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Research on the Integration of Triple Bottom Line Theory and Practice in Sustainable Supply Chain Management Within the Massage Chair Industry

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Abstract: In recent years, many manufacturing enterprises have recognized that sustainable supply chain management (SSCM) is a primary goal for contemporary enterprises. However, there's a gap between these studies and the actual operations of enterprises, leading to a biased understanding of the theory among industry personnel. Therefore, this study focuses on implementing enterprise SSCM practices. It uses a combination of quantitative and qualitative methods and applies various data analytics methods. The aim is to build a theoretical framework, provide evidence for enterprise decision-making, and raise management awareness. Empirical analysis shows that environmental and economic aspects are crucial for promoting SSCM implementation and are interdependent with social aspects. New aspects, resources, and innovation aspects are also proposed for considering SSCM implementation. The findings offer decision-making support for companies. This paper finds that regular environmental, social and governance(ESG) reporting can enhance their environmental, social, and economic performance and boost their global competitiveness.

Keywords: Sustainable supply chain management, Triple bottom line theory, Fuzzy Set Theory, Decision-making Trial and Evaluation Laboratory

1. Introduction

Sustainable supply chain management (SSCM) is a corporate practice. It integrates sustainable development principles to achieve integrated social, environmental, and economic goals. It also enhances the long-term performance of enterprises and their partners by optimizing operations, information flow, capital management, and collaborating with suppliers [1]. After the United Nations advocated the Sustainable Development Goals, enterprise sustainable development has drawn much attention [2]. However, the implementation of SSCM is facing difficulties and has a low adoption rate [3-4]. In the massage chair industry, production requires various raw materials and multiple processes. From the procurement of metal frames, leather fabrics, and others to processing and assembly, all links should pay attention to sustainability. This study uses various methods to explore SSCM in depth, build a theoretical framework, clarify the connection with enterprise operations, provide support for enterprise decision-making, improve management awareness, and help the sustainable development of the massage chair industry.

DOI: 10.54254/2754-1169/161/2025.19910

2. Literature Review

2.1. Triple Bottom Line Theory

The Triple Bottom Line (TBL), initially proposed in Elkington's research, encourages companies to go beyond just financial success. It emphasizes focusing on their broader environmental and social impacts to reach more comprehensive sustainability goals [5]. While pursuing economic benefits, enterprises should assume responsibility in three basic areas: economic, environmental, and social. This forms the so-called "triple bottom line" concept. The theory is constantly evolving. It involves a deepening understanding of multiple aspects of social responsibility. Scholars have extensively studied its measurement, application, and influencing factors. For example, Nogueira E analyzes the impact on relevant countries, and can be combined with SSCM to evaluate corporate sustainability [6].

2.2. Sustainable Supply Chain Management

According to Dyllick and Hockerts, SSCM is the integration of sustainability into supply chain management [7]. Modern scholars use it as an important framework to improve supply chain efficiency or study sustainability. For instance, Fraser IJ explores supply chain transparency in the electric vehicle industry [8]. Pavan R O analyzed the application of maturity models in SSCM, identified research trends and gaps, classified literature, and promoted knowledge progress in the SSCM field [9].

2.3. Research Theories and Methods

This research is based on the concept of social, environmental, and economic balance. It integrates SSCM and TBL theories and takes the massage chair industry as the research object. The details and explanations of C1 to C30, which represent various aspects and practices within the research scope, will be presented in Table 1. This is for a comprehensive and in-depth understanding.

The social aspect includes banning child labor and forced labor (C4) [10]. It also involves product compliance with the WEEE Directive (C11) [11]. There is a cloud management system to assess the environmental impact of the product life cycle (C7) [12]. The use of ERP and MES systems improves capital and material turnover (C13) [12]. Degradable materials are used to make packaging (C9) [13]. Products are donated to community service centers (C17) [14]. Automatic cutting machines are used to reduce production losses and improve material utilization (C21) [15]. The company serves as the standard group leader unit of *Commercial Massage Chair Safety Requirements* (C20) [16]. It also participates in the study of *Massage Chair Improves the Health of the Elderly Group* (C24) [16]. Additionally, it serves as the standard group leader unit of *Health Rehabilitation Massage Bed* (C25) [11]. Advanced safety measures are adopted to reduce the risk of production accidents (C30) [16]. A safe, healthy, and positive working environment is provided (C14) [17]. The foundation is established to care about the family status of employees (C27) and their access to vacation, provident fund, and medical benefits (C28) [17].

From an environmental perspective, SSCM has several practices. It selects leather suppliers with environmental certification (C1) [18]. It complies with the BSCI business social standard certification (C2) [19]. It recycles or offers trade-ins for scrap massage chairs (C3) [20]. Its products comply with the ROHS directive (C8), the "China Environmental Labeling Product Certification Certificate" (C5) [11,13], and the "Green Design Product Evaluation Technical Specification" (C26) [13]. They also comply with ISO14001 environmental management system certification (C15) [13]. SSCM regularly implements ESG reports (C16) [11]. It avoids toxic substances in the design and manufacturing process and improves environmental performance (C18) [21].

DOI: 10.54254/2754-1169/161/2025.19910

Economic sustainability is achieved through continuous product innovation, improved cost performance, and enhanced customer satisfaction (C19) [11]. It also involves using smart devices to boost production efficiency and lower work intensity (C22), forming industrial alliances with other enterprises (C29), and implementing sustainable supply chain plans at the top management level (C23) [22-23].

In addition, this study focuses on other TBL-related SSCM practices. These include product recycling of plastic parts (C6), sponge scrap return to the supplier for recycling (C10), and scrap metal supply to steel mills for reprocessing (C12) [13].

The proposed practices are founded on a comprehensive analysis of existing literature. The aim is to ensure the integration of SSCM practices with TBL theory. This is done to promote the overall sustainable development of organizations in three aspects: economic, environmental, and social.

3. Research Methods

3.1. Research Avenues

This study employs quantitative and qualitative methods. It targets the complexity of SSCM in enterprise practice and the need to explore the relationship between enterprise behavior and influencing factors. The study selects enterprises in the massage chair industry as the object.

3.2. Research Proposal

3.2.1. Data Collection Methods

After an in-depth study of relevant literature and consulting several senior management personnel in the massage chair industry as experts, 30 enterprise SSCM practices were identified. Then, a Likert five-level scale questionnaire was designed. The survey subjects were required to have some knowledge of logistics supply chain management and sustainable supply chain theory to ensure the questionnaire's effectiveness. The Likert Level 5 scale is a commonly used measurement method in questionnaires. It has five different response levels: "No Influence", "Very Low Influence", "Influence", "High Influence", and "Very High Influence". Respondents are required to choose and evaluate various questions or statements based on their own opinions.

3.2.2. Data Analytics Methods

Exploratory factor analysis (EFA) is a statistical method that reveals the internal relationship among variables. Variables are summarized into core factors by identifying correlations. First, when selecting variables, correlation tests are necessary. In this study, Kaiser-Meyer-Olkin (KMO) measurement and Bartlett sphericity test were employed to evaluate variable correlation. This ensured that the KMO value was greater than 0.7 and the p-value was less than 0.05. Also, the factor load of the rotation component matrix had to be greater than 0.4. Then, the normalized relationship was utilized for principal component analysis. Specific equations were used to calculate the factor load matrix, standard deviation, and so on. The rotation matrix was selected by the original rotation maximum variance method. The rotation operation was repeated until the total variance converged.

Principal component analysis is employed to standardize these relationships. It identifies uncorrelated variables by changing the coordinates. Then, using the following equation to uppercase F. The eigenvalue of the uncorrelated variable is calculated by $\varepsilon_x(\varepsilon_x > 0, x = 1,2, \dots, a)$. And the corresponding standard orthogonal eigenvectors are for the subload matrix of e_x.

$$f_{xy} = \sqrt{\varepsilon_x} v_{xy}, x = 1,2, \dots a, y = 1,2, \dots b, \quad (1)$$

DOI: 10.54254/2754-1169/161/2025.19910

$$F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1b} \\ f_{21} & f_{22} & \cdots & f_{2b} \\ \vdots & \vdots & \ddots & \vdots \\ f_{a1} & f_{a2} & \cdots & f_{ab} \end{bmatrix} = \begin{bmatrix} \sqrt{\varepsilon_1} e_{11} & \sqrt{\varepsilon_2} e_{12} & \cdots & \sqrt{\varepsilon_a} e_{1b} \\ \sqrt{\varepsilon_1} e_{21} & \sqrt{\varepsilon_2} e_{22} & \cdots & \sqrt{\varepsilon_a} e_{1b} \\ \vdots & \vdots & \ddots & \vdots \\ \sqrt{\varepsilon_1} e_{a1} & \sqrt{\varepsilon_2} e_{a2} & \cdots & \sqrt{\varepsilon_a} e_{ab} \end{bmatrix} \tag{2}$$

The reliability test employs Cronbach's α to gauge the consistency among different aspects. It ensures $\alpha > 0.7$ to guarantee the reliability of the study [24]. The test showcases the internal consistency and stability of the measurement tool, ensuring the accuracy of the data. The following formula is used to calculate Cronbach's α:

$$a = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} \sigma_i^2}{\sigma_T^2}\right) \tag{3}$$

Where K is the number of items on the scale. σ_i^2 is the variance of item i. σ_T^2 is the variance of all items as a whole.

Fuzzy Set Theory (FST) and Decision-making Trial and Evaluation Laboratory (DEMATEL): In manufacturing decision-making, team wisdom is often employed to find the optimal solution [25]. This study utilizes FST to process the questionnaire results. First, define the domain Y and the fuzzy set A. Then, construct the fuzzy number through the membership function.

The triangular fuzzy numbers can be written in the form of triplets:

$$f_{\overline{A}}(y) = \begin{Bmatrix} 0, y < a_1 \\ \frac{y-a_1}{b_2-a_1}, a_1 \le y \le b_2 \\ \frac{c_3-y}{(c_3-b_2}, b_2 \le y \le c_3 \\ 0, y > c_3 \end{Bmatrix} \tag{4}$$

In this study, fuzzy data is converted into definite values through specific methods [26-28]. For example, the fuzzy minimum-maximum method is used to determine the score range. When calculating the total score, the weighted average of membership functions is considered. When experts in the decision-making group consider standard fuzzy weights, they must normalize them. Then, they calculate the left and right normalized values and the total normalized definite values. Finally, they aggregate the expert judgment.

Suppose the k experts in the decision group need to consider the fuzzy weight of the i-th criterion $\overline{W}_{ij}^k = \left(w_{1ij}^k, w_{2ij}^k w_{3ij}^k\right)$. This weight will immediately affect the j-th criterion as determined by the k-th expert. So, the formula needs to be rewritten, namely:

A. Normalization:

$$yw_{1ij}^k = \left(w_{1ij}^k - \min w_{1ij}^k\right) / \Delta_{min}^{max} \tag{5}$$

$$yw_{2ij}^k = \left(w_{2ij}^k - \min w_{2ij}^k\right) / \Delta_{min}^{max}$$

$$yw_{3ij}^k = \left(w_{3ij}^k - \min w_{3ij}^k\right) / \Delta_{min}^{max}$$

At this point, $\Delta_{min}^{max} = \max w_{3ij}^k - \min w_{1ij}^k$

DOI: 10.54254/2754-1169/161/2025.19910

B. Aggregation of Explicit Values: Collect and aggregate values from the subjective judgments of k experts who synthesize different points of view:

$$\overline{W}_{ij}^{k} = \left(\frac{1}{k}\right)\left(\overline{W}_{ij}^{1} + \overline{W}_{ij}^{2} + \overline{W}_{ij}^{3} + \ldots \overline{W}_{ij}^{k}\right) \tag{6}$$

DEMATL is a tool suitable for analyzing the data in this study. It visualizes the composition of complex relationships through various types of matrices and diagrams [29]. Matrices and diagrams show the contextual interaction between standards and systems. Additionally, significant data can represent the strength of the impact of these practices. In fact, DEMATL must assume a system consisting of a standard set of uppercase $C = \{C_1, C_2, C_3, \ldots, C_n\}$. The pairs of data are constructed as mathematical model relationships. The steps are as follows:

1). Construction of the direct relationship matrix: The evaluation criterion comparison should follow the Likert five-level scale. The expert needs to judge the set of pairs of comparisons between the criteria to obtain the initial data, which serves as the direct relationship matrix $A_{n\times n}$. Where x_{ij} is defined as the degree to which criterion i affects criterion j.

2). Normalized direct relation matrix: The normalized direct relation matrix U can be obtained from the direct relation matrix A using the following equation.

$$U = k \times A \tag{7}$$

$$k = \frac{1}{\max\limits_{1\le i<n} \sum_{j=1}^{n} x_{ij}} \tag{8}$$

3). Get the overall relationship matrix:

When the normalized direct relation matrix is denoted by U, the all relation matrix denoted by S can be obtained using Equation (4), where I is the identity matrix.

$$S = U(I - U)^{-1} \tag{9}$$

4). Generative causal graph:

Using Equation (7), we can derive the sum of the effects of vector D and R from the total relation matrix S. On the horizontal axis, the sum of the vector $(D + R)$ shows the importance of each criterion, that is, their "significance". On the vertical axis, the difference between the vector $(D - R)$ reveals the "relationship" between the criteria. This helps us classify them as cause or effect. If $(D - R)$ has a positive value, the criterion is regarded as the cause. If it is negative, it is regarded as the result. Correspondingly, the causal graph is mapped by the coordinate point (D + R, D - R), dataset. This provides a valuable perception map for decision makers.

$$S = \left[s_{ij}\right]'_{n\times n},\ i,j = 1,2,\ldots,n \tag{10}$$

$$D = \left[\sum_{i-1}^{n} s_{ij}\right]_{n\times 1} = \left[s_i\right]_{n\times 1} \tag{11}$$

$$R = \left[\sum_{j-1}^{n} s_{ij}\right]_{n\times 1} = \left[s_j\right]_{1\times n} \tag{12}$$

At the same time, Equation (10-12) shows that the vectors D and R are total relational matrices. The row and column $S = \left[s_{ij}\right]'_{n\times 1}$

5). Get the intrinsic dependency matrix:

DOI: 10.54254/2754-1169/161/2025.19910

The inner dependence matrix can be collected by summing each column of the total relation matrix using the normalization method. The result of each column is equal to 1.

3.2.3. Research Process Arrangement

A. Based on the literature, relevant research, and consulting with experts, identify 30 implementation practices for sustainable supply chains in specific companies. Then, design a questionnaire according to the Likert 5 scale.

B. Use the EFA tool in SPSS software to analyze the obtained data for each practice. Calculate the KMO value of each variable, the factor load of the p value, and the rotation component matrix using formulas such as (1-2). After judgment, select the corresponding range of variables as their respective aspects.

C. Using the RT method, Equation (3) is employed to test the a-values of each aspect. This is done to ensure a higher correlation between aspects.

D. After ensuring the practice is effective, consult multiple experts to confirm the impact between various practices and aspects. Then, use FST to quantify the text information into fuzzy values (4). Next, use equations to de-blur the fuzzy values and obtain explicit values (5). Aggregate the explicit values obtained by each expert (6). Then, use DEMATEL (7-12). Apply the explicit values to the total DEMATEL relationship matrix and calculate the values of vectors D and R. Give a map of causal effects. Finally, analyze the results.

4. Empirical Analysis

4.1. Case Background

Taking the iRest brand as an example. It promotes advanced supply chain management concepts. However, it faces the problem of balancing profits and costs when implementing SSCM. In particular, there are environmental decision-making difficulties under the framework of the triple bottom line theory.

4.2. Analysis Results

A. Based on a survey of over 180 informed respondents, practical examples of brands, and expert advice, 30 practices related to sustainable supply chain management were determined.

B. The data collected was analyzed by EFA using SPSS software. According to the standard of factor load greater than 0.4 in the rotating component matrix, the relevant practices were divided into environmental aspects, social aspects, economic aspects, and resource and innovation aspects.

C. Each practice in the domain was tested through the reliability test in SPSS. The results are shown in Table 1, which includes environmental aspects, social aspects, economic aspects, and resource and innovation aspects. The significance met the conditions. At the same time, the Average Variance Extracted (AVE) and Composite Reliability (CR) of each aspect also met the corresponding standards [30]. This indicates that the scale has high reliability and strong interpretation ability and can provide stable and effective data support for research.

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Table 1: Proposed Practices from four Aspects

Aspects	Attributes
A1 Environment (Cronbach's Alpha = 0.952, AVE = 0.434, CR = 0.893)	C1 Select a leather supplier to hold environmental certification
	C2 Products comply with BSCI business social standards certification
	C3 Recycle or trade in scrap massage chairs
	C4 Products meets the China Environmental Labeling Product Certification
	C5 Products comply with the ROHS directive
	C6 Products comply with ISO14001 environmental management system certification
	C7 Periodic implementation of ESG reports
	C8 Avoid using toxic substances in the design and manufacturing processes to enhance environmental performance
	C9 Served as the standard team leader unit of Commercial Massage Chair Safety Requirements
	C10 Products comply with the Technical Specifications for Green Design Product Evaluation
	C11 Adopt advanced safety measures to reduce the risk of production accidents
A2 Resources and innovation (Cronbach's Alpha = 0.805, AVE = 0.525, CR = 0.766)	C12 Product recycling of plastic parts
	C13 Sponge scraps are returned to the supplier for regeneration
	C14 Scrap metal is supplied to steel mills for reprocessing
A3 Economy (Cronbach's Alpha = 0.895, AVE = 0.497, CR = 0.854)	C15 Prohibition of child labor and forced labor
	C16 Provide a safe, healthy and positive working environment
	C17 Continuously innovate products. Improve cost performance. Enhance customer satisfaction.
	C18 Create a foundation to care about the family situation of employees
	C19 Employees enjoy vacation, provident fund, and medical benefits
	C20 Establish industrial alliances with other companies
	C21 The cloud management system assesses the environmental impact of the product life cycle
	C22 The use of degradable materials for packaging
	C23 Products comply with the WEEE Directive
	C24 Utilizing ERP and MES systems to improve capital and material turnover
A4 Society (Cronbach's Alpha = 0.953, AVE = 0.404, CR = 0.868)	C25 Donate products to community service centers
	C26 Use automatic cutting machines to reduce production losses and enhance material utilization
	C27 Using smart devices to increase productivity and reduce work intensity
	C28 Senior management implements a sustainable supply chain plan
	C29 Participated in the study Massage chairs improve the health of the elderly
	C30 Served as the standard team leader unit of Health Rehabilitation Massage Bed

DOI: 10.54254/2754-1169/161/2025.19910

D. Invite multiple experts to evaluate the impact between practices. Use FST to quantify the experts' text evaluations into fuzzy values. Remove the ambiguity through a series of calculation steps to obtain explicit values and aggregate them. Then apply these explicit values to the DEMATEL relationship matrix. Calculate the values of vectors D and R. Then draw a causal effect map. The results are shown in Table 2 and Figure 1.

Table 2: Analysis Results of Causal Effects of Each Practice

	D	R	D+R	D-R
1	1.1140	1.0509	2.1649	0.0631
2	1.1260	0.9388	0.9388	0.1872
3	1.5401	1.1756	1.1756	0.3645
5	1.4344	1.4612	1.4612	-0.0269
8	0.3790	1.5347	1.5347	-1.1557
15	1.9424	1.4989	1.4989	0.4436
16	2.1183	1.7082	1.7082	0.4101
18	1.5044	1.5116	1.5116	-0.0072
20	1.0995	0.8484	0.8484	0.2511
26	1.4553	1.3785	1.3785	0.0767
30	1.0220	1.0400	1.0400	-0.0180
6	0.8390	1.1618	1.1618	-0.3228
10	1.0166	1.2003	1.2003	-0.1837
12	0.8541	1.2429	1.2429	-0.3888
4	0.8182	0.9016	0.9016	-0.0835
14	0.9105	1.1271	1.1271	-0.2165
19	1.2917	1.1588	1.1588	0.1329
27	0.4527	0.6431	0.6431	-0.1903
28	0.7265	0.8091	0.8091	-0.0826
29	1.4165	1.0579	1.0579	0.3586
7	1.2083	0.7080	0.7080	0.5004
9	1.0909	1.3636	1.3636	-0.2727
11	0.9788	1.3211	1.3211	-0.3424
13	0.8773	0.6131	0.6131	0.2643
17	0.4334	0.6433	0.6433	-0.2098
21	1.1927	1.2734	1.2734	-0.0807
22	1.2293	1.1094	1.1094	0.1199
23	1.2751	1.5927	1.5927	-0.3175
24	0.7172	0.6487	0.6487	0.0685
25	1.3123	0.6540	0.6540	0.6583

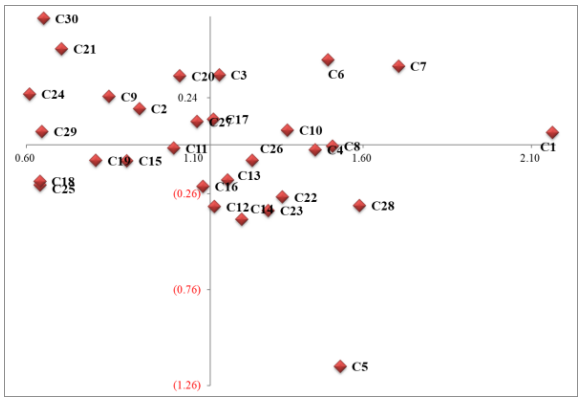

Figure 1: Causal Effect Relationship Diagram of Each Practice

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E. The analysis results indicate that practices like C16, C15, C3, C19, and C26 have a crucial causal role in sustainable supply chain management. Likewise, the same outcomes can be achieved for Aspects. Moreover, the degree of influence between Aspects can also be obtained [31], as presented in Table 3 and Figure 2.

Table 3: Analysis Results of Causal Effects of Each Aspect

Aspects	D	R	D+R	D-R
A1	10.205	10.807	21.013	0.602
A2	12.254	11.548	23.802	-0.706
A3	11.756	12.060	23.816	0.304
A4	12.859	12.659	25.518	-0.200

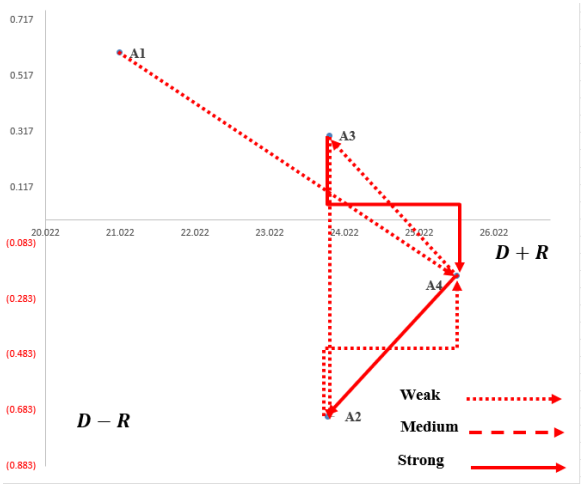

Figure 2: Causal Effect Relationship Diagram of Each Aspect

5. Discussion

5.1. Theoretical Implications

The results indicate that environmental (A1) and economic (A3) aspects are causal factors. Additionally, environmental and social (A2) aspects are interdependent. While environmental-related practices have a weak direct influence on social aspects, they hold great long-term significance. Practices like C26 and C1 can boost corporate image. Practices such as C15, C16, and C3 can assist in building sustainable business models and enhancing comprehensive value. Economic aspects are closely related to social, resource, and innovation aspects. Meeting customer needs and offering innovative products brings economic benefits. This lays the foundation for the long-term development of enterprises and fulfills social responsibility. It also reveals aspects that provide decision-making support for the industry and fill research gaps.

5.2. Management Implications

According to the analysis results, C26 has an environmentally friendly design concept. This helps enhance competitiveness and meet environmental regulations. C15 and C1 show environmental responsibility and management capabilities. This can reduce costs and improve brand perception. C16 increases company transparency, helps identify risk opportunities, and drives value growth. C3 reduces environmental impact and realizes resource recycling. C19 increases satisfaction and enhances corporate competitiveness. These practices show the way for corporate SSCM. Enterprises

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should pay attention to relevant aspects and promote the industry's transformation to sustainable development.

6. Conclusion

Under the United Nations Sustainable Development Goals and China's "double carbon" goal, this study explores enterprises' use of sustainable supply chain management (SSCM) to achieve TBL. It builds a framework for SSCM implementation. The study uses a mixed method to evaluate the impact. It also enhances awareness and promotes cooperation. The results identify key drivers, such as C26 and others. The study clarifies the relationship and contribution of various aspects.

The results show that environmental (A1) and economic (A3) aspects are driving factors. They are interdependent with social (A2) aspects and have a limited impact. Environmental measures have indirect positive effects on society. Economic aspects are closely related to and interact with social and resource and innovation (A4) aspects. Together, they promote sustainable development. Initiatives like C26, C15, C16, C3, C1, and C19 are key drivers of SSCM. They provide enterprises with development paths and verify their effectiveness.

Research contributions include enriching the theoretical framework of SSCM and providing empirical data. Diverse research methods enhance the objectivity and accuracy of evaluation. They transform practice relationships into visualization results to enhance scientific practicality. Evaluation results provide action guides for enterprise management, having practical value and management significance.

However, this study has certain limitations. For case selection, it only focuses on the iRest Chinese massage chair brand. With a single sample, it has limited industry representation and is difficult to promote to enterprises in other industries or regions. The scope of cases needs to be expanded in the future. Regarding data collection, it mainly relies on questionnaires and expert assessments. The data sources are relatively limited and may have subjective biases. In the follow-up, it should be combined with multi-channel data, such as the actual operation data of enterprises and consumer feedback data. This study provides a foundation for subsequent related research. But it still needs to be improved in many aspects to promote the continuous development of research in this field.

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