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Model for Sustainable Supply Chain Management in Cuba: validation in a case study

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ABSTRACT

Introduction: Sustainable supply chain management remains difficult to operationalize in economically constrained contexts such as Cuba, where disruptions, shortages, and uncertainty make sustainability trade-offs especially visible. **Objectives:** To evaluate current limitations in sustainable supply chain management practices in Cuban organizations and propose a methodological model to improve operational efficiency and effectiveness. The model is validated through a case study in the construction materials sector. **Methods:** Using a mixed-methods design (expert interviews, document review, checklists, and financial evaluation), key indicators were integrated into a composite supply chain sustainability index. The model was implemented in a case study involving three focal organizations and statistically validated with Wilcoxon non-parametric tests. **Results:** The supply chain sustainability index combines an economic dimension efficiency index, a social dimension effectiveness index, and an environmental dimension effectiveness index. Across a three-year evaluation (year 1–year 3), performance improved consistently: economic dimension efficiency index rose from 3.47 to 4.19, social dimension effectiveness index from 2.43 to 3.07, and environmental dimension effectiveness index from 3.00 to 4.00. Accordingly, supply chain sustainability index increased from 3.03 to 3.89, while overall supply chain sustainability planning Index improved from 1.45 to 2.85. **Conclusions:** These results show that multi-index measurement can guide prioritized, feasible improvement strategies even under severe constraints. The proposed model offers a practical and scalable framework for strengthening sustainable supply chainmanagement in Cuba and provides a transferable reference for similarly challenged regions, emphasizing efficiency, tailored interventions, and collaborative planning.

Keywords: sustainable supply chain management; Cuba, operational efficiency; operational effectiveness

Modelo para Gestión Sostenible en Cadenas de Suministro en Cuba: validación en un caso de estudio

RESUMEN

Introducción: La gestión sostenible de las cadenas de suministro sigue siendo difícil de operacionalizar en contextos económicamente restringidos como Cuba, donde las interrupciones, los desabastecimientos y la incertidumbre hacen especialmente visibles los compromisos (*trade-offs*) de sostenibilidad. **Objetivos:** Evaluar las limitaciones actuales de las prácticas de gestión sostenible de cadenas de suministro en organizaciones cubanas y proponer un modelo metodológico para mejorar la eficiencia y la efectividad operativa. **Métodos:** Mediante un diseño de métodos mixtos (entrevistas a expertos, revisión documental, listas de verificación y evaluación financiera), se integraron indicadores clave en un índice compuesto de sostenibilidad de la cadena de suministro. El modelo se implementó en un estudio de caso que incluyó 3 organizaciones focales y se validó estadísticamente con pruebas no paramétricas de Wilcoxon. **Resultados:** A lo largo de una evaluación de 3 años (año 1-año 3), el desempeño mejoró de manera consistente: el Índice de Eficiencia de la Dimensión Económica aumentó de 3.47 a 4.19, el índice de efectividad de la dimensión social de 2.43 a 3.07 y el índice de efectividad de la dimensión ambiental de 3.00 a 4.00. En consecuencia, el índice compuesto de sostenibilidad de la cadena de suministro se incrementó de 3.03 a 3.89, mientras que el índice de planificación de la sostenibilidad de la cadena de suministro mejoró de 1.45 a 2.85. **Conclusiones:** El modelo propuesto ofrece un marco práctico y escalable para fortalecer la gestión sostenible de cadenas de suministro en Cuba, proporcionando una referencia transferible para otras regiones, enfatizando la eficiencia y la planificación colaborativa.

Palabras clave: gestión de la sostenibilidad en las cadenas de suministros; Cuba; eficiencia operativa; efectividad operativa

INTRODUCTION

The integration of sustainability into supply chains has evolved from a peripheral concern to a central research and managerial priority. From a United Nations Sustainable Development Goals (SDGs) perspective, sustainable supply chains aim to manage environmental, social and economic impacts across the life cycle of goods and services. [1] In the same direction, sustainable supply chain management (SSCM) has become a mainstream domain in supply chain (SC) management scholarship over the last two decades. [2]

Conceptually, SSCM refers to the systematic integration of economic viability, environmental stewardship, and social responsibility into SC decisions and practices, with the aim of improving sustainability performance across firms and tiers while maintaining long-term competitiveness. [3,4]

Despite its relevance, SSCM implementation remains uneven and highly dependent on contextual conditions such as organizational capabilities, culture, geographic setting, and the quality of relationships among SC partners. Therefore, identifying and prioritizing barriers to SSCM is essential to move from broad sustainability goals to feasible interventions, particularly in complex economic environments where disruptions and resource scarcity intensify operational trade-offs. [5] However, evidence from such constrained contexts is still limited, especially regarding practical assessment models that can operate with incomplete data and support decision-making.

Prior research reports several persistent gaps that hinder the operationalization of SSCM. First, translating sustainability goals into operational efficiency and operational effectiveness and embedding them in a coherent performance measurement system, remains challenging. [6,7]

Second, literature highlights a shortage of transparent, implementable methodological tools (including quantitative and composite-index approaches) capable of supporting decision-making across multiple sustainability dimensions. [8,9] Third, SSCM implementation is frequently constrained by weak cross-organizational coordination and sustainability planning, particularly in emerging-economy contexts characterized by environmental turbulence and institutional voids; in construction-related networks, fragmented information sharing further reinforces these coordination problems. [10]

Fourth, there is limited convergence on economic, social, and environmental performance indicators, with evidence showing a proliferation of inconsistent metrics and persistent difficulties in measuring social issues at the SC level. [3,5,11] Finally, multiple studies emphasize capability and awareness limitations among supply chain actors as practical barriers to implementing sustainability strategies and maintaining continuous improvement trajectories. [12]

These constraints are particularly visible in construction materials supply chains, which are typically logistics-intensive, fragmented, and highly exposed to disruptions. [13,14,15] In such settings, decision-makers require parsimonious and operational assessment tools that translate qualitative diagnostics (e.g., checklists and expert judgments) into comparable sustainability scores and actionable priorities, even when data availability is limited.

Cuba represents a critical context for SSCM research and application. National frameworks explicitly incorporate sustainability into the development model through the Constitution of the Republic of Cuba and complementary legal instruments that emphasize environmental protection, social equity, and responsible resource governance. [16] At the same time, Cuban SC operate under persistent constraints: restricted access to inputs, energy limitations, financial scarcity, and external trade barriers, which amplify the frequency and impact of disruptions, shortages, and operational uncertainty.

As a result, improving logistics performance and SC coordination becomes not only an economic imperative but also a sustainability condition. The country's strategic priorities reinforce this need. Cuban economic and social policy promotes efficiency, renewable energy use, and environmental preservation under limited financial capacity, while encouraging integrated value chain management, risk management, and stronger links between science, innovation, and production.

In line with these priorities, the 2030 National economic and social development plan approved a science and innovation program in 2020 focused on the development of logistics and supply chains, signaling a national commitment to strengthening logistics and value networks across sectors. Nonetheless, literature and expert-based evidence consistently indicate that macroeconomic challenges, such as trade disruptions, investment delays, and chains of unpaid obligations, are closely related to weaknesses in logistics and SC performance. [17,18,19,20]

To ground the research problem in local practice, we conducted an initial expert consultation with specialists affiliated with Cuban National program of logistics and supply chains (n = 35). This consultation highlighted recurrent operational constraints that hinder SSCM implementation in the studied context, including: persistent service-level limitations driven by product shortages, forecasting errors and weak coordination among supply chain actors, limited uptake of internationally recognized management standards (e.g., ISO 28000 for supply chain security and ISO 26000 for social responsibility), low diffusion of sustainability tools such as life-cycle assessment, sustainable procurement and circular-economy practices, and regulatory gaps that limit collaborative structures (e.g., the absence of a clear legal framework for cluster development).

These context-specific barriers motivate the need for an operational, index-based assessment approach and for a prioritization method that emphasizes feasible interventions under constraints.

In response, this paper contributes by developing and applying a composite-index model to assess SSCM performance in a Cuban construction materials supply chain under high resource constraints. The model integrates three dimensions; economic, social, and environmental; through an economic dimension efficiency index (EDEI), a social dimension effectiveness index (SDFI), and an environmental dimension effectiveness index (NDFI), which together form a composite supply chain sustainability index (SCSI).

The study addresses two research questions:

RQ1) Which operational weaknesses most constrain SSCM performance in a Cuban construction materials supply chain?

RQ2) How can a composite-index approach support the prioritization of improvement strategies under resource-constrained conditions?

The objective of this paper is to evaluate current limitations in sustainable supply chain management practices in Cuban organizations and propose a methodological model to improve operational efficiency and effectiveness. The model is validated through a case study in the construction materials sector.

METHODS

A combination of theoretical and empirical methods, previously validated in the field by several authors was employed to ensure a thorough exploration of SSCM in the Cuban context. [21,22,23,24,25,26,27,28] A longitudinal embedded case study design was used to apply and validate the proposed composite-index model in a Cuban construction materials SC over a three-year period. For confidentiality reasons, calendar years are not reported; instead, measurement waves are labeled year 1-year 3 (baseline to follow-up). The interval between waves was one year, ensuring comparability of annual performance conditions. The goal was to quantify changes in sustainability-related performance and verify whether improvements after implementation were statistically significant.

The model was applied to three focal organizations within the supply chain (raw materials processing/production, distribution/logistics, and engineering/consumption). Each organization was assessed using the same instruments and scoring procedure to enable comparability across units and over time.

Data collection combined organizational records and structured instruments:

a) Economic indicator template at link level, based on organizational financial and logistics records (e.g., ROI and logistics cost structure);

b) social checklist for supply chain service level (SCSL) and supply chain integration level (SCIL), administered to knowledgeable employees and managers;

c) Environmental checklist (20 items) capturing practices at the supply chain-environment interface (SC-E), including reverse logistics, rated on a five-point Likert scale (1-5).

d) Sustainability planning survey to derive the supply chain sustainability planning index (SCSP).

In this paper, an indicator is a single measured variable (e.g., ROI, logistics cost ratio, checklist item score). An index (or composite indicator) is a synthesized measure obtained by aggregating multiple indicators, typically using normalization, weighting and aggregation rules (e.g., EfI, EDEI, SDFI, NDFI, SCSI).

All checklists and survey instruments were created or adapted from prior SSCM and construction SC literature and reviewed for content validity by the expert panel. A pilot administration was conducted to verify clarity and item relevance. Internal consistency was assessed using Cronbach's alpha for multi-item constructs ($\alpha \geq 0.70$ considered acceptable), and minor wording adjustments were made before full deployment. Instruments were administered through Google Forms, while secondary data were extracted from internal records.

An expert panel (n = 35) supported an initial study to identify gaps in SC activities, weighting of indices/criteria, and strategy evaluation. Experts were recruited using purposive sampling from the national logistics and supply chain program roster. Inclusion criteria were: 5 years or more of professional experience in logistics and supply chain roles, direct involvement in SSCM-related projects or decision-making, and willingness to participate in the weighting and consensus process. Invitations were sent by e-mail and phone through the program coordination team; participation was voluntary and anonymized. The final panel included representatives from academia, industry, and public-sector logistics, ensuring cross-sector perspectives. Inter-expert agreement was assessed using Kendall's coefficient of concordance (W) before finalizing weights.

The proposed model follows the operational workflow presented in figure 1 and links operational efficiency and operational effectiveness to the three sustainability dimensions (economic, social, and environmental). In this paper, operational efficiency is primarily captured through economic performance indicators, while operational effectiveness is captured through social (service/integration) and environmental (SC-E practices) outcomes.

The model is implemented as a sequential assessment:

- EDEI computed from economic indicators at link level and aggregated using link weights;
- SDFI computed from service level and integration assessments;
- NDFI computed from environmental management and reverse logistics practices at the SC–E interface;
- SCSI obtained as a weighted aggregation of EDEI, SDFI and NDFI;
- SCSP derived from the sustainability planning survey; and
- prioritization of improvement strategies using multi-criteria scoring and expert weighting.

Economic dimension efficiency index

The EDEI assesses financial health using:

- Return on investment (ROI): reflects profitability and liquidity.

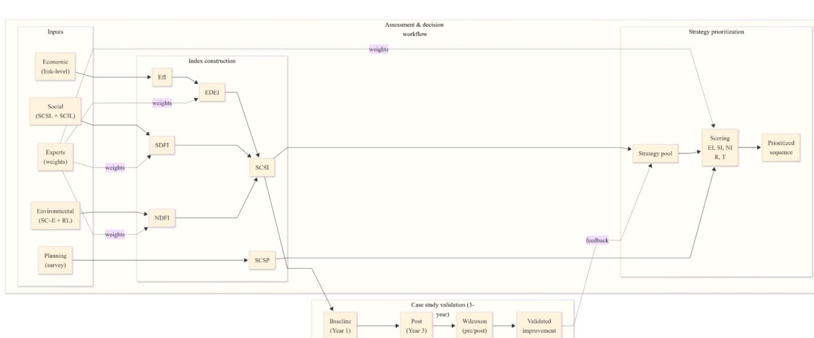

Fig. 1. Operational workflow of the proposed model

- Logistics cost-to-sales ratio (LC/sales): Benchmarked against sectoral references and internal targets (10%-15% for industrial firms, equal or bigger than 25% for service firms).

METHODS

a) Financial ratios: liquidity, solvency, and profitability metrics.

b) Logistics cost analysis: breakdown of procurement, warehousing, and distribution costs.

Efficiency Index (EfI): expression (1), adapted from the work of Vinajera Zamora is employed. [29] This equation makes it possible to quantitatively evaluate the performance of individual SC links by integrating weighted indicators, thereby offering a comprehensive perspective on their efficiency:

$$EfI = 5\left[1 - \sum_{i=1}^{n}\left((ME_i - E_i)\left(\frac{Wqi}{NEi}\right)\right)\right] \quad (1)$$

where EfI: efficiency index, MEi: maximum evaluation that can be reached by indicator I, Ei: evaluation given to indicator I, NEi: number of possible evaluations that indicator i can obtain and Wqi: weight of indicator i.

To evaluate the EfI of each link, consider the following scale: a score between 4.5 and 5.0 indicates good performance; between 4.0 and 4.49 is considered fair; and any score below 4.0 reflects poor performance. To calculate the EDEI, it is first necessary to determine the relative importance of each supply chain link. This can be achieved by applying techniques such as paired comparison and Kendall's concordance method, based on data collected through interviews and surveys with the work team. The specific weight assigned to each link is derived from its assessed level of importance.

Once the EfI of each link is known, the EDEI is calculated using expression (2):

$$EDEI = \sum_{i=1}^{n}(EfI(Wei)) \quad (2)$$

where EfI: efficiency index for link n and Wei: weight of link n. The same scale presented for the evaluation of the EfI is used to evaluate the EDEI.

Social dimension effectiveness index

SDFI evaluates social/organizational effectiveness through two components:

- Supply chain service level (SCSL), assessing gaps between designed targets, actual performance, and customer-perceived service.
- Supply chain integration level (SCIL), assessing internal and external integration factors (e.g., collaboration, contracts, joint planning, information exchange, joint decision-making, resource sharing, quality, worker welfare).

SDFI is computed as shown in expression (3):

$$SDFI = eSCSL(\mathrm{Wj}) + eSCIL\,(Wf) \quad (3)$$

Where eSCSL: evaluation of the SCSL, Wj: weight of the SCSL, eSCIL: evaluation of SCIL and Wf: weight of SCIL

Environmental dimension effectiveness index

This step evaluates the relationship between the SC and its environmental context (SC-E). A 20-item checklist is administered to knowledgeable employees, covering practices related to environmental management and reverse logistics. Each item is rated on a Likert scale from 1 to 5, indicating the frequency of each practice.

To analyze the results, Friedman's non-parametric test is applied across *k* organizations to identify statistically significant differences in environmental practices. The hypotheses tested are:

- H_0: No significant differences exist among organizations.
- H_1: Significant differences exist among organizations.

Results inform strategic planning in the next phase. The SC-E relationship score, called the NDFI, is determined by the mode of responses, reflecting the most frequent environmental practice. This score is interpreted on a five-point scale: 1 = deficient, 2 = insufficient, 3 = incipient, 4 = adequate, 5 = satisfactory.

Supply chain sustainability index

The Supply Chain Sustainability Index (SCSI) is calculated by combining three key components: the EDEI, SDFI, and NDFI. Each index is weighted (Wn, Wp, Wi) according to its relative importance, as determined by expert judgment using qualitative methods specific to the SC under analysis. Expression (4) shows how to calculate the index:

$$SCSI = EDEI(\mathrm{Wn}) + SDFI\,(Wp) + NDFI\,(Wi) \quad (4)$$

Based on the final SCSI value, the sustainability level is classified as follows:

- high: 4.5-5.0
- medium: 4.0-4.4
- low: below 3.9

Strategy prioritization procedure

Based on diagnostic results (lowest-performing dimensions and items), a set of candidate improvement strategies was compiled. Each strategy was evaluated using multi-criteria scoring based on expected impacts (economic impact EI, social impact SI, environmental impact NI) and feasibility criteria (resources required R, time required T). Expert weights were applied to compute strategy scores (Sj) and generate the prioritized implementation sequence (reported in table 1).

Statistical analysis and software

Internal consistency reliability of multi-item instruments (social, environmental, planning) was examined using Cronbach's alpha. Given the ordinal nature of checklist scores, non-parametric tests were applied. Differences across organizations and/or factors were assessed using the Friedman test where applicable. To test longitudinal change after implementation (year 1 vs year 3), the Wilcoxon signed-rank test was applied. Statistical significance was evaluated at $\alpha = 0.05$. Data processing and analysis were conducted using SPSS 21.0 and Google Forms.

RESULTS

To validate the research hypothesis, a case study was conducted in a construction materials supply chain, an economically strategic and environmentally impactful sector in Cuba. The chain includes three interconnected organizations:

- a raw materials processor producing aggregates, blocks, tiles, and other construction products;
- a distributor managing commercialization and logistics;
- an engineering firm that uses these materials in public infrastructure projects.

Economic dimension efficiency index

A financial analysis was conducted using standard ratios (e.g., liquidity, ROI, ROE) to assess each organization's economic performance. Despite variability across indicators, key inefficiencies were identified, particularly in logistics cost control. These costs are often poorly tracked, affect operational efficiency and long-term sustainability.

Two main criteria were selected for calculating the Efficiency Index (EfI):

- Return on Investment (ROI) (weight = 0.62)
- Total logistics cost as a share of sales (LC/S) (weight = 0.38)

Expert voting and Kendall's concordance method confirmed the relevance of these weights. Each organization was evaluated accordingly:

- organization 1: EFI = 3 ⟶ poor,
- organization 2: EFI = 5 ⟶ good,
- organization 3: EFI = 4.57 ⟶ good.

A paired comparison determined the importance of each organization to the supply chain:

- organization 1: 66% (most critical),
- organization 3: 24%,
- Organization 2: 10%,

Using these weights, the overall EDEI was calculated based on expression (2), as shown in expression (5):

The EDEI result is classified as "poor," primarily influenced by the IEf of Organization 1. As the most critical company in the supply chain, Organization 1 not only holds the highest weight in the efficiency index but also received the lowest evaluation in EfI, heavily impacting the overall EDEI assessment.

Social dimension effectiveness index

The three organizations analyzed share a common service level target of 80%, considered "high," serving as the benchmark

Table 1. Scoring of proposed strategies

Strategy	Criteria					S_j	Sequence
	EI	SI	NI	R	T		
Develop an ERP system	1.2	0.8	0.8	0.32	0.16	3.28	7
Conduct capacity studies in the organization 1	1.2	0.64	0.6	1.6	0.4	4.44	3
Conduct a value chain analysis of the construction aggregate product family	1.2	0.48	0.4	1.28	0.32	3.68	6
Establish commitment with suppliers	0.72	0.8	0.8	0.64	0.16	3.12	8
Supply chain security management	1.2	0.8	1	0.64	0.16	3.8	5
Communicating sustainability	0.96	0.8	1	1.6	0.4	4.76	2
Raise environmental awareness among staff	0.72	0.64	1	1.6	0.4	4.36	4
Adoption of codes of conduct	3	0.8	0.8	1.6	0.4	6.6	1
Construction aggregate product family life cycle analysis	1.2	0.32	1	0.32	0.08	2.92	9
Adopt a circular economy model	1.2	0.32	1	0.32	0.08	2.92	10
Create a productive chain	1.2	0.8	0.4	0.32	0.08	2.8	11

for evaluating actual performance and customer perception. Despite some indicators nearing the target (e.g., delivery reliability and product availability), overall service performance fell short. Perceived service levels ranged from 35.96% to 52.65%, with Organization 3 scoring highest, used as the reference for the entire supply chain. The gap between designed, actual, and perceived SL reflects clear service deficiencies.

To assess integration, a checklist was administered. Internal integration showed no significant differences ($p = 0.504$), indicating a consistent medium level, though weaknesses were noted in the security dimension. External integration showed significant differences ($p = 0.0164$), especially in collaboration with suppliers and customers. While some coordination exists, mainly due to shared ministerial oversight, gaps persist in logistics resource sharing. The overall SCIL was 3.16, also in the medium range.

In the social dimension, the SDFI was calculated using weighted scores based on expert judgment. The SCSL received a weight of 0.57 and the SCIL 0.43. Applying expression (3), the results are shown in expression (6):

This result classifies the social dimension as "poor", largely due to the low perceived service level. As a result, improving customer service should be prioritized in future sustainability strategies.

Environmental dimension effectiveness index

The checklist was administered to three groups: environmental management personnel, organizational managers, and production employees with greater environmental impact. Using IBM SPSS, the Friedman test revealed significant differences in environmental practices across supply chain organizations (asymptotic significance is $0.0083 < 0.05$), leading to the rejection of the null hypothesis and confirming varied approaches to environmental management.

The SC-E relationship was classified as incipient, with organizations 1 and 3 showing the greatest need for improvement, particularly organization 1 due to the higher impact of its activities. Key weaknesses identified include limited client concern for supplier environmental impacts, poor monitoring of supplier-generated waste, and a lack of requests for sustainability-related information, such as energy consumption, health and safety, and water use. These gaps highlight critical areas for enhancing environmental responsibility across the supply chain.

Calculate supply chain sustainability index

At this stage, the Supply Chain Sustainability Index (SCSI) was calculated using expression (4). Weights for each index, EDEI (0.45), SDFI (0.21), and NDFI (0.34), were determined tнrough expert ranking, and the Kendall concordance method was applied to ensure consensus and reliability in weight assignment.

The resulting calculation is in expression (7):

places the supply chain in the "low" sustainability category, according to the established evaluation scale. The primary limiting factor was the SDFI, indicating that the social dimension requires the most attention in future improvement strategies.

Strategic sustainability planning

To evaluate the sustainability approach, the survey designed by Pupo Pérez et al. was applied to team members with knowledge of how sustainability is integrated within the supply chain organizations. [30] The reliability of this survey was confirmed with a Cronbach's Alpha of 0.789, indicating strong reliability ($\alpha > 0.7$). Following this, the geometric mean was calculated for the survey responses, yielding a SCSP of 1.45. According to the scale proposed in the cited study, this value is classified as "low" (below 4), highlighting a substantial gap in sustainability integration across the supply chain.

The sustainability approach of the supply chain under study is assessed using the matrix proposed by Pupo Pérez et al., as shown in figure 2. [30] This matrix allows for a structured evaluation of the SC's sustainability practices across key dimensions. This approach offers actionable insights for aligning SC's sustainability efforts with strategic objectives.

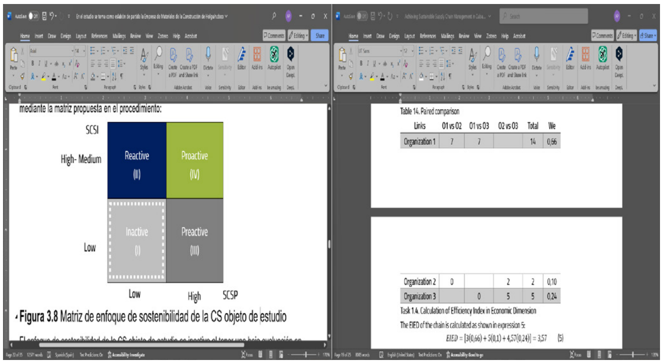

Fig. 2. Sustainability approach matrix of the supply chain under study

$$EDEI = [3(0.66) + 5(0.1) + 4.57(0.24)] = 3.57 \quad (5)$$

$$SDFI = 2(0.57) + 3\,(0.43) = 2.43 \quad (6)$$

$$ISCS = 3.47(0.45) + 2.43\,(0.21) + 3\,(0.34) = 3.03 \quad (7)$$

The sustainability approach of the SC under study is classified as "inactive", as indicated by its low SCSI and SCSP. Placement in this quadrant suggests a lack of sustainability planning and the absence of practical sustainability initiatives within the SC, directly contributing to the low SCSI. Given this inactive status, future strategies for this SC must be designed with a focus on addressing these deficiencies. These strategies should be developed based on the current assessment results, prioritizing sustainability planning and actionable measures that support improved sustainability integration.

Strategies for sustainable supply chain management

The initial step involves defining the vision and objectives for SSCM within the SC under study. Following the procedure outlined by Pupo Pérez et al. optimal strategies are then identified and selected for enhancing sustainability across the SC. [30] Once selected, the strategies are systematically organized and described in detail. To determine their prioritization, the Scoring method is applied, evaluating each strategy based on its feasibility of implementation.

This feasibility is assessed through five key criteria: economic impact (EI), social impact (SI), environmental impact (NI), resources required for implementation (R), and time required for implementation (T). These criteria are weighted according to their importance using Fuller's triangle method, ensuring a balanced consideration of both impact and feasibility. The outcomes of this analysis, detailing the priority order of each strategy, are presented in table 1.

The scoring results indicate that the highest-priority strategies are those combining high expected sustainability impact with feasible implementation under current constraints. In this case, the top-ranked actions emphasize governance and behavioral enablers (e.g., codes of conduct and communicating sustainability practices to stakeholders), which typically require lower capital intensity and shorter lead times, while enabling subsequent operational initiatives (e.g., ERP implementation and life-cycle analysis).

This prioritization is consistent with the diagnosis that social and planning-related factors are the main limiting dimensions of overall sustainability performance (i.e., lower SDFI/SCSP relative to the other indices). Moreover, strategies with longer implementation horizons (e.g., circular economy and full productive chain integration) appear later in the sequence due to higher resource and time requirements, despite their potential long-term benefits.

The strategies are then implemented following the established prioritization sequence, with control measures in place to monitor and ensure their effective progression. These control actions are essential for tracking development, addressing potential challenges, and making necessary adjustments to achieve the desired sustainability outcomes within the SC.

DISCUSSION

This study highlights the pressing need for further empirical research to better understand and address the challenges of SSCM within economically constrained environments like Cuba. While previous research has explored sustainability and supply chains independently in the Cuban context comprehensive analyses integrating both aspects are limited. [17,19,20,29,31,32,32,33,34,35] In response to this gap, the model developed in this study introduces a quantitative, multidimensional tool to assess SSCM performance and support targeted strategies. It emphasizes the role of efficiency and effectiveness, especially under economic constraints, as critical enablers of sustainable outcomes.

Importantly, this study addresses another core challenge in SSCM research: the difficulty of collecting data across multiple tiers of the supply chain. As Seuring et al. notes, access to focal companies, suppliers, and customers remains limited in most empirical work. [4] This research, however, collected and analyzed data from several levels of the supply chain, offering valuable insights into inter-organizational dynamics and integration, an aspect that strengthens the contribution and reception of this work.

Furthermore, our findings reinforce the need to transcend traditional efficiency-driven models and adopt broader social and environmental perspectives in supply chain planning. This aligns with Pagell and Wilhelm, who call to redefine supply chain excellence by centering people, communities, and ecosystems, not as externalities but as core elements of value creation. [36] In this light, our model contributes not only as an evaluation tool but as a framework for fostering collaborative, people-centered, and sustainable strategies across supply chains.

Finally, the results demonstrate that aligning sustainability actions with the efficiency-effectiveness relationship and integrating all three sustainability dimensions yields tangible improvements. Over the three-year evaluation period, key indicators such as EDEI, SDFI, and NDFI displayed a consistent upward trend (figure 3), confirming the model's potential to drive measurable and sustained performance gains in complex and constrained environments.

Additionally, the evaluation of both the SCSI and the SCSP demonstrates a favorable upward trend, thereby validating the effectiveness of the implemented strategies in promoting the sustainability of the chain. It is noteworthy that the SCSP has advanced at a more rapid rate, reflecting the intensive focus on strategies specifically designed to enhance sustainability

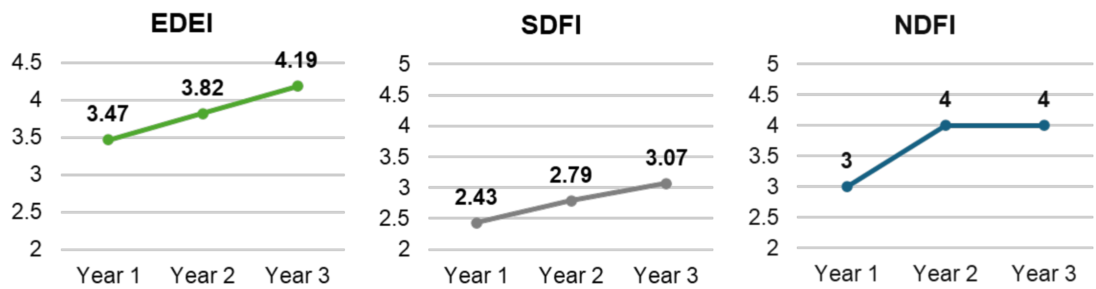

Fig. 3. Evolution of economic dimension efficiency index, social dimension effectiveness index and environmental dimension effectiveness index

planning. This finding aligns with the principle that effective sustainability management requires a strategic, well-structured plan. As demonstrated in fig. 4, the present study illustrates the growth trajectory in question, with particular attention being directed towards the advancements in sustainability planning and overall performance within the SC.

To statistically validate the results, the Wilcoxon signed-rank nonparametric test was applied using IBM SPSS to compare SC performance before and after implementing the proposed SSCM model. The hypotheses were as follows:

- H_0: No significant difference exists in supply chain performance before and after the model's implementation.
- H_1: The model significantly improves supply chain performance.

The analysis compares data from year 1 (baseline) and year 3 (post-implementation), yielding a p-value of 0.043 (asymptotic significance, two-sided), which is below the 0.05 threshold. As a result, the null hypothesis was rejected, indicating a statistically significant improvement in performance following the model's application.

This outcome supports the model's effectiveness in enhancing SC sustainability and suggests its potential as a valuable framework for other regions facing similar economic conditions.

Regarding RQ1, the diagnostic shows that the main bottlenecks are concentrated in the social and planning dimensions, particularly external integration and structured sustainability planning. Regarding RQ2, the proposed multi-index workflow (EDEI–SDFI–NDFI aggregated into SCSI, complemented by SCSP) proved useful to prioritize feasible strategies and to track improvements over time under resource constraints.

International evidence from the construction sector consistently highlights inter-organizational collaboration, particularly

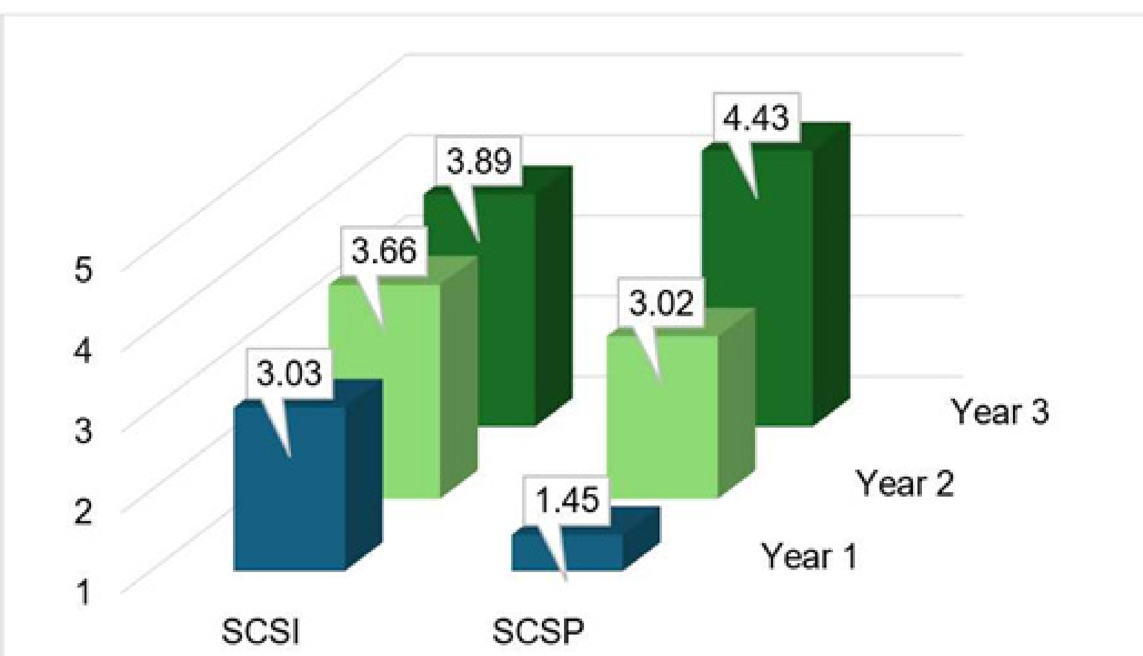

Fig. 4. Evolution of supply chain sustainability index and supply chain sustainability planning

supplier engagement, information sharing, and joint environmental initiatives, as a critical enabler of sustainability performance in fragmented, project-based supply chains. Empirical work shows that environmental collaboration among partners (e.g., shared standards, joint planning, and supplier involvement in sustainability goals) supports the adoption of sustainable practices and improves coordination across the network.

In our case, the comparatively low overall sustainability performance is similarly constrained by weak external integration and limited environmental information exchange with key partners, which directly depresses the social and environmental indices (SDFI and NDFI) and hinders the consolidation of sustainability planning (SCSP). This alignment suggests that, while Cuba's constraints are distinctive, the mechanisms observed internationally, collaboration, structured information sharing, and governance practices, remain decisive levers for improving SSCM performance and for enabling more resource-intensive interventions over time [13,14,35,37]

This study provides a focused examination of SSCM within the unique economic and regulatory conditions of Cuba, shedding light on how sustainability efforts can be structured and evaluated in such a context. However, because it is confined to a single SC within Cuba, there are inherent limitations to generalizing these findings universally. The model's effectiveness, while promising here, may be shaped by specific local factors, such as Cuba's regulatory landscape, government influence, resource constraints, and socio-economic priorities, that vary greatly across regions. These factors can influence how supply chain strategies are implemented and perceived. To enhance the study's applicability and address these limitations, future research could replicate the model in other countries or regions, especially in those with similarly complex economic conditions. Testing the model in diverse environments would allow researchers to observe whether the proposed strategies achieve similar improvements in sustainability or if adjustments are required based on regional factors, such as distinct regulatory frameworks, market structures, and cultural considerations. For example, a SC in a heavily industrialized economy with more robust infrastructure might yield different results than one in a primarily resource-based economy with constrained infrastructure, even if both operate under economic pressures.

Conducting comparative studies in various economic contexts would also provide valuable insights into which elements of the model are universally effective versus those that may require adaptation. This could help refine the model into a more flexible framework that organizations globally could use to guide their sustainability efforts, while still considering the specific challenges and resources of their unique environments. Moreover, a broader base of empirical evidence from various contexts would enrich our understanding of the interactions between efficiency, effectiveness, and sustainability, illuminating how these dynamics play out under different economic and policy constraints. Ultimately, this approach would contribute to a more comprehensive and adaptable framework for managing SC sustainability, offering practical guidance for organizations worldwide striving for sustainability amid economic complexities.

Conclusions

This study confirms that implementing structured SSCM is feasible and beneficial, even under Cuba's challenging economic conditions. The proposed model, centered on efficiency and effectiveness across economic, social, and environmental dimensions, proved adaptable and effective in enhancing sustainability performance.

Key findings highlight that economic efficiency and resource optimization are essential foundations. Managing financial performance and logistics costs enables organizations to mitigate resource constraints. However, greater integration of social and environmental dimensions is needed, particularly in areas like waste management, reverse logistics, and community engagement.

A major barrier identified is the lack of formal sustainability planning, which results in fragmented efforts. The study stresses the importance of having a clear sustainability vision and long-term planning framework. It also emphasizes the value of collaborative and cross-organizational strategies, which strengthen integration and reduce costs through shared goals and joint decision-making.

Moreover, the findings reveal the need for tailored strategies that reflect the distinct roles and impacts of each supply chain link. This approach enhances the effectiveness of sustainability initiatives across the network.

Finally, the model shows positive impacts on supply chain performance, with measurable improvements in key indicators over time. As such, it offers a replicable framework for SSCM in other economically constrained contexts, contributing both practical and theoretical value to the field.

In relation to RQ1, SSCM limitations in the case study are primarily explained by weaknesses in social integration mechanisms and sustainability planning capabilities. In relation to RQ2, the methodological model operationalizes SSCM through a replicable index-based workflow that supports strategy prioritization and demonstrates measurable pre and post improvements.

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Conflicts of interest

The authors confirm that there are no conflicts of interest related to this study.

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