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Contextual and Organizational Factors in Sustainable Supply Chain Decision-Making: Grey Relational Analysis and Interpretative Structural Modeling

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Abstract: Sustainable supply chain emerges as a major business trend essential to long-term competitive advantage. Relevant corporate decisions concern a broad range of factors and require novel analytical models for critical control. This study conducts mathematical analyses to identify the factors that are vital yet receiving insufficient attention from researchers and practitioners. Valid survey observations were collected from 113 enterprises in China, the biggest emerging economy that faces the dilemma between development and sustainability. Grey relational analysis (GRA) and interpretative structural modeling (ISM) assess the importance levels of contextual and organizational factors and explore their joint effects. Validated with conventional expert interviews, the results prioritize the factors that play crucial roles in sustainable supply chains. In particular, enterprises should pay close attention to three factors: corporate collaboration, clean production and supplier selection, which provide useful clues on the best practices of formulating low-carbon decisions. With a better understanding of critical factors, enterprises may make supply chains more sustainable with limited resources. To enhance the generalizability of findings, future studies may collect more observations from multiple countries and validate the results in the settings of global supply chains.

Keywords: Sustainable Supply Chain, Low-carbon Decisions, Grey Relational Analysis (GRA), Interpretative Structural Model (ISM).

1 Introduction

Climate change has increasingly drawn people's attention to environmental problems around the world (Danlami, Applanaidu, & Islam, 2018b). Exacerbated by human activities, especially production and logistics, the emissions of pollutants like carbon dioxide in the atmosphere contribute to climate change. As the environment regulation is becoming more and more stringent, enterprises in emerging economies like China pursue sustainable development to fulfill their social responsibilities (Dou & Cui, 2017a; Garg & Sharma, 2018). Almost every industry relies on supply chain operations, and how to reduce their environmental impacts is a strategic decision for organizations to make (Ashby, 2018).

More and more enterprises switch from the traditional supply chains to sustainable supply chains to enhance their competitiveness (Renukappa, Akintoye, Egbu, & Goulding, 2013). The sustainability of supply chains relies on the use of emerging technologies in resource reservation, environment protection and material recycling to accomplish economic, environmental and social goals at the same time (Ghadimi, Wang, & Lim, 2019). However, green technologies and organizational transformations are not easy to implement (Flynn, Huo, & Zhao, 2010). In addition, sustainable supply chains concern the transparent and strategic integration of key business processes across organizations (Carter & Rogers, 2008). Therefore, the transition to sustainable supply chains is challenging yet pivotal for enterprises to achieve both economic and environmental goals in the long run (Dou, 2013). Managers need to take into account different aspects of situations, and formulate relevant low-carbon decisions (Kolk & Pinkse, 2004). Identifying the most influential factors is the key to the development of appropriate decision-making models for sustainable supply chains.

Most extant studies focus on certain aspects of sustainable supply chains, especially organizational factors, using singular methods (Azevedo, Carvalho, Ferreira, & Matias, 2017; Beermann, 2011). This study examines the whole supply chain process by including contextual factors in addition to organizational factors with integrated methods. Based on a survey on low-carbon decisions, it identifies the crucial factors essential to sustainable supply chains with grey relational analysis (GRA), and further explores their interactions and relationships using interpretative structural modeling (ISM). The results from both GRA and ISM lead to a low-carbon decision-making model that reduces the subjectivity from traditional expert scoring, and the influential factors identified help nail down the ones requiring the most attention from all those previously recognized. Specifically, this study attempts to answer the questions below:

(1) What are the influential factors for sustainable supply chains?

(2) What core low-carbon decisions do enterprises need to make in supply chain operations?

(3) How contextual and organizational factors interact with each other in low-carbon decision making?

The remainder of this article is organized as follows. It first summarizes the factors that influence low-carbon decisions with a literature review. Based on the understanding, a questionnaire is developed to find out how enterprises actually make low-carbon decisions. Using the methods of grey relational analysis and interpretative structural model, the observations collected are analyzed to identify important low-carbon factors and examine their joint effects in decision-making. The decision model derived is compared with the one obtained from the traditional expert scoring method for cross-validation. Findings are discussed in terms of theoretical and practical implications, followed by the conclusion.

2 Research Background

2.1 Low-carbon Decisions

Sustainable development concerns all nations as economic growth and energy consumption have led to serious environmental degradation (Danlami, Applanaidu, & Islam, 2018a). As an important part of business operations, supply chain is the key for enterprises to carry out sustainable practices (Garg & Sharma, 2020). In response to public demands for environment protection and emission reduction, enterprises make greener supply chain decisions from raw materials procurement to final product delivery. In particular, managers take government regulations into account when they make relevant decisions to comply with environmental obligations (Cao et al., 2017). In terms of organizational strategies, it is necessary to set low-carbon targets, invest in green technologies, and predict customer demands for environment-friendly products. Enterprises engage in all kinds of activities to make their supply chains sustainable, including green product design, energy conservation in production, green packaging, low-carbon storage, green transportation, and product recycling.

To meet both environmental and developmental requirements, enterprises devote themselves to set low-carbon targets and make decisions on how to reach them (L. Chen, Xu, Xu, & Yang, 2016). For instance, the IT industry achieves sustainability by investing in low-carbon industrial parks and buildings (Zhu, Weiwei, Yu, Yu, & Panpan, 2018). Based on the forecast of market demands, manufacturers make corresponding plans, such as providing low-carbon products to customers and reducing the carbon emission in downstream logistics (Li, Long, & Chen, 2017).

To maximize corporate sustainability, an enterprise needs to make low-carbon decisions on almost all supply chain activities including product design, manufacturing, packaging, transportation, storage and recycling. Concerning the materials required and functions provided, the low-carbon design of a product affects subsequent manufacturing and sales (He, Wang, Huang, & Wang, 2015). At the production stage, the improvement of efficiency and the use of clean energy reduce operational costs and environmental impacts (Hukkalainen et al., 2017). As for logistics, many companies adopt supply-chain-centric packaging, smart inventory management and green transportation to reduce carbon emissions from product packaging, storage and transportation (Lee, Hashim, Ho, Fan, & Klemeš, 2017; Sohrabpour, Oghazi, & Olsson, 2016). Finally, the recycling of used products reduces the waste of resources and promotes the sustainability of supply chain (Turk, Reay, & Haszeldine, 2018).

Based on the literature, low-carbon decisions mostly concern about: low-carbon target, partner cooperation, internal management, energy conservation, employee motivation, corporate investment, technology innovation, customer demand, green product design, green procurement, inventory IT support, low-carbon manufacturing, green packaging, green storage, low-emission transportation, and product recycling. In making different low-carbon decisions, managers need to consider numerous factors, both internal and external.

2.2 Influential Factors of Low-carbon Decisions

To make low-carbon decisions in line with a company's green strategy, decision-makers must consider the implications of intended actions (Rodríguez-Serrano, Caldés, Rúa, Lechón, & Garrido, 2016). It is essential to identify the most influential factors and establish decision-making models. In this process, organizational factors are fundamental, as low-carbon decisions are made for the interests of business stakeholders. As a strategic endeavor, corporate sustainability requires managers to have a good understanding of the company's green strategy (Jabbour, Neto, Jr, & Ribeiro, 2015). In addition, managers must engage operational-level employees in collective decision-making (A. Kaur & Sharma, 2018). Therefore, manager support and employee participation are both critical to low-carbon decisions.

The literature suggests different strategies that affect low-carbon decisions based on economic, environmental and social considerations (Rao, Goh, & Zheng, 2017). First of all, supplier selection is an important business strategy directly related to sustainable supply chain (Choi, 2013; Das & Jharkharia, 2018). Considering time, quality and delivery timeliness, enterprises choose lean suppliers to reduce the impact on the environment (Torğul & Paksoy, 2019). As the other side of the coin, the procurement strategy of participating organizations largely determines whether the supply chain in question is sustainable or not (Shaw, Shankar, Yadav, & Thakur, 2012). The green procurement policy is meant to reduce environmental impacts as well as business costs (H. Kaur & Singh, 2017). Internally, enterprises need to dilute the traditional profit-oriented business strategy with the emerging climate change mitigation strategy (Y. Tong, 2017). At the operational level, how well companies deploy green supply chain management depends on the organizational adjustments to the new requirement of operational management (Alves, Kannan, & Jabbour, 2017). Therefore, the strategies affecting low-carbon decisions can be summarized as supplier selection, procurement policy, climate change mitigation, and operational management.

As for the implementation of specific low-carbon decisions, it is vital to consider the factors that shape the process from production to final product delivery. Technology innovation and clean production complement each other, and an organization's successful transition to low-carbon operations relies more on small-scale than large-scale technologies (Hoggett, 2014). Individual manufacturers use innovative technologies to collaborate with each other for supply chain integration as well as to involve customers (Kesidou & Sorrell, 2018). Therefore, the employment of information and communication technologies (ICT) is essential to the development of sustainable supply chain networks (Luthra, Mangla, Chan, & Venkatesh, 2018), leading to eventual competitive advantages (Jin et al., 2017). Clean production plays an important role on the manufacturing side (Ahmed & Sarkar, 2018), and carbon emission reduction requires the close cooperation among companies in the acquirement of product parts (C. M. Chen, 2017; Zu, Chen, & Fan, 2018). As for product distribution and sales, transportation and inventory are important links in sustainable supply chains (Das & Jharkharia, 2018). The reduction of carbon emission from transportation relies on careful vehicle scheduling and route planning with methods like the network optimization model (KrishnenduShaw, RaviShankar, Yadav, & Thakur, 2013). Optimized inventory coordination cuts down carbon emission by reducing shipment frequency (Tang, Wang, Yan, & Hao, 2015), and a three-tier model is recommended (Sarkar, Ahmed, & Kim, 2018).

From the outside, customer low-carbon awareness and government intervention drive corporate decision-making regarding the integration of sustainability into supply chains (Ji, Zhang, & Yang, 2017; S. C. Tseng & Hung, 2014). Whereas regulatory measures exert coercive pressures on supply chain sustainability (Shokri, Oglethorpe, & Nabhani, 2014), the government may also reward enterprises that meet certain environmental goals through incentive programs (Ding, Zhao, An, & Tang, 2016). Enterprises respond to external driving forces with efforts conducive to sustainable supply chain, such as cleaner procurement, internal organizational coordination, and organizational system review (Grose & Richardson, 2013).

Table 1 lists the 13 key factors identified from the literature. Among them, supplier selection, transportation management, inventory control, manager support, procurement policy, employee engagement, clean production, operational management, and climate change mitigation strategy concern different aspects of sustainable supply chain decision-making. Meanwhile, technology innovation and corporate collaboration largely pertain to the organizational context in which supply chain operations are carried out. Except for the two external forces (i.e., customer low-carbon awareness and government intervention) over which enterprises have little control, the 11 organizational and contextual factors are the primary focus of this study.

Table 1. Frequency Table of Low-carbon Decision-making in Sustainable Supply Chain in Literature

Author \ Factor	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13[a]
Jabbour et al. (2015)	√	√			√		√						
Rao and Goh (2017)			√										
Choi (2013)			√			√							√
Tong (2017)				√									
Chiranjit et al. (2017)			√						√		√		
Alves (2017)				√	√								
Kaur (2017)						√							
Shaw et al. (2012)			√			√							
Jin et al. (2017)							√						
Luthra (2018)							√						
Ahmede (2018)								√			√		
Zu (2018)									√			√	√
Chen (2017)									√		√		
Krishnendu et al. (2013)				√						√			
Tang (2015)				√						√	√		
Sarkar et al. (2018)				√							√		
Ji et al. (2017)				√								√	
Tseng (2014)				√								√	√
Ding (2016)									√				√
Grose et al. (2013)								√					√

[a]F1-manager support; F2-employee engagement; F3-supplier selection; F4-operational management; F5- climate change mitigation strategy; F6-procurement policy; F7-technology innovation; F8-clean production; F9-corporate collaboration; F10-transportation management; F11-inventory control; F12-consumer awareness; F13-government intervention

Nevertheless, consumer awareness and government intervention guide the decision-making of enterprises regarding the direction of sustainable supply chain development. This is the primary consideration in choosing the targeting population for this study. Among all countries, China is facing tremendous environmental problems that concern its people, and the government formulates low-carbon policies for enterprises (Dou & Cui, 2017b). Under such external influences, enterprises make green products for which customers are willing to pay higher prices (W. Tong, Mu, Zhao, Mendis, & Sutherland, 2019). In this way, enterprises can benefit from the low-carbon economy while conserving the environment. In terms of internal factors, raw material acquisition directly affects the subsequent production and sales (Kondo, Kinoshita, Yamada, Itsubo, & Inoue, 2019). Good operation management of enterprises can be conducive to the overall control of the supply chain (Y. Tong, 2017). The use of innovative technologies and methods is essential to reduce carbon emission from manufacturing, inventory and logistics (Daryanto, Wee, & Astanti, 2019). As external factors constitute a common environment for the enterprises within a country while internal factors are specific to each, this study examines how low-carbon decisions are subject to supplier selection, procurement policy, operational management, technology innovation, and so on.

3 Research Design

Based on grey relational analysis (GRA) and interpretative structural modeling analysis (ISM), this study constructs a low-carbon decision model. GRA is used to identify the factors that have a relatively large influence on low-carbon decision-making in terms of attention received and strategic importance. The application of ISM method is to stratify these relatively influential factors and examine their relationships in depth. The final decisions need to consider the low-carbon strategies already adopted by different enterprises, and commonly-recognized factors do not necessarily make the most differences in actual decisions. The combination of GRA and ISM is to reveal the structural relationships involved in low-carbon decision-making, as shown in Figure 1.

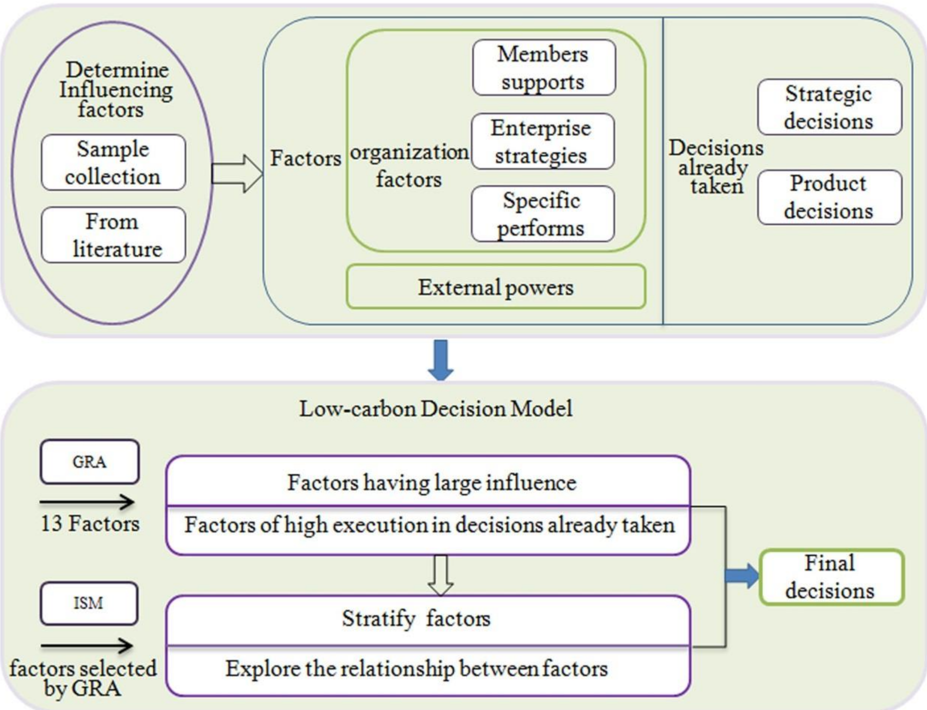

Fig. 1 Research Design Overview

3.1 Data Collection

To find out how enterprises make low-carbon decisions to achieve sustainability, this study elicited responses from participating organizations at different levels of supply chains with an online questionnaire. The questionnaire items were adapted from the studies listed in Table 1 to the context of participating enterprises in sustainable supply chains. As shown in Appendix A, there were two parts with questions on low-carbon decisions and influential factors, respectively.

As China launched the low-carbon initiative in 2010, it is advocated that all enterprises take sustainable development as a primary business strategy (Ying & Liu, 2017). Therefore, the sample of this study comprised 153 managers from different Chinese enterprises. Each was sent the link to the questionnaire and asked to answer the questions based on the recent low-carbon decision-making in his/her organization. One week after the initial invitation, a follow-up message was sent out to increase the response rate. At the end of the data collection period, 131 responses were collected, among which 113 were complete, resulting in a valid response rate of 74%. As shown in Table 2, a little bit more than two-thirds of participants were managers at the operational level, and the rest were at the middle and executive levels. They were from different departments that were more or less related to supply chain management. A comprehensive representation of industries and a good mixture of organizational sizes and ages ensured sampling validity.

Table 2. Participant and Organization Profiles

Characteristics		Frequency	Percentage
Job roles	Operational level	78	69.03
	Middle and executive level	35	30.97
Department	Functional departments	44	38.94
	R&D department	7	6.19
	Production department	24	21.24
	Marketing department	30	26.55
	Purchasing department	1	0.89
	Other departments	7	6.19
Years of company establishment	1-5	28	24.78
	6-10	29	25.66
	11-20	27	23.89
	21-30	11	9.73
	>30	18	15.94
Company size (The number of employees)	1-49	28	24.78
	50-99	16	14.16
	100-499	28	24.78
	500-1000	13	11.50
	>1000	28	24.78
Industry	Manufacturing	27	23.89
	Wholesale and retail	14	12.39
	Construction industry	11	9.73
	Transportation industry	5	4.43
	IT industry	13	11.50
	E-commerce	9	7.97
	Service	21	18.59
	Other industries	13	11.50

Common method bias (CMB) is a systematic error of high covariation among predicted and explanatory variables due to the same data source and measurement instrument (Podsakoff, Mackenzie, Lee, & Podsakoff, 2003). This study uses Harman's single-factor test to assess the common method bias often associated with the survey methodology. The test found that the proportion of the first principal component in the unrotated factor matrix was 39%, less than 50%. The result indicated that none of the factors extracted accounted for the majority of variance. Thus, common method bias is not a major concern.

3.2 Grey Relational Analysis

Grey Relational Analysis (GRA) is used to determine the correlations among different groups of factors based on their perceived similarities (Haq & Kannan, 2007). This method can utilize a relatively small amount of data to establish the mathematical model of correlational relationships. It helps reveal the relationships between 16 low-carbon decisions and 13 influencing factors identified from the literature review and expert interview. Here are GRA steps:

(1) Determine reference and comparison series. Set reference sequence $x_0=\{x_0(t) \mid t=1, 2 \ldots N\}$; where N is the number of respondents, with the most popular response as a reference sequence. Set comparison series $X_i = \{x_i(t) \mid t=1, 2 \ldots N\}, i= (1, 2 \ldots M)$, where i represents the number of influencing factors. The reference number indicates the enterprise that makes the low carbon decisions, and the comparison series comprise the influential

factors on low-carbon decisions. The reference numbers and comparison numbers are calculated by taking the means of means (M. L. Tseng, Ming, Wu, Zhou, & Bui, 2018).

(2) Based on different data series, calculate the absolute values of the differences between the comparison sequence and the reference sequence, and then get the minimum and maximum values:

$$\Delta_i(t) = |x_0(t) - x_i(t)| \quad (3.1)$$

$$\Delta_{min}^{(i)} = \min_{i,t} |x_0(t) - x_i(t)| \quad (3.2)$$

$$\Delta_{max}^{(i)} = \max_{i,t} |x_0(t) - x_i(t)| \quad (3.3)$$

(3) The index interval processing is carried out to get the grey correlation coefficient of each factor, which then paves the order of the next degree of relevance. The process is used for all data of the same matrix by dividing the difference between the minimum value and the grey correlation coefficient in the matrix and the difference between the minimum and maximum values.

$\zeta_i(t)$ is the grey correlation coefficient of the time *t*, and ρ is the resolution coefficient.

$$\zeta_i(t) = \left(\Delta_{min}^{(i)} + \rho_{max}^{(i)}\right) / \left(\Delta_i(t) + \rho_{max}^{(i)}\right), \rho \in [0,1],\ \rho/(1+\rho) \le \zeta_i(t) \ll 1 \quad (3.4)$$

(4) The grey relational degree between the comparison and reference sequences is calculated as:

$$\gamma_{\mathrm{i}} = 1/n \sum_{t=1}^{n} \zeta_i(t) \quad (3.5)$$

3.3 Interpretative Structural Modeling

Interpretative Structural Modeling (ISM) is a structural modeling technique to decompose a complex system into multiple subsystems based on logical operations. The deliverable is a hierarchical display of structural relationships among variables that transforms vague thoughts and views into intuitive multi-layer progressive models. This study used ISM to analyze the structural relationships among the factors selected through GRA. It established a structural similarity (SSIM) matrix based on the correlations among the factors and then used binary (i.e., 0-1) variables form an adjacency matrix. The resulted reachability matrix can be divided into different levels, leading to the final structural interpretation model. Below are the specific steps of ISM (Ali, Arafin, Moktadir, Rahman, & Zahan, 2018).

(1) Determine the correlations among variables.

(2) Establish the SSIM matrix based on the relationships among the elements with the following rules:

O indicates that there is no any effect between factor *i* and factor *j*;
V indicates that factor *i* has an effect on factor *j*;
A indicates that factor *j* has an effect on factor *i*;
X indicates the bidirectional effect between factors *i* and *j*.

(3) Establish the adjacency matrix, and the process is to replace the relationship between factor *i* and factor *j* with 0 or 1.

If the relationship between the two influencing factors in the SSIM matrix is V or X, then use 1 instead.
If the relationship in the SSIM matrix between the two influencing factors is A or O, then use 0 instead.

(4) Establish a matrix *R*, compute $A(S_i)$ and $R(S_i)$, using 0-1 variables to visually display all the direct and indirect links between the variables.

$$R(S_i) = \{S_j \in N | m_{ji} = 1\} \quad (3.6)$$

$$A(S_i) = \{S_i \in N | m_{ji} = 1\} \quad (3.7)$$

N is the set point of the left and right set, and m_{ij} is the reached value of *i* to *j*.

(5) Divide the elements into reach and unreachable, calculate whether $R(S_i) \cap A(S_i)$ is an empty set, and determine the connected domain. Then divide all the elements in the system into different levels by the criterion of the accessible matrix, namely: $L(n) = [L_1, L_2, \dots \dots L_n]$.

(6) Draw the structure model and interpretative structural model to transform each hierarchy into a more intuitive hierarchical diagram form.

4 Results

4.1 Low-carbon Decision Model Results

For sorting out preliminary factors with GRA, this study used the resolution coefficient of 0.5 to identify the prominent factors for low-carbon decision-making in enterprises. As shown in Table 3, GRA correlation analysis sorted the primary order of factors based on grey relational degrees. Based on the rule-of-thumb regarding grey correlation degree above 0.70, the first eight factors were selected as salient factors that influence the low-carbon decision-making of enterprises. Among them, all were enterprise-specific factors except for government intervention and consumer awareness.

Table 3. Grey Relational Degree Sorting of Influential Factors

Factor	Degree	Ranking
F1. Manager support	0.7908	1
F13. Government intervention	0.7853	2
F12. Consumer awareness	0.7834	3
F6. Procurement policy	0.7560	4
F8. Clean production	0.7559	5
F3. Supplier selection	0.7503	6
F7. Technology innovation	0.7247	7
F9. Corporate collaboration	0.7113	8
F10. Transportation management	0.6982	9
F11. Inventory control	0.6944	10
F2. Employee engagement	0.6736	11
F4. Operational management	0.6617	12
F5. Climate change mitigation strategy	0.6612	13

Based on survey responses, grey associations were obtained to further sort low-carbon decisions made by enterprises. As shown in Table 4, all but one grey correlation degrees were above 0.7. A closer look suggested that the gap between 7th and 8th decisions was relatively large, suggesting that companies paid more attention to the first seven strategies. The results largely corroborated the ranks of the six most influential factors as they pertain to important decisions. For instance, the green procurement decision depends on the procurement policy, and corporate investment decision requires manager support.

Table 4. Grey Relational Degree Ranking of Low-carbon Decisions

Decision	Degree	Raking
Green procurement	0.8102	1
Inventory IT support	0.7864	2
Corporate investment	0.7736	3
Green packaging	0.7735	4
Green storage	0.7676	5
Low-carbon target	0.7675	6
Green technology	0.7585	7
Low-carbon manufacturing	0.7445	8
Low-emission transportation	0.7405	9
Product recycling	0.7377	10
Partner cooperation	0.7276	11
Employee motivation	0.7262	12
Energy conservation	0.7193	13
Customer demand	0.7188	14
Green product design	0.7146	15
Internal management	0.6866	16

The ISM analyses further stratify the factors at the enterprise level for maximum joint effects. Based on their correlations, each of the six factors serves as a reference sequence to obtain the rankings of grey relational degree. Government intervention and consumer awareness were excluded as external factors. In place of subjective expert scoring, the comparison factors with a grey correlation degree above 0.82 that account for two thirds of shared variance (i.e., 0.82^2=67.24%) were considered to have a significant influence on the reference factors. Because the six factor labels have been scrambled, they were renumbered to facilitate the establishment of the ISM shown in Table 5. None of the other factors particularly pertained to the primary factor of manager support, which may affect all of them to a certain degree. The other factors were more closely inter-related.

Table 5. Factor Correlations

Reference Factor	Comparison Factor	Degree
S1 Manager support	None	
S2 Procurement policy	S5 Technology innovation	0.8422
	S4 Supplier selection	0.8251
S3 Clean production	S4 Supplier selection	0.8574
S4 Supplier selection	S3 Clean production	0.8483
S5 Technology innovation	S6 Corporate collaboration	0.8689
	S1 Manager support	0.8265
S6 Corporate collaboration	None	

Table 6 shows SSIM matrix formulation and describes different types of relationships among the factors. The establishment of SSIM matrix is based on Table 5, in which a comparison factor is denoted as *j*, and a corresponding reference factor is denoted as *i*. If factor *j*'s grey correlation degree against factor *i* is greater than 0.82, *j* is considered to have an influence on *i*. Similarly, if factor *i*'s grey correlation degree against factor *j* is greater than 0.82, *i* is considered to have an influence on *j* as well. Based on the rules, corresponding relationships A, O, V and X are established in the SSIM matrix. About one third (4 out of 15) of the relationships were directional (i.e., A or V), and one (1 out of 15) was bidirectional (i.e., X), and the remaining ten (10 out of 15) were not as clear (i.e., O). The result indicates how important factors influenced each other in low-carbon decision making.

Table 6. SSIM Matrix of Influencing Factors

Factor \ Factor	S1	S2	S3	S4	S5	S6
S1 Manager support	-	O[a]	O	O	V[b]	O
S2 Procurement policy		-	O	A[c]	A	O
S3 Clean production			-	X[d]	O	O
S4 Supplier selection				-	O	O
S5 Technology innovation					-	A
S6 Corporate collaboration						-

[a] O indicates that there is no effect between factors *i* and *j*;
[b] V indicates that factor *i* has an effect on factors *j*;
[c] A indicates that factor *j* has an effect on factors *i*;
[d] X indicates the bidirectional effect between factor *i* and factor *j*.

A high degree of grey correlation indicates that a comparison factor *j* impacts a reference factor *i*. As shown in Table 7, an adjacency matrix was derived by digitizing the relationships in the SSIM matrix with binary coding (i.e., 1: impactful vs. 0: otherwise).

Table 7. Adjacency Matrix

Factor \ Factor	S1	S2	S3	S4	S5	S6
S1 Manager support	0	0	0	0	1	0
S2 Procurement policy	0	0	0	0	0	0
S3 Clean production	0	0	0	1	0	0
S4 Supplier selection	0	1	1	0	0	0
S5 Technology innovation	0	1	0	0	0	0
S6 Corporate collaboration	0	0	0	0	1	0

The adjacency matrix is used to build up the reachability matrix *R* with Formula 4.1, where *A* is an adjacency matrix and *I* is a unit matrix.

$$A_{r-1} = (A+1)^{r-1} = R \tag{4.1}$$

$$A+I=\begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

Table 8 shows the reachability matrix. It provides the basis for the layering of six factors for a better understanding of how they interplay with each other.

Table 8. Reachability Matrix

Factor \ Factor	S1	S2	S3	S4	S5	S6
S1 Manager support	1	1	0	0	1	0
S2 Procurement policy	0	1	0	0	0	0
S3 Clean production	0	1	1	1	0	0
S4 Supplier selection	0	1	1	1	0	0
S5 Technology innovation	0	1	0	0	1	0
S6 Corporate collaboration	0	1	0	0	1	1

Building a hierarchy based on the interpretive structure model further reveals the relationships among the six factors. Table 9 shows the position of each factor in the hierarchy.

Table 9. Hierarchy Level

Factor	Reachability set	Antecedent set	Intersection set	Level
S1 Manager support	1,2,5	1	1	
S2 Procurement policy	2	1,2,3,4,5,6	2	I
S3 Clean production	2,3,4	3,4	3,4	
S4 Supplier selection	2,3,4	3,4	3,4	
S5 Technology innovation	2,5	1,5,6	5	
S6 Corporate collaboration	2,5,6	6	6	
S1 Manager support	1,5	1	1	
S3 Clean production	3,4	3,4	3,4	II
S4 Supplier selection	3,4	3,4	3,4	II
S5 Technology innovation	5	1,5,6	5	
S6 Corporate collaboration	5,6	6	6	
S1 Manager support	1,5	1	1	
S5 Technology innovation	5	1,5,6	5	III
S6 Corporate collaboration	5,6	6	6	
S1 Manager support	1	1	1	IV
S6 Corporate collaboration	6	6	6	IV

The reachability matrix is stratified to established a hierarchical structure of the six factors based on the ISM. Table10 shows the layered result in a hieratical table.

Table 10. Hierarchical Table

Level	Factor
I	S2 Procurement policy
II	S3 Clean production
	S4 Supplier selection
III	S5 Technology innovation
IV	S1 Manager support
	S6 Corporate collaboration

The graphical representation of the hierarchical table is an interpretative structure model. As shown in Figure 2, the model delineates four layers of the structure: the bottom layer (Level I) contains procurement policy, the second layer (Level II) comprises clean production and supplier selection, and the third layer covers innovation technology (Level III), the upper layer (Level IV) includes manager support and corporate collaboration. Manager support to some extent defines the internal context of green supply chain, and corporate collaboration largely shapes its external context. The two contextual factors at the upper layer interact with each other and affect subsequent green supply chain activities at the layers below. Technology innovation supports the supplier selection and clean production, which are externally-oriented and internally-oriented, respectively. Finally, procurement policy at the bottom layer pertains to both activities as they involve organizational procurement of goods, equipment and/or services. This model reflects low-carbon decision making from the internal and external aspects of sustainable supply chains.

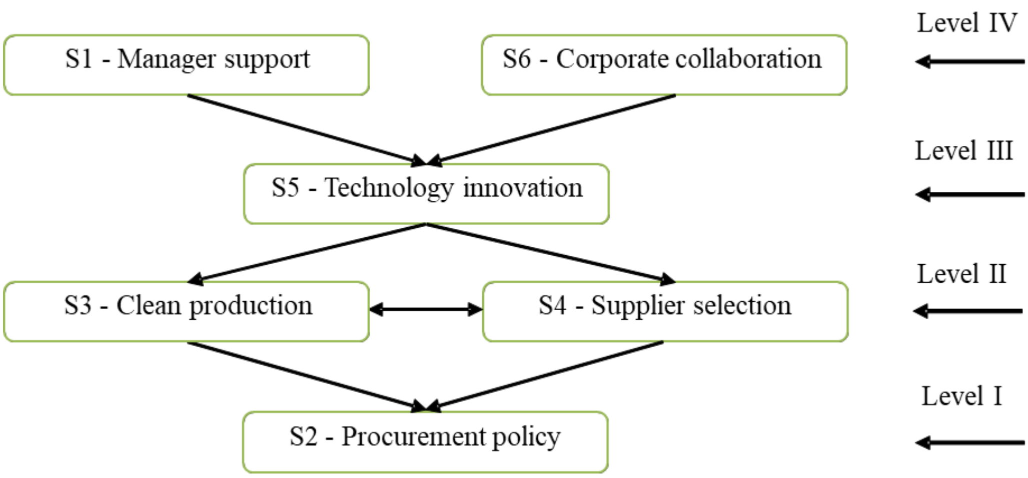

Fig. 2 Low-carbon Decision Model

4.2 Model Validation

In order to validate the SSIM matrix derived with GRA, this study uses the alternative expert rating method to generate another SSIM matrix as shown in Appendix B. A focus group of five industrial experts was presented with the empty SSIM matrix of six factors. They were asked to score the relationships individually based on their experiences. With the initial ratings, the panel further discussed and modified the scores until they reached a consensus. The new SSIM matrix leads to another interpretative structure model to be compared with the aforementioned low-carbon decision model for cross-validation.

The graphical representation of the layered results is shown in Figure 3. Compared to the original low-carbon decision model, the new model based on the SSIM matrix determined by experts is somewhat different. The bottom layer (Level I) contains clean production, indicating that the experts considered it as what is eventually affected by other factors. In such a production-oriented view, procurement policy, supplier selection and corporate collaboration at the second layer (Level II) serves clean production. In the original low-carbon decision model, on the other hand, procurement policy locates at the bottom layer, which is subject to clean production and supplier selection as internal and external low-carbon decisions. Focusing on different stages of sustainable supply chain, the two models imply that either procurement policy or clean production can be the primary consideration guiding low-carbon decisions in an enterprise. Other than that, they are quite similar in model structures.

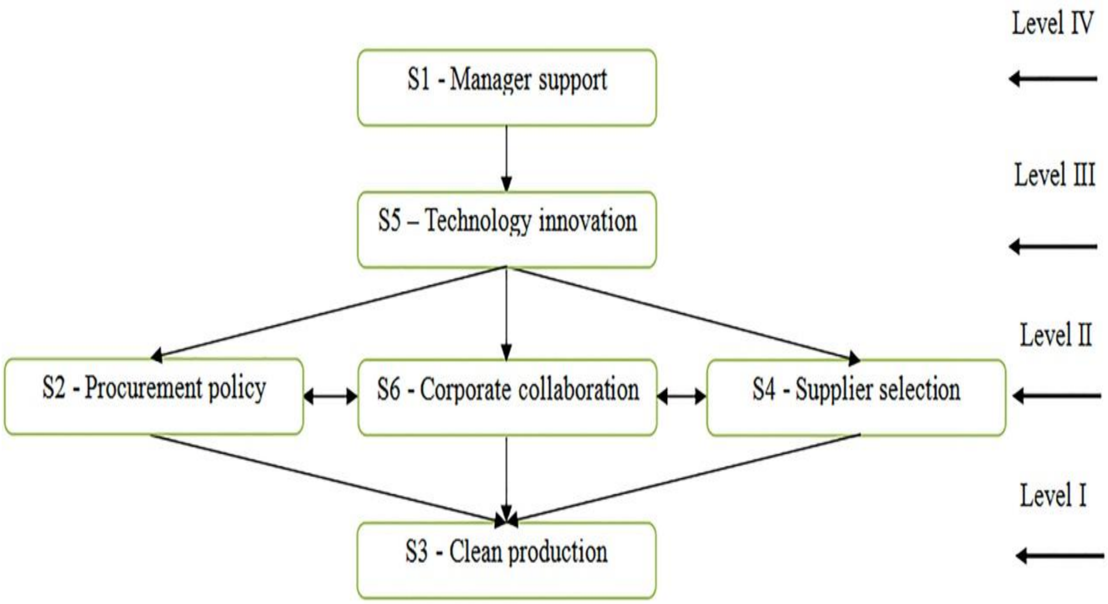

Fig. 3 Low-carbon Decision Model from Expert Scoring

The low-carbon decision models based on ISM ignore the weak correlations among some factors but pay more attention to those that have salient impacts on organizations. As the key to making low-carbon decisions is to choose factors with greater influence, both models are sensible in practice. In comparison, expert opinions consider whether there is a relationship between each pair of factors whereas GRA also assesses its strength. The distinction leads to two ISM models that are not identical. Nevertheless, the results validate the combination of GRA with ISM for the generation low-carbon decision models as a more objective alternative to the traditional approach based on expert input.

5 Discussions

The findings suggest that manager support and corporate collaboration are the most influential factors in sustainable supply chain context. Manager support is the enabling factor from inside, as it drives organizations to arrive at the sustainable supply chain strategy to reduce direct and indirect carbon emission (KrishnenduShaw et al., 2013). At the same level, corporate collaboration imposes the requirements on the subsequent decision-making of enterprises from the outside. Firms that collaborate with their supply chain partners benefit from better supplier-customer relationships and improved customer satisfaction, leading to sustainable development in the long run (Pakdeechoho & Sukhotu, 2018).

Driven by these two contextual factors, enterprises carry out technology innovation, which supports subsequent decision-making regarding clean production and supplier selection. The findings confirm the essential role that innovation plays in sustainable development (Yang, Sun, Zhang, & Wang, 2018). By reducing energy consumption alone, the use of innovative technology in the industrial sector can cut 29% of total carbon emission (Ford & Despeisse, 2016). For clean production, the use of biofuel energy is a good example (Z. Chen & Andresen, 2014). Supplier selection concerns the carbon footprint across different stages of a supply chain and contributes to its overall sustainability. Together, they provide the answer to the first research question regarding what are the most influential factors pertaining to sustainable supply chain establishment.

The GRA ranking of low-carbon decisions in Table 4 indicates that procurement, inventory, investment, packaging, and target, through well recognized in the literature, have limited influences in the final model. Technology innovation and corporate collaboration, on the other hand, are contextual factors that have been largely ignored but play more critical roles. Within an organization, manager support, clean production and supplier selection concern the implementation of specific decisions. As manager support and technology innovation reflect organizational strategies, corporate collaboration, clean production and supplier selection pertain more to the second question in terms of pivotal decisions in sustainable supply chains.

The sustainability management of a supply chain typically starts with upstream procurement. To different extents, the major decisions that an enterprise makes shape its procurement policy eventually. Therefore, organizational factors closely related to supply chain decisions mediate the effects of contextual factors on upstream procurement. Such relationships depicted in the decision-making model from the ISM analysis answer the third research question regarding how contextual and organizational factors interact with each other in low-carbon decision making.

The GRA sorting of influential factors in Table 3 indicates that consumer awareness and government intervention have somewhat higher degrees of correlations than other factors except for manager support. Consumer awareness is an external factor over which managers do not have direct control but must consider in making low-carbon decisions. Similarly, government intervention is excluded from the decision-making model as it is not enterprise-specific but rather common at the national level. Almost all enterprises in a country need to abide by its governmental regulations.

The findings yield helpful insights for managers to implement sustainable supply chains effectively. The GRA and ISM analyses of how enterprises make low-carbon decisions lead to a hierarchical model. There have been a number of studies based on expert evaluations, and this study's quantitative approach adds to the scientific inquiry of decision-making for supply chain sustainability. In particular, the findings suggest that low-carbon decision making largely concerns corporate collaboration, clean production, and supplier selection. Manager support and corporate collaboration are necessary for organizations to overcome the resistance to low-carbon decisions but embrace supply chain sustainability. Further enabled by technology innovation, clean production and supplier selection, the low-carbon goal of sustainable supply chains may be accomplished.

For practitioners, the results suggest the best practices of formulating low-carbon decisions. The observations collected with the survey instrument may be used to enhance an enterprise's operational efficiency through supply chain optimization. The comprehensive understanding of critical factors and important decisions is conducive to low-carbon decision making. It is important that managers understand the importance of supply chain sustainability and develop a strategic plan. Though the transition from the traditional production mode to the new sustainability mode can be uncomfortable or even costly, low-carbon decisions will pay off in the long run. Beyond the advocate role, managers should adapt decisions to the sustainability requirements of supply chain upstream, midstream and downstream.

6 Conclusion

As climate change emerges as a focal point of public attention, it is imperative for enterprises to reduce carbon dioxide emissions in productive activities as a major corporate social responsibility. This study attempts to answer three questions concerning the contextual factors, core decisions, and bottom-line consequence of sustainable supply chains. Based on a literature review, 13 significant factors are identified: two contextual and 11 organizational. The survey observations collected provide the basis for GRA and ISM that led to a low-carbon decision model.

In this study, the logical relationships are determined by GRA and ISM based on survey data. Compared with previous studies using expert input, the findings are less susceptible to the influence of subjectivity. Yet this study has limitations to be remedied in the future. First, the sample is relatively small to represent the whole population. It does not include all types of businesses and industries, to which the findings may not be directly generalizable. Secondly, this study focuses on enterprise-specific factors in low-carbon decisions, but they are by no means the complete set. Finally, all observations were collected from a single country, but different cultures and development stages may have significant impacts on low-carbon decision making. Therefore, future research may broaden influential factors, sampling schemes and participating countries to enhance the generalizability of findings.

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Appendix A: Questionnaire Items

Part I: Questions on the decisions regarding the implementation of sustainable supply chain (1 – strongly disagree; 2 - disagree; 3 - somewhat disagree; 4 - uncertain; 5 - somewhat agree; 6 - agree; 7 – strongly agree):

1. (Low-carbon target) Based on the current situation of our company, the management specifies the corresponding low-carbon target.

2. (Internal management) Our company has a working low-carbon policy for internal management.

3. (Green product design) The design of our new products embodies the concept of environmental sustainability (e.g., using environment-friendly materials).

4. (Partner cooperation) Our management maintains good cooperative relationships with upstream and downstream enterprises for sustainable supply chain.

5. (Energy conservation) Our company uses energy wisely to reduce carbon footprint.

6. (Low-carbon manufacturing) Our company reduces carbon emission during the manufacturing process.

7. (Green Procurement) Our company adopts the low-carbon procurement method to get environment-friendly materials from suppliers.

8. (Green packaging) Our company incorporates the low-carbon concept in the product packaging.

9. (Low-emission transportation) Our company cuts down carbon emission in the transportation process (e.g., with careful route planning).

10. (Product recycling) Our company recycles used products to avoid resource wasting and environment pollution.

11. (Green technology) Our company implements innovative technologies to reduce carbon emission.

12. (Employee motivation) Our company motivates employees to participate in sustainable supply chain activities.

13. (Green storage) Our company uses green materials for storage.

14. (Inventory IT support) Our company manages inventory with information technology.

15. (Customer demand) Our company values customer demand for low-carbon products.

16. (Corporate investment) Our company makes low-carbon investments in all aspects.

Part II: Questions on the importance of the factors affecting low-carbon decisions (1 - no influence at all; 2 - little influence; 3 - some influence; 4 - noticeable influence; 5 - significant influence; 6 - strong influence; 7 – overwhelming influence):

F1. Manager support

F2. Employee Engagement

F3. Supplier Selection

F4. Operational Management

F5. Climate Change Mitigation Strategy

F6. Procurement Policy

F7. Technology Innovation

F8. Clean Production

F9. Corporate Collaboration

F10. Transportation Management

F11. Inventory Control

F12. Consumer Awareness

F13. Government Intervention

Appendix B: SSIM Matrix of Influencing Factors from Expert Scoring

To verify the low-carbon decision model established in this study, an alternative SSIM matrix was derived from expert scoring:

Factor \ Factor	S1	S2	S3	S4	S5	S6
S1 Manager support	--	V	V	V	V	V
S2 Procurement policy		--	V	V	A	X
S3 Clean production			--	A	A	A
S4 Supplier selection				--	A	V
S5 Technology innovation					--	V
S6 Corporate collaboration						--

V indicates that factor *i* has an effect on factors *j*;

A indicates that factor *j* has an effect on factors *i*;

X indicates the bidirectional effect between factor *i* and factor *j*.