. One important strategy for reducing environmental effects is sustainable procurement, which guarantees the ethical sourcing of products and services at every stage of their lifespan. This strategy is in line with worldwide sustainability goals, regulatory challenges, and rising stakeholder expectations.

The idea of IS, which is promoted as an adjunct to sustainable procurement, has been covered in this study. IS enables easier for companies to share their resources and reuse trash, converting the waste of one into raw materials for another. This cooperative strategy improves resource optimization and economic efficiency while also lessening environmental effects. This study mainly tries to emphasize how IS is becoming more and more important in tackling sustainability issues and how it has the power to revolutionize conventional supply chain procedures, especially in the textile industry. The study offers a conceptual framework to investigate procurement capabilities and environmental issues while highlighting the advantages of IS and sustainable procurement by concentrating on the textile sector in the Aegean area. The study illustrates via case studies how IS can help the industry shift to more environmentally friendly practices, pointing out both potential and obstacles to its adoption, such as supplier reluctance and infrastructural constraints. The results highlight how crucial it is to combine IS with sustainable procurement practices in order to meet the twin goals of environmental sustainability and economic prosperity.

The findings of this study may not be as applicable or generalizable due to a number of constraints. By concentrating on the Aegean textile industry, the scope is limited to a particular sector and location, making it less applicable to other sectors with distinct characteristics. Further concerns include the changing impact of policies and laws, as well as infrastructural issues, especially in rising economies. Furthermore, the study does not thoroughly assess the long-term effects of the suggested strategies, highlighting the necessity of additional research to examine wider contexts, legislative frameworks, and longitudinal results in order to improve comprehension and execution of sustainability projects. To improve generalizability, future studies might examine the use of IS and sustainable procurement in different sectors and geographical areas. The long-term effects of these strategies on social, environmental, and economic results might be evaluated through longitudinal research. For real-world applications, studies on overcoming supplier opposition and resolving infrastructural issues in emerging economies would also be helpful. The research requires special handling because it faces both contextual and sector-specific limitations, while researchers need to manage the study's methodological restrictions that arise from using fuzzy DEMATEL. Expert assessments form the foundation of this method because they establish the limits which restrict results to what experts subjectively perceive. Fuzzy logic serves to decrease uncertainty, yet the matrix operations and causal propagation mechanisms lead to increased individual biases which impact DEMATEL outcomes. The model's causal structure responds to user-selected methods because the model's parameters depend on two factors: normalization procedures and threshold values which determine causal diagram construction. The expert panel composition and size directly affect the results because different expert groups may generate distinct causal structures. The method identifies perceived causal links which deviate from actual empirical evidence and requires decision-support interpretation which stands apart from proof of causation.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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AI Disclosure

The author(s) declare that no assistance is taken from generative AI to write this article.

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