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Sustainability Challenges to the Steel Industry in a Developing Country: Sanctions and Security Issues at the Forefront

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ABSTRACT

This article contributes to sustainability research by investigating the complex, geopolitically induced challenges faced by industrial supply chains under international sanctions. Using Iran's steel industry as a case, it examines sustainability barriers through the lens of stakeholder theory. A mixed methods approach was employed. First, seven critical sustainability challenges were identified through a thematic analysis of qualitative data from 18 expert interviews and two panel discussions. These challenges were then quantitatively prioritized using the best–worst method (BWM) and its Bayesian extension, based on survey responses from 28 representatives across four stakeholder categories: manufacturers, government, NGOs, and buyers. The findings reveal that while challenges such as resource scarcity align with global studies, international sanctions and cyberattacks emerge as distinct, high-priority barriers in the sanctioned context. Quantitative BWM results identified resource scarcity (final weight: 0.0789) and international sanctions (final weight: 0.056) as the two highest priority challenges across the stakeholder landscape. However, significant stakeholder divergence was observed: Manufacturers emphasized sanctions as paramount, whereas NGOs and buyers downplayed their significance. These results underscore the critical need for context-sensitive policies and multistakeholder collaboration that explicitly acknowledges these prioritization disparities. The study contributes to stakeholder theory by contextualizing its application in politically constrained environments and advocates policy reforms to address the interplay among geopolitical, institutional, and operational factors in building resilient and sustainable supply chains.

1 | Introduction

Global steel demand is projected to rise by 20% by 2050, driven largely by population growth and construction needs, placing unprecedented pressure on the industry's intricate supply chains, which run from raw material extraction to final product distribution (Azimifard et al. 2018; Liu et al. 2017; World Steel Association [WSA] 2024b). A critical aspect of any effective supply chain is sustainability. Steel production, a heavy industry with a substantial global ecological impact, serves as a critical representative of sustainability in manufacturing worldwide; it has been identified as among the most polluting sectors, with significant wastewater, solid waste, and emissions (Zhang and Asutosh 2025). In addition to the environmental dimension, the scholarly discourse emphasizes that advancing sustainable supply chain systems requires greater attention to social dimensions, including the systematic incorporation of human communities—such as employees and workers on the supplier side—into sustainability considerations (Pagell and Shevchenko 2014; Pagell and Wilhelm 2025).

The implementation of sustainability practices may encounter barriers; given their complexity, researchers have emphasized the importance of identifying those barriers to develop targeted mitigation strategies (Banihashemi et al. 2023; Govindan et al. 2014; Özaşkın and Görener 2023; Rashid et al. 2024). Despite this body of work, a research gap remains in understanding the sustainability barriers in contexts heavily influenced by geopolitical forces such as sanctions and how these forces are differentially perceived by stakeholder groups. Addressing this gap is critical, as these disruptions create country-specific conditions that challenge the transition to a sustainable supply chain. Iran's steel industry provides a compelling context for this investigation. According to a WSA report (2024a), Iran, a developing country, produced 31.1 million tons of crude steel (58.4% of Western Asia's total output), positioning it as the 10th-largest producer globally. Yet it operates under stringent economic sanctions and is subject to significant cyberattacks, creating a unique operational environment (Bednarski et al. 2024).

The present study adopts Iranian steel production as the industry sector to examine sustainability barriers within steel industry supply chains (Nezamoleslami and Hosseinian 2020). By delving into the various barriers to sustainable supply chain management (SSCM) practices in Iran's steel industry supply chain, this study uses a stakeholder-informed analysis aims to offer valuable insights into supply chain sustainability enhancements in the steel sector and manufacturing more broadly for developing countries and other regions seeking to improve their sustainability performance. The findings contribute to the literature by moving beyond generic barrier identification to provide a nuanced, empirically grounded analysis that reveals the contested nature of sustainability challenges under duress, thereby contextualizing stakeholder theory in politically constrained environments and offering practical insights for policymakers and managers.

Stakeholder theory is an effective framework for analyzing how different groups (e.g., manufacturers, governments, NGOs, and buyers) perceive and prioritize risks based on their distinct exposures and interests. The central problem is that existing research is too generic and fails to account for how stark, context-specific pressures such as sanctions create divergent stakeholder priorities, ultimately fragmenting efforts toward sustainability.

The remainder of the paper is organized as follows. First, the literature review and theoretical background underpinning the study are presented. Subsequent sections detail the qualitative and quantitative research methodology and present the key findings derived from the analysis. The paper concludes with a discussion of the research outcomes, emphasizing their theoretical significance and practical implications for overcoming barriers to SSCM in the steel industry.

2 | Literature Review and Theoretical Background

2.1 | Barriers to a Sustainable Supply Chain

Scholars have investigated the challenges of implementing sustainable supply chain practices in developed and developing countries and across different industries. Kashyap and Shukla (2023) studied the prominent barriers in the sustainable *makhana* (foxnut) industry supply chains in India. They found that the failure to adopt organic agricultural management techniques, a lack of modern technology, multiple intermediaries, weak economic conditions of farmers, and deficiencies in proper knowledge are prominent barriers in this industry.

In studying the Australian food and beverage sector, Adams et al. (2023) identified the lack of a governmental regulatory and environmental framework as the key barrier. A recent study found political pressure to be the most critical barrier to implementing climate change mitigation strategies in the Indian iron and steel industry (Singh et al. 2024). In the UK construction industry, barriers such as cost, availability and storage, low client demand, traceability, supply chain gaps, and a lack of integration hinder the reuse of structural steel (Tingley et al. 2017).

A recent study reported the barriers to implementing climate change mitigation strategies in the Indian iron and steel industry, highlighting and prioritizing several critical factors that hinder sustainable practices (Singh et al. 2024). The authors identified barriers such as a financial crunch, poor environmental commitment, a lack of environmental knowledge, missing technical expertise, the complexity of new processes, poor social values and ethics, political pressure, ineffective processes and administration, inadequate industrial policy and research, and unrealistic and misaligned goals. Another study identified significant policy and pricing barriers to the decarbonization of the UK steel industry, emphasizing the need for a whole-systems approach to achieve climate targets (Richardson-Barlow et al. 2022). The authors recommended removing carbon pricing discrepancies and reducing industrial electricity prices to enhance competitiveness for green steel producers.

In the Iranian steel industry context, there is limited research into understanding these challenges. One study identified 41 barriers to SSCM through a systematic analysis of the literature (Heidary Dahooie et al. 2021). In that research, a lack of sustainable product and service promotion and weak social pressures were identified as the top two barriers in SSCM. However, the study's limitations include a narrow focus on a single organization without incorporating perspectives from broader stakeholder groups. Additionally, country-specific industries may face distinct or region-specific challenges in adopting sustainability measures, underscoring the need for a more extensive, context-sensitive exploration.

2.2 | Stakeholder Theory

Stakeholder theory, as elaborated by Freeman (2010), posits that organizations manage complex environments by navigating a network of relationships with groups that affect or are affected by their actions. This framework is particularly salient for sustainability challenges, which inherently involve navigating trade-offs among the economic, environmental, and social interests of diverse stakeholders (Harrison and Wicks 2013; Hörisch et al. 2014). For supply chain management, this implies that effective strategies must integrate the perspectives of a wide array of actors, including government agencies, suppliers, customers, communities, and NGOs (Marcon Nora et al. 2023; Steurer 2006).

Stakeholder theory serves as the primary analytical lens through which this study views a key gap; understanding how extreme geopolitical pressures, such as sanctions and cyberattacks, create divergent perceptions of sustainability barriers among different stakeholder groups. A central premise of that theory is that stakeholders will prioritize barriers differently based on their distinct roles, exposures, and interests (Mahajan et al. 2023; Soundararajan et al. 2021). For instance, manufacturers may prioritize operational and sanction-related barriers, while NGOs may emphasize social or governance issues. This kind of unsurprising divergence is a core tenet of stakeholder theory, which predicts that misalignments arise from differing interests and information asymmetries (Muthuri et al. 2012).

Consequently, the application of the theory is not merely conceptual but operational. Employing the best–worst method (BWM) to quantify the priorities of four distinct stakeholder categories allows for an empirical test of these divergences. This approach moves beyond generic barrier identification to show how and why priorities fracture under geopolitical duress. The findings demonstrate how stakeholder theory explains the identified priority differences, illustrating that a one-size-fits-all approach to sustainability is ineffective in politically constrained environments. Ultimately, this diagnostic application of the theory provides a structured basis for designing targeted, multistakeholder engagement strategies and collaborative governance mechanisms that are essential for implementing SSCM practices under complex constraints (Kayikci et al. 2022; Reshad et al. 2023).

3 | Methodology

A mixed methods approach was employed in this study. First, sustainability challenges were identified through a thematic analysis of qualitative data from 18 expert interviews and two panel discussions. Second, the identified challenges were quantitatively prioritized using the BWM and its Bayesian extension, based on survey responses from 28 representatives across four stakeholder categories: manufacturers, government, NGOs, and buyers.

3.1 | Qualitative Data Collection and Analysis

To identify key sustainability barriers in Iran's steel supply chain, this study employs a qualitative approach integrating primary and secondary data. The former were collected via the 18 semistructured interviews referred to above. Participants were selected through purposive sampling to ensure a diversity of perspectives and expertise in sustainability roles in Iran's Kerman region. The interviews, which lasted from 40 to 180 min, followed a consistent protocol of open-ended questions designed to elicit detailed accounts of implementation challenges, with follow-up probes used to explore emerging themes. Table 1 provides details on the organizations and anonymized descriptions of the interviewees' roles. Secondary data were derived from two expert panels organized at a seminar on sustainable supply chains hosted by Shahid Bahonar University of Kerman in 2023 and the 26th Annual Steel Symposium in Iran in 2024. In addition, internal documents shared by interviewees and public data from company websites were collected.

Data analysis followed a structured thematic approach to ensure analytical rigor. Interview and panel transcripts were systematically analyzed using open coding to identify first-order concepts without predefined categories. These codes were then synthesized into second-order themes, which were abstracted to higher level dimensions reflecting institutional and public policy-level barriers. To enhance reliability, the coding protocol was developed iteratively, with thematic saturation confirmed when subsequent interviews yielded no new substantive barriers. In addition, the results were validated in the 2023 seminar organized at Shahid Bahonar University of Kerman, where participants from different stakeholder groups shared their opinions, ensuring a comprehensive and contextually grounded identification of sustainability challenges.

3.2 | Quantitative Data Collection and Analysis

To prioritize the key sustainability barriers identified in the Iranian steel supply chain, the BWM was selected; it is a structured multicriteria decision-making technique based on pairwise comparisons between a decision-maker's most and least preferred criteria (Rezaei 2020). Its selection was driven by key advantages over similar techniques such as the analytic hierarchy process (AHP). BWM requires significantly fewer pairwise comparisons, reducing the burden on experts and minimizing potential response inconsistency (Rezaei 2016, 2020). This efficient design enhances the reliability of results and provides a verifiable consistency ratio to quantify each expert's input reliability.

For group aggregation, the Bayesian BWM was employed to address a critical limitation of the classical approach (Mohammadi and Rezaei 2020). Bayesian BWM advances the original BWM method by addressing its limitations in group decision making; it lacks a probabilistic framework to manage collective input amid uncertainty. The Bayesian approach introduces a hierarchical model that enables the integration of diverse expert perspectives without simplistic averaging, derives posterior distributions to represent criteria weights probabilistically, and explicitly measures decision uncertainty and robustness.

These enhancements are critical in this study, where expert views from manufacturers, governments, NGOs, and buyers were anticipated to vary significantly due to the subjective interpretations and institutional complexities inherent in operating under sanctions. The Bayesian framework provides a statistically rigorous mechanism to capture and analyze this heterogeneity, offering deeper insights into the consensus and conflicts among different stakeholder groups under conditions of geopolitical uncertainty.

3.2.1 | BWM

The steps of BWM are as follows (Rezaei 2016).

Step 1. Determine a set of n decision criteria $\{C_1, C_2, \ldots, C_n\}$.

TABLE 1 | Summary of interviewee details.

Company name	Company type/role in steel supply chain	Number of interviews and their roles	Interview duration (min)	Interview type
SISCO	Total supply chain from mine to customer	Four experts and managers of health, safety, and environment (HSE), and management and system development departments	120	In person
ZISCO	Total supply chain from mine to customer	Two managers of the HSE and the social responsibility departments	180	In person
Goharzamin (GZ)	Total supply chain from mine to pelletizing plant	One environmental department manager	60	Online (Google Meet)
Shokofa Sanat Pouya Company	Customer (producing steel structures)	Two factory and HSE managers	90	In person
Memradco	Supplier (production and burning of lime and dolomite)	One expert at an HSE department	60	Online (Google Meet)
Ahan Online	Wholesaler	Deputy CEO and board member	40	In person
Kerman Department of Environment	Government body (environmental assessment)	Two experts and managers	120	In person
Kerman Province Mining Industry and Trade Organization	Government body (mining industry and trade monitoring)	Four experts and managers	120	In person
Jahan Tejarat Company	Nongovernmental organization (sustainable steel market)	CEO	60	Online (Google Meet)

Step 2. Determine the best (e.g., most desirable and most important) and worst (e.g., least desirable and least important) criteria.

Step 3. Determine the preference of the best overall criterion on a scale of one to five. The resulting best-to-others (BO) vector would be

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{1}$$

where a_{Bj} indicates the preference of the best criterion B over criterion j.

Step 4. Determine the preference of all criteria over the worst criterion on a scale of one to five. The resulting others-to-worst (OW) vector would be

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})^T \tag{2}$$

where a_{jW} indicates the preference of the criterion j over the worst criterion W.

Step 5. Find the optimal weights of criteria $(w_1^*, w_2^*, \ldots, w_n^*)$ according to the following optimization model:

$$\begin{aligned} &\min max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_w} - a_{jW} \right| \right\} \\ &\text{s. t.} \\ &\sum_j \mathrm{w_j} = 1 \\ &w_j \geq 0 \ \text{ for all } j. \end{aligned} \tag{3}$$

This model can be transformed into a nonlinear constrained optimization model as follows:

$$\begin{aligned} &\min \xi \\ &\text{s. t.} \\ &\left| \frac{\mathrm{w_B}}{\mathrm{w_j}} - \mathrm{a_{Bj}} \right| \leq \xi \\ &\left| \frac{\mathrm{w_j}}{\mathrm{w_w}} - \mathrm{a_{jW}} \right| \leq \xi \\ &\sum_j \mathrm{w_j} = 1 \\ &w_j \geq 0 \text{ for all } j \end{aligned} \tag{4}$$

The linear model of this optimization problem can be presented as follows:

$$\begin{aligned} &\min \xi^L \\ &\text{s. t.} \\ &\left| \mathrm{w_B} - \mathrm{a_{Bj} w_j} \right| \leq \xi^{\mathrm{L}}, \text{for all j} \\ &\left| \mathrm{w_j} - \mathrm{a_{jW} w_w} \right| \leq \xi^{\mathrm{L}}, \text{for all j} \\ &\sum_j \mathrm{w_j} = 1 \\ &w_j \geq 0, \text{for all j} \end{aligned} \tag{5}$$

Step 6. Calculate the consistency ratio (CR) as follows:

$$CR = \frac{\xi^*}{Consistancy\ Index}, \tag{6}$$

TABLE 2 | Consistency Index (CI).

a_{BW}	1	2	3	4	5
CI	0.00	0.44	1.00	1.63	2.30

where the consistency index (CI) is calculated based on Table 2.

The consistency ratio serves as an indicator of reliability in expert-derived weightings: lower values reflect greater consistency and rationality in results, with a consistency ratio of zero indicating absolute agreement among experts.

3.2.2 | Bayesian BWM

The steps of Bayesian BWM are as follows (Mohammadi and Rezaei 2020):

Step 1. Determine a set of n decision criteria$\{C_1, C_2, \ldots, C_n\}$.

Step 2. Each of the K decision makers selects the best (most important) and worst (least important) criteria. Then, similar to BWM, the two vectors BO $(A_B^k = (a_{B1}^k, a_{B2}^k, \ldots, a_{Bn}^k))$ and OW $(A_w^k = (a_{1w}^k, a_{2w}^k, \ldots, a_{nw}^k)^T)$ are configured.

Step 3. Obtain the aggregated weights $w^* = (w_1^*, w_2^*, \ldots, w_n^*)$ and the weight for each decision-maker$w^k, k = 1, .., K$, based on the following probabilistic model:

$$\begin{aligned} &A_B^k \Big| w^k \sim multinomial\left(\frac{1}{w^k}\right), \forall k = 1, .., K \\ &\mathrm{A_w^k} \Big| \mathrm{w^k} \sim multinomial(\mathrm{w^k}), \forall \mathrm{k} = 1, .., \mathrm{K} \\ &\mathrm{w^k} \Big| w^* \sim Dir(\gamma \times w^*), \forall \mathrm{k} = 1, .., \mathrm{K} \\ &\gamma \sim gamma(0.1, 0.1) \\ &w^* \sim Dir(1), \end{aligned} \tag{7}$$

where *multinomial* is the multinomial distribution, *Dir* is the Dirichlet distribution, and *gamma* (0.1, 0.1) is the gamma distribution with shape parameters of 0.1. A Markov-chain Monte Carlo method is used to calculate the probabilistic model presented in MATLAB.

4 | Findings

After coding the content of interviews and panels, 31 first-order categories were identified. Categorizing them into second-order themes identified the following seven key challenges: legal and policy barriers, government and environmental agency regulatory challenges, international sanctions, internal organizational barriers, challenges in accessing natural resources and infrastructure, challenges related to customers and suppliers, and supply chain security challenges from cyberattacks. Table 3 shows the first-order categories and second-order themes.

Table 4 summarizes the prevalence of sustainability challenges across company interviews and panels. Legal and policy barriers, government and environmental agency regulatory challenges, and challenges in access to natural resources and

TABLE 3 | Sustainability challenge categories and themes.

Second-order themes	First-order categories
Legal and policy barriers (B1)	• Lack of appropriate legislation (transparent, up-to-date, nondiscriminatory, and accounting for the characteristics of different companies) (B11) • Lack of protective legislation for local suppliers, despite lower costs than foreign suppliers (B12) • Neglect of small- and medium-sized enterprises in the development of the supply chain, with the aim of job creation and regional development (B13) • Lack of effective incentive and disincentive mechanisms for the implementation of environmental and social legislation (B14) • Mandatory control of prices, restrictive tariffs and barriers such as export licenses for the final product, and customs fees (B15) • Conflicts between the aims of government agencies and companies in the implementation of environmental and social considerations (B16)
Government and environmental agency regulatory challenges (B2)	• Lack of experienced health, safety, and environment experts and inspectors in government agencies to monitor industries (B21) • Weak follow-up by government managers in the province to receive financial incentives from the central government in the area of sustainability (B22) • Implementation of laws by regulatory agencies in favor of governmental or semigovernmental institutions over private sector companies (B23) • Lack of specific metrics for environmental agencies to implement sustainability measures in organizations (B24) • Lack of necessary knowledge, technology, and budget in environmental agencies to monitor and control the sustainability performance of companies (B25)
International sanctions (B3)	• Difficulty in transferring new technologies and knowledge (B31) • Sustainability challenges in importing raw materials and exporting products (B32) • Inability to communicate and compare with international peers regarding sustainability practices and competitive advantages (B33)
Internal organizational barriers (B4)	• Lack of commitment and willingness among top management to implement sustainability-related matters (B41) • Organizational culture not aligned with sustainable development, including employees unaware of its benefits (B42) • High costs of sustainable production methods and limited access to financial resources to invest in them (B43) • Loss and shortage of sustainability experts in companies (B44) • Companies' failure to provide transparent reports on environmental and sustainability efforts (B45)
Challenges in access to natural resources and infrastructure (B5)	• Limited access to essential resources such as water and renewable energy (51) • Lack of access to sustainably produced raw materials (B52) • Weakness in sustainable transport infrastructure (B53)
Challenges related to customers and suppliers (B6)	• Insufficient pressure from customers on companies to adhere to environmental and social sustainability principles (B61) • Difficulty in finding and retaining qualified suppliers with valid certificates (B62) • Inability of both companies and environmental organizations to assess the sustainability of suppliers' internal production processes (B63) • Pressure to select specific suppliers without considering sustainability criteria (B64)
Supply chain security challenges from cyberattacks (B7)	• Dependence of industries on software, hardware, and third-party service providers, and the risks associated with these suppliers (B71) • Use of outdated equipment and technologies in the technological infrastructure of industries with greater vulnerability (B72) • Lack of cybersecurity standards for third-party suppliers of equipment and software (B73) • Lack of transparency and control over the qualifications of suppliers and the quality of their products at lower layers and the possibility of viruses and malware entering the system (B74) • Internal and external cyberattacks on hardware and software equipment used in the supply chain (B75)

TABLE 4 | Sustainability challenges reported by company and panel.

	Stakeholders									Panels	
	Manufacturer/supplier				Customer/ wholesaler		Government body		NGO		
Challenges	SISCO	ZISCO	GZ	MEMC	SSPC	AO	KDOE	KPMITO	KJC	Seminar at Kerman University	Symposium of Green Steel
B1	*	*	*	*	*		*		*	*	
B2	*	*			*			*	*	*	*
B3	*	*	*					*		*	*
B4	*	*	*	*	*				*		
B5	*	*	*		*		*	*		*	*
B6	*	*			*	*					*
B7											*

Abbreviations: AO, Ahan Online; GZ, Goharzamin; KDOE, Kerman Department of Environment; KJC, Jahan Tejarat Company; KPMITO, Kerman Province Mining Industry and Trade Organization; MEMC, Memradco; SSPC, Shokofa Sanat Pouya Company.

infrastructure emerged as concerns universally acknowledged by stakeholders in the steel supply chain. While steel manufacturers and suppliers identified international sanctions as a primary obstacle, NGOs and downstream customers did not prioritize sanctions in their sustainability assessments. Internal organizational barriers were cited by most stakeholders but dismissed by government-affiliated entities. Notably, cybersecurity threats to supply chains were exclusively flagged as a critical sustainability challenge during discussions at the 26th Annual Steel Symposium in Iran.

In the next stage, a structured questionnaire based on the BWM was developed to prioritize the sustainability challenges identified in the study. Initial outreach involved contacting relevant companies and organizations by telephone to explain the purpose of the questionnaire and the completion procedure. For entities requiring formal authorization, the questionnaire was distributed together with an official university letter; for others, it was shared directly via email or professional social platforms. Follow-up support was provided to clarify any ambiguities and ensure accurate responses, using telephone calls or digital communication as needed. Table 5 presents the profiles of the 13 participating organizations, including sector, operational scope, and number of expert respondents.

For organizations with a single expert respondent, prioritization was determined using the BWM model. For those with multiple participating experts, Bayesian BWM was employed to aggregate diverse inputs and account for decision uncertainty. The resulting organizational prioritization weights for sustainability challenges, derived using BWM or Bayesian BWM, were then aggregated to compute average challenge weights stratified by stakeholder groups—manufacturers/suppliers, government bodies, NGOs, and downstream consumers (see Table 6). The prioritization of sustainability challenges across stakeholder groups reveals distinct perspectives shaped by organizational roles and operational contexts.

TABLE 5 | Organizations participating in the BWM-based survey.

Number of experts	Stakeholder group	Companies or organizations
2	Manufacturer/supplier	ZISCO
3	Manufacturer/supplier	SISCO
2	Manufacturer/supplier	BISCO
1	Manufacturer/supplier	GMIC
1	Manufacturer/supplier	GZ
1	Manufacturer/supplier	RSC
3	Manufacturer/supplier	KCMC
3	Government body	KPMITO
1	Government body	KDOE
1	Government body	KMSDOH
1	NGO	IWMA
1	Customer/wholesaler	KOSC
8	Customer/wholesaler	IBKO

Abbreviations: GMIC, Golgohar Mining and Industrial Company; IWMA, Iran Waste Management Association; KCMC, Kerman Coal Mines Company; KMSDOH, Kerman Medical Sciences Department—Occupational Health; KOSC, Khouzestan Oxin Steel Company; RSC, Ravar Steel Complex.

Manufacturers and suppliers gave highest priority to access to natural resources and infrastructure (B5) due to their operational reliance on uninterrupted material and energy supplies, which are severely constrained by international sanctions that limit imports of critical equipment and technologies. Their emphasis on government and environmental agency regulatory challenges (B2) and international sanctions (B3) stems from the direct impact these external pressures have on increasing bureaucratic complexity, compliance costs, and supply chain

TABLE 6 | Sustainability challenge average weights based on stakeholder group.

	Stakeholders				
Challenges	**Manufacturer/supplier**	**Customer/wholesaler**	**Government body**	**NGO**	**Total average**
B1	0.1413	0.1693	0.1630	0.1053	0.1447
B2	0.1705	0.2433	0.1050	0.1579	0.1692
B3	0.1481	0.1556	0.1166	0.1579	0.1446
B4	0.1151	0.0910	0.1024	0.2105	0.1298
B5	0.1867	0.1181	0.2466	0.1579	0.1773
B5	0.1236	0.1127	0.1511	0.0526	0.1100
B7	0.1147	0.1099	0.1151	0.1579	0.1244

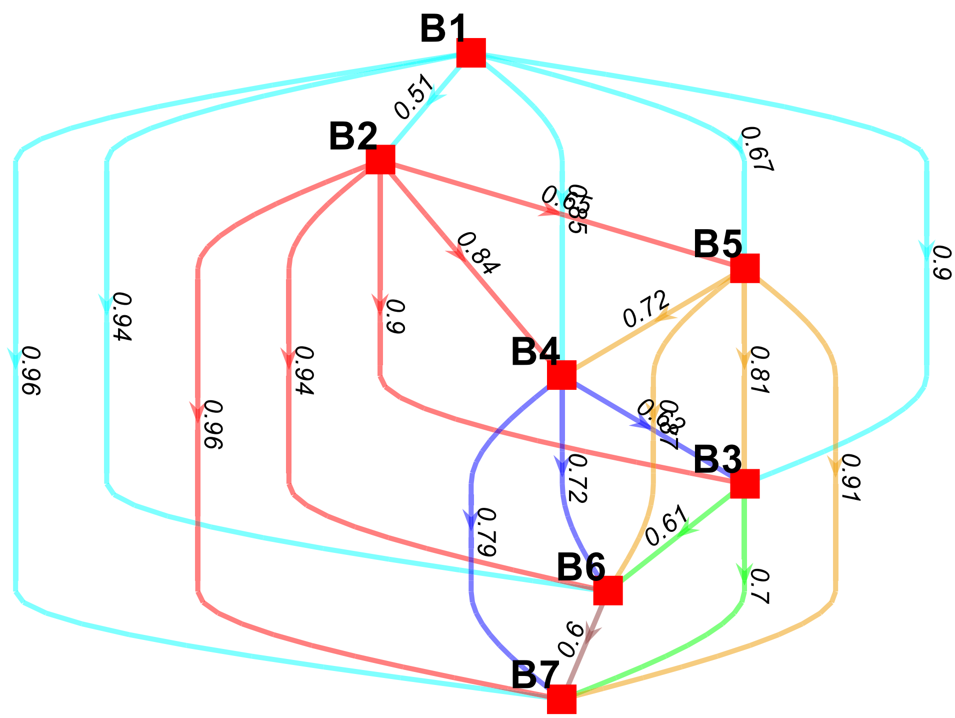

FIGURE 1 | Credal ranking graph of sustainability challenges at ZISCO.

disruptions. Legal and policy barriers (B1) further exacerbate operational uncertainty in an already volatile environment.

Government bodies assigned high importance to resource access (B5), legal and policy barriers (B1), and international sanctions (B3) because their institutional role requires them to navigate and mitigate systemic risks affecting national industrial stability. Sanctions reduce fiscal flexibility and complicate international cooperation, thereby intensifying regulatory and diplomatic challenges. Their focus on customer and supplier challenges (B6) aligns with their responsibility to maintain supply chain continuity and mediate stakeholder relations under external pressures. The lower priority given to internal organizational barriers (B4) and supply chain security challenges from cyberattacks (B7) reflects a strategic emphasis on macrolevel threats rather than internal institutional issues.

NGOs uniquely ranked internal organizational barriers (B4) as their top concern, noting that weak governance and inadequate accountability—often worsened by geopolitical isolation—hinder effective sustainability implementation. Their equal weighting of government and environmental agency regulatory challenges (B2), international sanctions (B3), access to natural resources and infrastructure (B5), and supply chain security challenges from the perspective of cyberattacks (B7) underscores their comprehensive view of sustainability, where geopolitical factors like sanctions erode institutional capacity and increase vulnerability to digital threats.

Customers and wholesalers highlighted government and environmental agency regulatory challenges (B2) as their primary concern, due to the need for predictable, transparent market rules, which are currently often undermined by sanctions-induced policy instability. Their subsequent focus on legal and policy barriers (B1), international sanctions (B3), and access to natural resources and infrastructure (B5) reflects dependence on manufacturing stability and product availability, while their lesser emphasis on internal organizational (B4) and supply chain security challenges from cyberattacks (B7) indicates a downstream focus on transactional and regulatory certainty rather than upstream operational risks.

Geopolitical constraints—especially sanctions—directly amplify these priorities by restricting access to technology and capital, destabilizing regulatory environments, and increasing institutional fragmentation. Stakeholders' priorities are thus shaped by their distinct roles and exposures and the cascading effects of these external pressures on operational and strategic decision-making.

The credal ranking graph in Figure 1 depicts the aggregated expert consensus on sustainability challenge prioritization for ZISCO's steel supply chain, which was selected as representative of the 13 organizations studied. Vertically ordered nodes reflect hierarchical priorities, with lower positions indicating diminished relative importance. Directional arrows between nodes encode the confidence level (numerical value, 0–1 scale) that experts assign to the superiority of one challenge or subchallenge over another, derived via Bayesian BWM. For instance, an arrow from node B1 (legal and policy barriers) to B7 (supply chain security challenges from cyberattacks) with a value of 0.96 signifies a strong consensus among ZISCO's experts that legal and policy barriers outweigh supply chain security challenges from cyberattacks. Presenting ZISCO's graph balances methodological transparency with conciseness, avoiding redundancy while preserving insights into how stakeholder priorities coalesce or diverge under shared geopolitical constraints.

Subsequently, the weights of sustainability subchallenges within each challenge category were calculated for all organizations using BWM or Bayesian BWM. To derive the aggregated priorities of subchallenges across the four stakeholder groups (see Table 7), a two-tiered weighting approach was applied. Each organization's subchallenge weights were multiplied by the corresponding challenge-level weights, ensuring hierarchical integration of stakeholder-specific and overarching priorities. The study's findings are structured across the four analytical dimensions described below.

4.1 | Cross-Stakeholder Consensus on Sustainability Challenges

Subchallenges related to natural resource scarcity dominate stakeholder priorities. B51 (limited access to water and renewable energy) received the highest average weight (0.0789), with a peak among government bodies (0.1292), thus underscoring institutional concerns over resource bottlenecks. B52 (lack of access to sustainably produced raw materials) and B53 (weakness in sustainable transport infrastructure) also ranked highly, particularly among NGOs (0.0965) and manufacturers (0.0528), reflecting sector-specific operational vulnerabilities. Sanctions-driven barriers such as B31 (difficulty in transferring new technologies and knowledge, 0.056 average) and B32 (import/export sustainability challenges, 0.0488) were prioritized

TABLE 7 | Sustainability subchallenge final weights of organizations and stakeholder groups.

	Stakeholders																
	Manufacturer/supplier								Customer/wholesaler			Government body				NGO	Total
Subchallenges	ZISCO	SISCO	BISCO	GMIC	GZ	RSC	KCMC	Average	KOSC	IBKO	Average	KPMITO	KDOE	KMSDOH	Average	IWMA	average
B11	0.0263	0.0424	0.0172	0.0140	0.0075	0.0756	0.0229	0.0294	0.0303	0.0299	0.0301	0.0397	0.0098	0.0405	0.0300	0.0104	0.0250
B12	0.0371	0.0267	0.0172	0.0052	0.0113	0.0287	0.0200	0.0209	0.0110	0.0260	0.0185	0.0443	0.0218	0.0158	0.0273	0.0138	0.0201
B13	0.0448	0.0224	0.0188	0.0209	0.0188	0.0215	0.0201	0.0239	0.0202	0.0191	0.0197	0.0395	0.0218	0.0211	0.0275	0.0176	0.0222
B14	0.0385	0.0344	0.0258	0.0105	0.0075	0.0430	0.0206	0.0258	0.0469	0.0302	0.0386	0.0438	0.0163	0.0089	0.0230	0.0364	0.0310
B15	0.0282	0.0191	0.0262	0.0314	0.0113	0.0130	0.0183	0.0211	0.0303	0.0271	0.0287	0.0455	0.0163	0.0158	0.0259	0.0207	0.0241
B16	0.0365	0.0281	0.0172	0.0140	0.0038	0.0172	0.0251	0.0203	0.0303	0.0371	0.0337	0.0329	0.0424	0.0126	0.0293	0.0063	0.0224
B21	0.0265	0.0347	0.0211	0.0257	0.0272	0.0551	0.0289	0.0313	0.0428	0.0305	0.0367	0.0313	0.0097	0.0193	0.0201	0.0551	0.0358
B22	0.0391	0.0374	0.0210	0.0083	0.0084	0.0414	0.0188	0.0249	0.0641	0.0367	0.0504	0.0240	0.0065	0.0193	0.0166	0.0147	0.0267
B23	0.0442	0.0304	0.0210	0.0593	0.0147	0.0827	0.0323	0.0407	0.1026	0.0467	0.0747	0.0345	0.0030	0.0060	0.0145	0.0220	0.0380
B24	0.0516	0.0374	0.0290	0.0193	0.0147	0.0251	0.0152	0.0275	0.0257	0.0383	0.0320	0.0358	0.0082	0.0129	0.0190	0.0330	0.0279

(Continues)

TABLE 7 | (Continued)

	Stakeholders																
	Manufacturer/supplier								Customer/wholesaler			Government body				NGO	Total
Subchallenges	ZISCO	SISCO	BISCO	GMIC	GZ	RSC	KCMC	Average	KOSC	IBKO	Average	KPMITO	KDOE	KMSDOH	Average	IWMA	average
B25	0.0464	0.0530	0.0308	0.0154	0.0147	0.1454	0.0171	0.0461	0.0641	0.0351	0.0496	0.0533	0.0171	0.0342	0.0349	0.0330	0.0409
B31	0.0346	0.0571	0.0316	0.0501	0.0699	0.0249	0.0729	0.0487	0.0338	0.0523	0.0431	0.0568	0.0688	0.0143	0.0466	0.0855	0.0560
B32	0.0563	0.0269	0.0673	0.0110	0.1049	0.0912	0.0362	0.0563	0.0508	0.0517	0.0513	0.0219	0.0413	0.0609	0.0414	0.0461	0.0488
B33	0.0174	0.0305	0.0229	0.0157	0.1748	0.0166	0.0240	0.0431	0.0846	0.0380	0.0613	0.0281	0.0183	0.0394	0.0286	0.0263	0.0398
B41	0.0192	0.0331	0.0198	0.0050	0.0259	0.0251	0.0560	0.0263	0.0089	0.0359	0.0224	0.0339	0.0237	0.0187	0.0254	0.0739	0.0370
B42	0.0266	0.0285	0.0312	0.0033	0.0432	0.0071	0.0295	0.0242	0.0089	0.0247	0.0168	0.0254	0.0395	0.0289	0.0313	0.0202	0.0231
B43	0.0390	0.0485	0.0334	0.0165	0.0115	0.0095	0.0295	0.0268	0.0235	0.0316	0.0276	0.0303	0.0158	0.0187	0.0216	0.0269	0.0257
B44	0.0235	0.0187	0.0311	0.0066	0.0259	0.0143	0.0212	0.0202	0.0041	0.0204	0.0123	0.0167	0.0079	0.0187	0.0144	0.0358	0.0207
B45	0.0182	0.0284	0.0170	0.0099	0.0259	0.0043	0.0191	0.0175	0.0067	0.0172	0.0120	0.0128	0.0095	0.0068	0.0097	0.0538	0.0233
B51	0.0342	0.0710	0.1267	0.1968	0.1421	0.0186	0.0904	0.0971	0.0458	0.0623	0.0541	0.0635	0.1772	0.1468	0.1292	0.0351	0.0789
B52	0.0930	0.0454	0.0645	0.0328	0.0284	0.0684	0.0371	0.0528	0.0247	0.0542	0.0395	0.0430	0.0928	0.1048	0.0802	0.0965	0.0673
B53	0.0438	0.0241	0.0586	0.0656	0.0284	0.0124	0.0313	0.0377	0.0141	0.0349	0.0245	0.0361	0.0337	0.0419	0.0372	0.0263	0.0314
B61	0.0241	0.0420	0.0211	0.0790	0.0225	0.0123	0.0350	0.0337	0.0103	0.0329	0.0216	0.0219	0.0642	0.0459	0.0440	0.0213	0.0302
B62	0.0264	0.0228	0.0500	0.0132	0.0225	0.0164	0.0481	0.0285	0.0308	0.0271	0.0290	0.0183	0.0257	0.1147	0.0529	0.0063	0.0292
B63	0.0312	0.0341	0.0272	0.0263	0.0128	0.0433	0.0386	0.0305	0.0205	0.0294	0.0250	0.0352	0.0128	0.0229	0.0236	0.0100	0.0223
B64	0.0118	0.0242	0.0359	0.0527	0.0417	0.0075	0.0418	0.0308	0.0513	0.0228	0.0371	0.0201	0.0257	0.0459	0.0306	0.0150	0.0284
B71	0.0155	0.0148	0.0203	0.0118	0.0176	0.0188	0.0250	0.0177	0.0161	0.0175	0.0168	0.0233	0.0314	0.0045	0.0197	0.0351	0.0223
B72	0.0177	0.0271	0.0311	0.0846	0.0316	0.0331	0.0440	0.0385	0.0483	0.0262	0.0373	0.0185	0.0791	0.0145	0.0374	0.0497	0.0407
B73	0.0217	0.0241	0.0236	0.0367	0.0070	0.0125	0.0330	0.0227	0.0161	0.0205	0.0183	0.0236	0.0235	0.0212	0.0228	0.0234	0.0218
B74	0.0143	0.0202	0.0251	0.0367	0.0117	0.0094	0.0315	0.0213	0.0161	0.0248	0.0205	0.0300	0.0235	0.0097	0.0211	0.0146	0.0194
B75	0.0122	0.0125	0.0225	0.0220	0.0117	0.0057	0.0158	0.0146	0.0161	0.0179	0.0170	0.0153	0.0128	0.0145	0.0142	0.0351	0.0202

by NGOs (0.0855) and manufacturers (0.0563). These priorities reflect stakeholders' direct operational exposure to sanctions, which restrict access to foreign technology, financing, and equipment, thereby intensifying domestic resource competition. Geopolitical isolation forces organizations to prioritize immediate resource and infrastructure survival over longer term strategic investments.

4.2 | Stakeholder-Specific Priorities

Manufacturers/suppliers focused on B51 (limited access to essential resources such as water and renewable energy, 0.0971) and B52 (lack of access to sustainably produced raw materials, 0.0528), aligning with production dependencies. B72 (outdated infrastructure vulnerability, 0.0385) and B25 (lack of necessary knowledge, technology, and budget by environmental agencies, 0.0461) further emphasize operational risks from institutional and technological gaps. Manufacturers prioritize these barriers due to their immediate impact on production continuity and cost efficiency, which are further exacerbated by sanctions that limit modernization and by import alternatives. Government bodies prioritized B51 (limited access to essential resources such as water and renewable energy, 0.1292) and B62 (difficulty in finding and retaining qualified suppliers with valid certificates, 0.0529), reflecting mandates to manage resource allocation and to oversee the supply chain. Surprisingly, B16 (conflict of interest in sustainability implementation, 0.0293) and B21 (lack of inspectors in government agencies, 0.0201) received lower weights, suggesting an under-prioritization of institutional accountability. Government actors focus on macrolevel resource and supply chain stability to mitigate sanctions-induced economic instability, often at the expense of internal reform. NGOs highlighted B41 (lack of management commitment, 0.0739) and B45 (nontransparent sustainability reporting, 0.0538) as top barriers, emphasizing governance failures. B31 (difficulty in transferring new technologies and knowledge, 0.0855) and B75 (internal and external cyberattacks, 0.0351) also ranked highly, linking external disruptions to internal governance gaps. NGOs attribute sustainability failures to weakened governance under sanctions, which reduce accountability and increase vulnerability to external threats such as cyberattacks. Customers and wholesalers focused on B23 (biased implementation of laws by regulatory agencies, 0.0747) and B22 (weak follow-up by government managers to receive financial incentives from the government in the area of sustainability, 0.0504), signaling distrust in regulatory fairness and market mechanisms. Customers prioritize these barriers because of their direct impact on market competition and product affordability, both of which are distorted by sanctions and institutional favoritism.

4.3 | Under-Prioritized but Still Critical Challenges

Despite Iran's high risk of cyberattacks, B75 (internal and external cyberattacks) and B74 (supplier-related malware risks) received low average weights (0.0202 and 0.0194, respectively), except among NGOs (0.0351 for B75). This discrepancy suggests a limited awareness or reporting among operational stakeholders. Moreover, while NGOs prioritized B41 (lack of management commitment) and B45 (nontransparent sustainability reporting), other groups deprioritized these areas, revealing a disconnect between institutional advocacy and industry practices. Geopolitical pressures such as sanctions divert attention toward immediate operational and economic survival, leading stakeholders to deprioritize perceived secondary risks, such as cybersecurity. The lack of institutional incentives and regulatory mandates further reduces organizational investment in these areas.

4.4 | Policy and Operational Tensions

The results highlight tensions between systemic challenges (e.g., sanctions and resource access) and institutional gaps (e.g., regulatory bias and internal governance). For instance, the high weights for B51 and B52 call for investment in renewable infrastructure and circular supply chains. Disparities in B23 (biased implementation of laws by regulatory agencies) and B22 (weak follow-up by government managers to receive financial incentives from the government in the area of sustainability) call for reforms to align regulatory practices with stakeholder expectations. The under-prioritization of cybersecurity (B71–B75) signals a need for awareness campaigns and standardized protocols. Policy efforts must address how geopolitical constraints such as sanctions deepen institutional weaknesses and distort stakeholder incentives. Effective interventions should combine resource diplomacy to ease pressure from sanctions with governance reforms to rebuild trust and coordination across stakeholders.

5 | Discussion

The present study has identified seven key sustainability challenges in the steel industry in Iran's Kerman province: legal and policy barriers, government and environmental agency regulatory challenges, international sanctions, internal organizational barriers, challenges in access to natural resources and infrastructure, challenges related to customers and suppliers, and supply chain security challenges from cyberattacks. A comparative analysis of these challenges reveals consensus on the sustainability impact of international sanctions (B3) and challenges in access to natural resources and infrastructure (B5), which ranked highly across all stakeholder groups. Divergences emerged in the prioritization of governance-related challenges, where manufacturers and buyers emphasized government and environmental agency regulatory challenges (B2), government bodies focused on challenges related to customers and suppliers (B6), and NGOs uniquely stressed internal organizational barriers (B4).

On a theoretical level, this research advances stakeholder theory by applying its principles within geopolitically volatile environments. Stakeholder theory encourages organizations to acknowledge, consider, promote understanding, and manage the needs, wants, and demands of their stakeholders, thereby enabling them to be strategic, maximize value creation, and safeguard long-term success and sustainability (Mahajan et al. 2023). Its core objective is value creation, generating multiple benefits for different stakeholders (Mahajan et al. 2023; Marcon Nora et al. 2023). Value creation includes both tangible benefits such as economic returns and intangible benefits such as a sense of organizational justice, mutual affiliation, and protected interests (Harrison and Wicks 2013).

The identified challenges, particularly international sanctions and supply chain security challenges from cyberattacks, fundamentally fracture the notion of stakeholder consensus in the context of the steel industry in Iran. International sanctions (B3) pose a severe threat to any organization's ability to create value for its stakeholders (Harrison and Wicks 2013; Marcon Nora et al. 2023). Because sanctions restrict access to markets, limit resource availability, and complicate financial transactions, they profoundly undermine the instrumental approach of stakeholder theory, which posits that effective stakeholder management contributes positively to financial outcomes and conventional business objectives, thereby making it difficult to maximize organizational value (Harrison and Wicks 2013; Mahajan et al. 2023; Marcon Nora et al. 2023). Furthermore, the observed stakeholder divergence—where manufacturers prioritize operational survival dictated by challenges in access to natural resources and infrastructure (B5) and international sanctions (B3)—highlights a breakdown of the normative obligation to treat all stakeholders as ends rather than merely means (Mahajan et al. 2023; Marcon Nora et al. 2023).

The emergence of supply chain security challenges from cyberattacks (B7) underscores the critical role of external stakeholders in driving effective risk management, an essential function for long-term organizational legitimacy. Stakeholders that uniquely stress cybersecurity (B7) and internal organizational barriers (B4), such as NGOs, act as drivers and facilitators of organizational change and capability development (Siems et al. 2023). This pressure compels focal firms to adopt proactive measures to anticipate and mitigate potential issues arising from external threats that could harm organizational operations and reputation (Mahajan et al. 2023; Siems et al. 2023). Investing in robust cybersecurity infrastructure (B7) is a necessary instrumental action to ensure the long-term continuity of organizational operations and relationships (Harrison and Wicks 2013).

The convergence of international sanctions and supply chain security challenges from cyberattacks requires supply chain governance models to expand beyond traditional sustainability frameworks—which often fail to account for geopolitical risk—by incorporating specific resilience mechanisms. The demonstrated stakeholder divergence confirms that governance priorities are inherently split during periods of volatility. For supply chains to remain sustainable under these threats, the following steps should be taken:

- Policymakers (governmental entities, acting as drivers) must focus on harmonizing legal and policy barriers (B1) and government and environmental agency regulatory challenges (B2) with sanctions-driven realities. This implies supporting the creation of robust legal and policy frameworks (Siems et al. 2023; Tingley et al. 2017) that incentivize stabilizing challenges in access to natural resources and infrastructure (B5) through regional partnerships.
- Supply chain governance must shift toward a model emphasizing collaborative and proactive strategies (Siems et al. 2023). This is achieved by intentionally integrating external societal stakeholders (NGOs and research institutions) to leverage their expertise as facilitators in closing knowledge and resource gaps, particularly for complex emerging issues such as cybersecurity.

The supply chain security challenges from cyberattacks highlight the criticality of enhancing resilience via digital and network governance, which must mandate stringent cybersecurity measures (B7) to protect the flow of information across the supply chain network (Kayikci et al. 2022). Implementing controls for data integrity and network protection directly supports collaborative communication and ensures the viability of selective monitoring for risk management (Siems et al. 2023). Furthermore, the successful implementation of proactive security measures by industry leaders creates a competitive advantage that encourages competitors to mimic these practices to safeguard their own legitimacy and market position, thereby elevating industry-wide governance standards under external threats (Adams et al. 2023; Siems et al. 2023).

6 | Conclusion and Suggestions For Future Research

This study has revealed seven key sustainability challenges facing the steel sector in Iran's Kerman province, highlighting international sanctions (B3) and supply chain security challenges from cyberattacks (B7) as especially destabilizing factors that fragment stakeholder agreement and transform established sustainability management methods. The findings show that while legal and policy barriers (B1), government and environmental agency regulatory challenges (B2), and challenges in access to natural resources and infrastructure (B5) are widely acknowledged, their intensity and perceived urgency are sharply amplified by the external pressure of sanctions. For instance, sanctions exacerbate internal organizational barriers (B4) by limiting access to foreign technology and expertise while also intensifying challenges related to customers and suppliers (B6) by disrupting export channels and payment systems. These connections reveal that sustainability under sanctions is not merely an operational issue but a structural one, and it demands reconfigured governance models that can function amid external fragmentation.

The prioritization of challenges varied significantly across stakeholders, underscoring the need for dialogue mechanisms to reconcile divergent perspectives. Steel manufacturers emphasized international sanctions (B3) and challenges in access to natural resources and infrastructure (B5), while NGOs focused on internal organizational barriers (B4) and supply chain security challenges from cyberattacks (B7). Government entities, by contrast, prioritized challenges related to customers and suppliers (B6). These differences highlight that effective responses must be multiscalar; steel firms should invest in cybersecurity infrastructure and localize supply chains to mitigate sanctions-induced disruptions, while policymakers should work to harmonize regulations and foster regional partnerships to alleviate government and environmental agency regulatory challenges (B2) and legal and policy barriers (B1). Such coordinated action is essential to bridge the gap between operational survival and long-term institutional reform. Moreover, since dialogue mechanisms are essential to reconcile stakeholders' divergent perspectives, establishing knowledge exchange platforms will enable the lateral spread of best practices across the supply chain. To move beyond mere compliance, the industry requires clear incentives that encourage leaders to raise the ceiling of what is possible. These include providing green tax credits and establishing public procurement criteria that favor sustainable production, which create direct financial and market-based motivations for improvement. Furthermore, supporting benchmarking initiatives against global leaders encourages mimetic learning and the widespread adoption of best practices, fostering a culture of continuous innovation and ambitious goal-setting.

Future research may further examine how geopolitical alliances could reshape the effects of international sanctions (B3), particularly in relation to challenges in accessing natural resources and infrastructure (B5). Future work could also explore how emerging digital technologies, such as blockchain and artificial intelligence, can mitigate supply chain security vulnerabilities arising from cyberattacks (B7). As digital technologies increasingly mediate trade flows, compliance monitoring, and risk assessment, scholars in SSCM have a growing responsibility to examine how these tools can drive positive change. In particular, blockchain and related technologies may not only reduce operational risks but also enhance accountability, inclusivity, and social impact across supply chain tiers. Understanding these dynamics is essential for developing a more holistic view of how digital transformation intersects with geopolitical, environmental, and social pressures in global supply chains.

Another important avenue for future research is to analyze the broader economic, environmental, and social repercussions of sanctions on global supply chains, including spillover effects such as material flow disruptions and market instability in non-sanctioned economies. Comparative studies across sanctioned contexts could help clarify contextual variations in internal organizational barriers (B4) and challenges related to customers and suppliers (B6). Finally, expanding stakeholder samples to include international actors, integrating real-time data sources (e.g., sanctions alerts and cyberthreat indicators), and employing scenario-based analyses under escalating disruption conditions could move research beyond static assessments toward more dynamic and adaptive resilience planning.

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Conflicts of Interest

The authors declare no conflicts of interest.

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