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Applying a Hybrid MCDM Model to Evaluate Green Supply Chain Management Practices

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Abstract: The COVID-19 pandemic has prompted global supply chain managers to reassess their operations. Developing a green supply chain requires successfully integrating environmental responsibility principles and benchmarks into supply chain management practices. In the past, there have been few studies on the most effective strategies for reducing the environmental impact of supply chains and improving their sustainability. This study used the decision-making trial and evaluation laboratory (DEMATEL) method to construct a structural model evaluation system of the green supply chain management (GSCM) to evaluate the interdependent relationships among dimensions and criteria. A GSCM evaluation system was created after using the DEMATEL-based ANP (DANP) to convert the GSCM evaluation indicators and impact factors into degrees of importance. This study explores the obstacles and challenges that organizations face when implementing GSCM practices and how these challenges can be overcome. The results found that organizational changes had the most significant impact, given that they would also improve the other three dimensions. Among the 16 evaluation criteria, resource allocation and market expansion optimization were the most important. Based on these findings, the study proposed specific improvement strategies that corporations and other stakeholders could use to adopt GSCM practices.

Keywords: green supply chain management; DEMATEL; MCDM; DANP

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1. Introduction

Green supply chain management (GSCM) includes evaluating and selecting green suppliers, pricing and procurement of materials, organizing incoming and outgoing materials, and planning the resource supply and demand balance in the production line [1]. Manufacturing-based industries spend more than 60% of their overall revenue on suppliers for necessities such as raw materials, components, and outsourced processing. A survey conducted by Lo et al. [2] demonstrated that the role of suppliers could affect a company's business performance and sustainable enterprise development. Some studies have pointed out that 45% of greenhouse gas emissions are from production activities [3].

Some problems may be associated with supply chain disruptions in a post-COVID-19 scenario [4]. Supply chain disruptions lead to shortages of raw materials, components, and finished products, which impact the availability of goods and services. Supply chain disruptions also lead to higher costs for raw materials, transportation, and other inputs, which can impact the profitability of businesses [5]. Due to supply chain disruptions, customers may be dissatisfied if they are unable to obtain the necessary goods or services, and businesses suffer reputational damage if they cannot fulfill orders or meet customer expectations. By identifying contractors with these core competencies, it could be possible to more effectively address problems associated with supply chain disruptions in a post-COVID-19 scenario [6].

Research on supplier selection is abundant, with the earliest publications dating back to the 1960s [7]. This is because suppliers must also measure their environmental performance in addition to traditional factors such as supplier cost, quality, delivery time, and

flexibility. Over the past decade, one of the most common green supplier evaluation and selection methodologies has been multiple criteria decision-making (MCDM) [8]. In the decision-making process, multiple conflicting factors/criteria/attributes must be considered simultaneously to determine an optimal solution [9]. MCDM provides an evaluation framework that addresses practical problems using scientifically based analytical methods that assist decision-makers in effectively addressing various evaluation problems [10]. Applying advanced MCDM methods to analyze issues related to green supplier selection is a modern research trend. MCDM methods are a class of mathematical techniques that can be used to evaluate and compare alternatives based on multiple criteria. They are commonly used in decision-making problems where multiple, often conflicting, criteria need to be considered. In the context of green supplier selection, MCDM methods can be used to evaluate and compare different suppliers based on a range of environmental and sustainability criteria, such as carbon emissions, waste reduction, and water conservation. This can help organizations make more informed and strategic decisions about their supplier selection and support their efforts to reduce their environmental impact.

There are many different MCDM methods that can be used to analyze issues related to green supplier selection [11]. Some common methods are the analytic hierarchy process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [12], and multi-attribute utility theory (MAUT) [13]. The last is a method that uses utility theory to evaluate alternatives based on their relative performance according to multiple criteria. These and other MCDM methods can be applied to green supplier selection problems in various ways. For example, they can be used to identify the most sustainable suppliers based on a set of predefined criteria, or to prioritize and select suppliers based on their relative performance on different sustainability measures. MCDM methods can also be used to evaluate the trade-offs and relative importance of different sustainability criteria [14], and to support decision-making in the face of uncertainty or incomplete information [15].

The decision-making trial and evaluation laboratory (DEMATEL) method is a technique used in multi-criteria decision-making to analyze the interdependent relationships between criteria [16]. It is based on the premise that the importance or influence of a criterion on the overall decision-making process is determined by its importance and other criteria that it depends on or affects. In the context of decision-making for the wire and cable industry (WCI), DEMATEL can be used to explore the interdependent relationship between criteria, such as carbon emissions, water usage, and waste reduction [17]. By analyzing these relationships, DEMATEL can help decision-makers to understand which criteria are the main factors affecting others, and which criteria are the most important in terms of their overall impact on the decision-making process [18]. This can provide valuable insights and support more informed and effective decision-making. Overall, the use of DEMATEL in WCI decision-making can help organizations better understand the interdependent relationships between different criteria and make more strategic and effective decisions that support their sustainability goals.

The topic of GSCM is important for several reasons [19]. First, concerns about the environmental impact of business activities have been growing in recent years, and there is increasing pressure on organizations to reduce their carbon footprint and minimize their environmental impact. This has made GSCM an increasingly important issue for businesses, as it is one of the key ways in which organizations can address these concerns and reduce their environmental impact [20]. Second, GSCM can help organizations reduce operating costs and improve competitiveness. Organizations can save money and improve their bottom line by reducing waste and inefficiency in their supply chains [21]. Third, GSCM can help organizations improve their reputation and public image. By demonstrating a commitment to sustainability and environmental responsibility, organizations can improve their relationships with stakeholders and enhance their reputation in the eyes of customers, employees, investors, and other stakeholders [22]. Overall, GSCM is important because it can help organizations address many important business and environmental concerns.

To our best understanding, some research gaps exist in relation to GSCM in the following areas:

- The effectiveness of different GSCM strategies and practices. Few studies discuss which strategies and practices are most effective for reducing supply chains' environmental impacts and improving business operations' sustainability;
- The costs and benefits of GSCM. Existing studies do not investigate the financial implications of implementing GSCM practices, and the costs and benefits of these practices compared with those of other business strategies;
- The potential barriers and challenges to implementing GSCM. Few studies explore the obstacles and challenges that organizations face when trying to implement GSCM practices, and how these challenges can be overcome;
- The role of government and other external stakeholders in promoting GSCM. Few studies explain the ways in which governments and other stakeholders can support and incentivize the adoption of GSCM practices.

Since the above topics are worthy of further research and analysis to address the research gaps, this study proposes an MCDM approach for evaluating and selecting suitable suppliers for WCI. First, DEMATEL is applied to explore the interdependent relationship between criteria, which can help WCI decision-makers understand which are the main criteria affecting others. Second, DANP can generate the influence weight of a set of criteria according to the survey results from DEMATEL, which can then be used to rank each criterion. This study uses a new hybrid MCDM model to solve WCI's GSCM problem, and improves the evaluation performance of interdependence between criteria.

2. Literature Review

2.1. Evaluation of GSCM Practices

In recent years, the use of MCDM methods in green supplier selection has gained significant attention in both academia and industry [23]. There are several reasons for this trend. First, the increasing awareness of environmental and sustainability issues has led organizations to prioritize these concerns in their supplier selection processes [24]. Second, the stakeholder theory suggests that organizations have a responsibility to consider the interests of all of their stakeholders, including customers, employees, investors, suppliers, and the broader community, when making decisions. In the context of GSCM, this could mean considering the environmental impact of the organization's practices on all of its stakeholders [24]. The growing availability of environmental and sustainability data has made it possible to quantitatively evaluate and compare suppliers on a range of sustainability measures [25]. Third, MCDM methods provide a structured and systematic approach for analyzing complex supplier selection problems with multiple, often-conflicting criteria [26]. In addition to green supplier selection problems, MCDM methods can be applied to other sustainability-related problems and decision-making contexts [27]. For example, they can be used to evaluate and compare different sustainability initiatives or projects within an organization, or to assess the environmental and sustainability performance of different products or services. MCDM methods can also be used to support decision-making in the face of uncertainty or incomplete information, such as in the case of new or emerging sustainability issues [28].

A corporation can use various methods to evaluate its GSCM practices. Some of the key steps in this process might include the following [23–28]:

- Identify the goals and objectives of the corporation's GSCM efforts. This is based on the triple bottom line theory that organizations have three bottom lines: financial, social, and environmental. According to this theory, organizations should strive to balance their performance across these three dimensions in order to be truly sustainable and successful [29]. This could include reducing the supply chain's environmental impact, improving its operations' sustainability, or achieving other goals related to environmental responsibility;

- Develop metrics and benchmarks for evaluating the corporation's GSCM practices. These metrics could include the corporation's carbon footprint, waste reduction, water use, energy consumption, and other environmental performance indicators;
- Collect and analyze data on the corporation's GSCM practices. This could involve conducting surveys, interviews, and other research to gather information on the corporation's current practices and environmental impact;
- Compare the corporation's performance on the selected metrics and benchmarks with those of other organizations in the same industry or with predetermined goals. The resource-based view theory proposes that organizations should focus on managing and leveraging their internal resources, such as their knowledge, skills, and capabilities, in order to create a competitive advantage and improve their performance. In the context of GSCM, this could mean building expertise and capabilities in areas such as waste reduction, energy efficiency, and sustainable sourcing [30]. This could involve using data envelopment analysis (DEA) or other performance evaluation methods to assess the corporation's efficiency and identify areas for improvement;
- Develop and implement strategies for improving the corporation's GSCM practices. The sustainability theory suggests that organizations should strive to achieve long-term sustainability by balancing the economic, social, and environmental dimensions of their activities. In the context of GSCM, this could mean considering the long-term impact of the organization's practices on the environment and finding ways to reduce that impact [31]. This could include identifying and addressing inefficiencies, reducing waste and emissions, and implementing other strategies to enhance the environmental performance of the corporation's supply chain.

Overall, the above theories can help us understand the issue of GSCM by providing frameworks and perspectives for thinking about the relationships between organizations, the environment, and other stakeholders. Evaluation criteria are essential to the WCI's GSCM evaluation system. First, critical criteria should be fully incorporated into the evaluation system to reflect the characteristics and intentions of the WCI's GSCM. Initial criteria were determined based on related studies and expert interviews. Second, a decision-making group comprising experts in business management, economic and social development, and environmental protection was created. The group included professors and corporate practitioners, who reviewed the initial criteria and chose the important ones. Finally, the GSCM evaluation framework for the WCI was developed. Overall, sixteen evaluation criteria for the WCI's GSCM were divided into four dimensions, as shown in Table 1.

Table 1. WCI's GSCM evaluation criteria.

Dimension	Criteria	References
Environmental (D_1)	Green design (A_{11})	[32,33]
	Green procurement (A_{12})	[33,34]
	Green production (A_{13})	[32,34]
	Optimal resource allocation (A_{14})	[33,35]
Social (D_2)	Compliance with regulations (A_{21})	[2,36]
	Liability risk (A_{22})	[37]
	Customer relationship management (A_{23})	[35,36]
	Social requirements (A_{24})	[37,38]
Economic (D_3)	Supply chain requirements (A_{31})	[39,40]
	Improving business performance (A_{32})	[32]
	Market expansion (A_{33})	[40]
	Cost reduction (A_{34})	[12,32]
Organization (D_4)	Stakeholders (A_{41})	[12,41]
	Corporate image (A_{42})	[12,42]
	Supervisor support (A_{43})	[12,35]
	Employee motivation (A_{44})	[35,43]

2.2. Environmental Dimension

The evaluation criteria for the WCI's environmental protection are green design (A_{11}), green procurement (A_{12}), green production (A_{13}), and optimal resource allocation (A_{14}).

- Green design (A_{11}) refers to a company's consideration of a product's potential harm to humans, spanning from conception to preliminary design, to final design. It also takes into account any possible effects on the environment and the level of resource wastage [43];
- Green procurement (A_{12}) applies to the evaluation and development of a company's supplier selection process [44], which considers the supplier's operations, logistics, packaging, recycling, reuse, and resource reduction processes [32];
- Green production (A_{13}) relates to the requirement for companies to respect and protect the natural environment in their production process, creating a GSC system [34]. Green production focuses on how the integration of green resources in the supply chain can effectively enhance corporate image and implement environmental protection policies [34];
- Optimal resource allocation (A_{14}) assesses whether a company utilizes resources effectively, which would help them avoid or reduce waste to maximize profits [33].

2.3. Social Dimension

The social dimension (D2) refers to the social care capability of internal and external aspects of an organization. The evaluation criteria are compliance with regulations (A_{21}), liability risk (A_{22}), customer relationship management (CRM) (A_{23}), and social requirements (A_{24}).

- Compliance with regulations (A_{21}) means investing in green manufacturing processes to reduce the use and production of hazardous substances, while simultaneously reducing water, land, and air pollution to comply with various laws and regulations [2];
- Liability risk (A_{22}) involves the use of hazardous substances or processes that cause harm to people or the environment, which in turn makes the company bear liability and damage its reputation [37];
- CRM capability (A_{23}) is the process by which consumer trust is strengthened through green manufacturing. It can also enhance customer loyalty, because of cost reduction and quality improvement [36];
- Social requirements (A_{24}) refer to the requirements placed on companies by society to fulfill their responsibilities in product safety and environmental protection [38].

2.4. Economic Dimension

The economic dimension (D3) refers to the assessment of business performance and management capabilities, comprising supply chain requirements (A_{31}), improving business performance (A_{32}), market expansion (A_{33}), and cost reduction (A_{34}).

- Supply chain requirements (A_{31}) are based on green manufacturing requirements. Upstream manufacturers must pay attention to environmental protection throughout the production process, including when acquiring raw materials, processing, packaging, storage, transportation, use, and disposal of products [39];
- Improving business performance (A_{32}) is an assessment of the investment process in green manufacturing [45], management improvement through energy saving, efficient resource use, and waste product recycling [32];
- Market expansion (A_{33}) assesses a company's ability to obtain international certification for its green manufacturing processes, which is helpful for corporate developments and new market expansions [40];
- Cost reduction (A_{34}) assesses how companies maximize resource utilization, reduce resource consumption, and directly cut costs through process-based improvements, innovative designs, or new technologies [12].

2.5. Organization Dimension

The organization dimension (D4) is one of the most important competencies in WCI. WCI is not only an indispensable member of the supply chain from traditional industries, such as infrastructure construction and the automobile industry, to high-tech industries, such as the semiconductor industry, but also an industry with high energy consumption, heavy resource usage, and high environmental pollution risk [35]. It comprises stakeholders (A_{41}), corporate image (A_{42}), supervisor support (A_{43}), and employee motivation (A_{44}).

- Stakeholders (A_{41}) refer to stakeholder participation, including shareholders and their views on environmental protection [41];
- Corporate image (A_{42}) refers to the WCI's corporate image, which is an important asset of any modern company. Through the promotion of green manufacturing and an emphasis on environmental protection, a high-quality corporate image can be created [42];
- Supervisor support (A_{43}) refers to the degree of support provided by supervisors in the concept of green manufacturing and related initiatives [12];
- Employee motivation (A_{44}) refers to employees' awareness and understanding of green manufacturing and their ability to cooperate with relevant corporate policies and regulations actively [43].

3. Methods

This study used the DEMATEL method to analyze and confirm the relationship between dimensions and criteria. Simultaneously, the DANP method was used to analyze their exact influence weights [34]. Saaty proposed the Analytic Hierarchy Process (AHP) in 1971 [46]. Scholars from various fields have highly valued it, since it can provide various contributions to decision-making problems [47]. Saaty further studied the AHP in 1996 and proposed the analytic network process (ANP) [48]. The difference between ANP and AHP is that ANP considers each factor's interdependencies and mutual influence. The purpose of ANP is to predict the precise internal relationship between each factor and to obtain the system's structure of interacting indicators and evaluation indicator weights through a pairwise comparison of evaluation models. The significant difference between the two is that AHP considers each criterion independently [49]. Concurrently, ANP is a research method applied to solve nonlinear and complex network relationships, which considers the existence of interdependence and feedback between dimensions and criteria or alternatives [50].

ANP uses a pairwise comparison method to compare and analyze dimension with dimension and criterion with criterion, with the matrix formula used to determine influence weights [51]. This study analyzed key influence differences and obtained the precise relationship between criteria, objectives, and programs through evaluation metrics, including the post-interaction weight of each cluster and element. Therefore, DANP was used with the DEMATEL method to confirm the different degrees of influence of each cluster. The "Dynamic Importance Influence Relationship", implicit in the total influence relationship matrix T obtained by DEMATEL, was further used. The total influence relationship matrix T of DEMATEL was applied to the supermatrix of ANP. This study combined the characteristics of ANP with DEMATEL to solve the problem of inter-criteria weighting. The steps of DANP are as follows:

Step 1: Build a system structure model. First, the DEMATEL method was used to establish a network structure diagram, which is also the system structure model.

Step 2: Build an unweighted supermatrix. The total influence relationship matrix $\boldsymbol{T}_C$ of the factors (criteria) obtained by Formula (1) was used to derive the normalized total-influence matrix $\boldsymbol{T}_C^{\alpha}$ by normalizing each column in the same dimension, as seen in Formula (2). $\boldsymbol{T}_C^{ij}$ is the sub-matrix by dimension (Formula (3)), and $\boldsymbol{T}_C^{\alpha ij}$ is a normalized sub-matrix obtained from Formula (4). By including the normalized total-influence matrix

$\boldsymbol{T}_C^{\alpha}$ inside $\boldsymbol{W} = \left(\boldsymbol{T}_C^{\alpha}\right)^T$, the unweighted supermatrix of ANP can be obtained, as shown in Formula (5).

$$\boldsymbol{T}_C = \begin{array}{c} \\ D_1 \\ \\ \\ \\ D_2 \\ \\ \\ \vdots \\ \\ D_n \\ \\ \end{array} \begin{array}{c} \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \\ \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \begin{array}{c} \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \end{array} \\ \begin{array}{cccc} c_{11} \ldots c_{1m_1} & c_{21} \ldots c_{2m_2} & \cdots & c_{n1} \ldots c_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{T}_C^{11} & \boldsymbol{T}_C^{12} & \cdots & \boldsymbol{T}_C^{1n} \\ \boldsymbol{T}_C^{21} & \boldsymbol{T}_C^{22} & \cdots & \boldsymbol{T}_C^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{T}_C^{n1} & \boldsymbol{T}_C^{n2} & \cdots & \boldsymbol{T}_C^{nn} \end{bmatrix} \end{array} \tag{1}$$

$$\boldsymbol{T}_C^{\alpha} = \begin{array}{c} \\ D_1 \\ \\ \\ \\ D_2 \\ \\ \\ \vdots \\ \\ D_n \\ \\ \end{array} \begin{array}{c} \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \\ \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \begin{array}{c} \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \end{array} \\ \begin{array}{cccc} c_{11} \ldots c_{1m_1} & c_{21} \ldots c_{2m_2} & \cdots & c_{n1} \ldots c_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{T}_C^{\alpha 11} & \boldsymbol{T}_C^{\alpha 12} & \cdots & \boldsymbol{T}_C^{\alpha 1n} \\ \boldsymbol{T}_C^{\alpha 21} & \boldsymbol{T}_C^{\alpha 22} & \cdots & \boldsymbol{T}_C^{\alpha 2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{T}_C^{\alpha n1} & \boldsymbol{T}_C^{\alpha n2} & \cdots & \boldsymbol{T}_C^{\alpha nn} \end{bmatrix} \end{array} \tag{2}$$

$$\boldsymbol{T}_C^{ij} = \begin{array}{c} \\ C_{i1} \\ \\ C_{i2} \\ \\ \vdots \\ \\ C_{im_i} \end{array} \begin{array}{c} \begin{array}{cccc} C_{j1} \cdots & C_{1i} & \cdots & C_{1m_i} \end{array} \\ \begin{bmatrix} \boldsymbol{t}_{i1j1} & \boldsymbol{t}_{i1jq} & \cdots & \boldsymbol{t}_{i1jm_j} \\ \boldsymbol{t}_{i2j1} & \boldsymbol{t}_{i2jq} & \cdots & \boldsymbol{t}_{i2jm_j} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{t}_{im_ij1} & \boldsymbol{t}_{im_ijq} & \cdots & \boldsymbol{t}_{im_ijm_j} \end{bmatrix} \end{array} \tag{3}$$

$$\boldsymbol{T}_C^{\alpha ij} = \begin{bmatrix} \boldsymbol{t}_{i1j1}^{ij}/d_{i1}^{ij} & \boldsymbol{t}_{i1jq}^{ij}/d_{i1}^{ij} & \cdots & \boldsymbol{t}_{i1jm_j}^{ij}/d_{i1}^{ij} \\ \boldsymbol{t}_{i2j1}^{ij}/d_{i2}^{ij} & \boldsymbol{t}_{i2jq}^{ij}/d_{i2}^{ij} & \cdots & \boldsymbol{t}_{i2jm_j}^{ij}/d_{i2}^{ij} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{t}_{im_ij1}^{ij}/d_{im_i}^{ij} & \boldsymbol{t}_{im_ijq}^{ij}/d_{im_i}^{ij} & \cdots & \boldsymbol{t}_{im_ijm_j}^{ij}/d_{im_i}^{ij} \end{bmatrix} = \begin{bmatrix} \boldsymbol{t}_{i1j1}^{\alpha ij} & \boldsymbol{t}_{i1jq}^{\alpha ij} & \cdots & \boldsymbol{t}_{i1jm_j}^{\alpha ij} \\ \boldsymbol{t}_{i2j1}^{\alpha ij} & \boldsymbol{t}_{i2jq}^{\alpha ij} & \cdots & \boldsymbol{t}_{i2jm_j}^{\alpha ij} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{t}_{im_ij1}^{\alpha ij} & \boldsymbol{t}_{im_ijq}^{\alpha ij} & \cdots & \boldsymbol{t}_{im_ijm_j}^{\alpha ij} \end{bmatrix} \tag{4}$$

where,

$$d_{i1}^{ij} = \sum_{jq=1}^{m_j} t_{ipjq}^{ij}, ip = 1, 2, \ldots, m_i$$

$$\boldsymbol{W} = (\boldsymbol{T}_C^{\alpha})^T = \begin{array}{c} \\ D_1 \\ \\ \\ \\ D_2 \\ \\ \\ \vdots \\ \\ D_n \\ \\ \end{array} \begin{array}{c} \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \end{array} \\ \vdots \\ \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} \begin{array}{c} \begin{array}{cccc} D_1 & D_2 & \cdots & D_n \\ c_{11} \ldots c_{1m_1} & c_{21} \ldots c_{2m_2} & \cdots & c_{n1} \ldots c_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{W}^{11} & \boldsymbol{W}^{12} & \cdots & \boldsymbol{W}^{1n} \\ \boldsymbol{W}^{21} & \boldsymbol{W}^{22} & \cdots & \boldsymbol{W}^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{W}^{n1} & \boldsymbol{W}^{n2} & \cdots & \boldsymbol{W}^{nn} \end{bmatrix} \end{array}$$

$$\boldsymbol{W}^{11} = \begin{array}{c} \\ C_{11} \\ \\ \\ C_{1j} \\ \\ \\ \vdots \\ \\ C_{1m_i} \\ \\ \end{array} \begin{array}{c} \begin{array}{cccc} C_{j1} & \cdots & C_{1i} & \cdots & C_{1m_i} \end{array} \\ \begin{bmatrix} \boldsymbol{t}_{11}^{\alpha 11} & \boldsymbol{t}_{i1}^{\alpha 11} & \cdots & \boldsymbol{t}_{m_i1}^{\alpha 11} \\ \boldsymbol{t}_{1j}^{\alpha 11} & \boldsymbol{t}_{ij}^{\alpha 11} & \cdots & \boldsymbol{t}_{m_ij}^{\alpha 11} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{t}_{1m_i}^{\alpha 11} & \boldsymbol{t}_{im_i}^{\alpha 11} & \cdots & \boldsymbol{t}_{m_im_i}^{\alpha 11} \end{bmatrix} \end{array} \tag{5}$$

Step 3: Calculate the weighted supermatrix. Through the criterion (factor) of Formula (1), the total-influence matrix T_C is obtained from the total-influence matrix

of dimensions T_D, as shown in Formula (6). Subsequently, after T_D is normalized; the normalized total-influence matrix of dimensions T_D^α is as shown in Formula (7).

$$T_D = \begin{bmatrix} t_D^{11} & t_D^{1j} & \cdots & t_D^{1m} \\ t_D^{i1} & t_D^{ij} & \cdots & t_D^{im} \\ \vdots & \vdots & \ddots & \vdots \\ t_D^{m1} & t_D^{mj} & \cdots & t_D^{mm} \end{bmatrix} \tag{6}$$

where,

$$t_D^{ij} = \frac{1}{m_i m_j} \sum_{ip=1}^{m_i} \sum_{jk=1}^{m_j} t_{ipjk}$$

$$T_D^\alpha = \begin{bmatrix} t_D^{11}/d_1 & t_D^{1j}/d_1 & \cdots & t_D^{1m}/d_1 \\ t_D^{i1}/d_i & t_D^{ij}/d_i & \cdots & t_D^{im}/d_i \\ \vdots & \vdots & \ddots & \vdots \\ t_D^{m1}/d_m & t_D^{mj}/d_m & \cdots & t_D^{mm}/d_m \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1m} \\ t_D^{\alpha i1} & t_D^{\alpha ij} & \cdots & t_D^{\alpha im} \\ \vdots & \vdots & \ddots & \vdots \\ t_D^{\alpha m1} & t_D^{\alpha mj} & \cdots & t_D^{\alpha mm} \end{bmatrix} \tag{7}$$

where,

$$d_i = \sum_{j=1}^{m} t_D^{ij} \text{and } t_D^{\alpha ij} = t_D^{ij}/d_i$$

Elements of the normalized total-influence matrix of dimensions t_D^α are used as the weighted values of the unweighted supermatrix (W) to obtain the weighted supermatrix W^α, and $W^\alpha = T_D^\alpha \times W$ is shown in Formula (8).

$$W^\alpha = T_D^\alpha W = \begin{bmatrix} t_D^{\alpha 11} w^{11} & t_D^{\alpha 1j} w^{1i} & \cdots & t_D^{\alpha 1m} w^{1m} \\ t_D^{\alpha 1j} w^{j1} & t_D^{\alpha ij} w^{ji} & \cdots & t_D^{\alpha mi} w^{im} \\ \vdots & \vdots & \ddots & \vdots \\ t_D^{\alpha 1m} w^{m1} & t_D^{\alpha im} w^{mi} & \cdots & t_D^{\alpha mm} w^{mm} \end{bmatrix} \tag{8}$$

Step 4: Apply the limit procedure to W^α until convergence, $\lim_{g \to \infty} (W^\alpha)^g$.

After convergence, the global priority vectors in the stable supermatrix can be obtained, which demonstrate ANP weights or DANP influence weights.

4. Results

According to the DEMATEL theoretical literature, between 5 and 15 experts in a group is considered an appropriate size [52]. Overall, 14 experts were surveyed for this study, including professors in related fields and industry executives. These experts have more than ten years of professional experience in SCM-related fields, as shown in Table 2.

Table 2. Introduction to the background and academic experience of the specialists.

Expertise	Specialist Background	Number of Specialists
Practical Experience(years)	1–10	2
	11–20	6
	21–30	6
Field	Academia	4
	Manufacturing industry	10

4.1. Dimension Relevance

First, data were collected through expert questionnaires and converted into an average (initialized) influence matrix, as shown in Table 3. Second, the rows and columns of the average influence matrix were summed up, and all the values in the average influence matrix were divided by the maximum value. After that, a new matrix, the normalized average influence matrix, with values between 0 and 1, was obtained, as shown in Table 4. Subsequently, the normalized average influence matrix was applied to the multiple and indirect influences between factors to obtain the total-influence matrix, as shown in Table 5. The influence of each dimension was then calculated, as shown in Table 6.

Table 3. Average influence matrix.

	D_1	**D_2**	**D_3**	**D_4**
D_1	0.00	2.77	2.62	2.23
D_2	2.85	0.00	2.54	2.38
D_3	2.46	2.31	0.00	2.31
D_4	2.77	2.23	2.92	0.00

Table 4. Normalized average influence matrix.

	D_1	**D_2**	**D_3**	**D_4**
D_1	0.00	0.34	0.32	0.28
D_2	0.35	0.00	0.31	0.30
D_3	0.30	0.29	0.00	0.29
D_4	0.34	0.28	0.36	0.00

Table 5. Total influence matrix (T).

	D_1	**D_2**	**D_3**	**D_4**	**r**
D_1	3.85	3.84	4.10	3.64	15.43
D_2	4.17	3.64	4.15	3.71	15.68
D_3	3.88	3.61	3.64	3.46	14.60
D_4	4.22	3.91	4.23	3.53	15.88
d	16.12	15.00	16.12	14.34	

Table 6. Influence of dimensions.

	r	**d**	**r + d**	**r-d**
D1	15.43	16.12	31.55	−0.69
D2	15.68	15.00	30.67	0.68
D3	14.60	16.12	30.72	−1.53
D4	15.88	14.34	30.23	1.54

Figure 1 indicates the influential network-relationship map (INRM) of the four dimensions and their subsystems. When r-d > 0, the dimension is an influencing factor. When r-d < 0, the dimension is the affected factor. The results show that, of the four dimensions, the organization dimension D_4 has the greatest influence and is the main source of influence on the other dimensions. The social dimension D_2 was next, followed by the environment dimension D_1. The economic dimension D_3 was affected by other dimensions, and was ranked last. As seen in the mutual influence and causal relationship between the various dimensions, it is clear that the other three dimensions could be utilized to improve the economic dimension. The environment dimension D_1 can be improved through efforts in the organization and society dimensions, which can also affect the economic dimension. From this, it can be seen that improving the organization dimension can lead to improvements in the other three, making it the ideal starting point for improvement efforts.

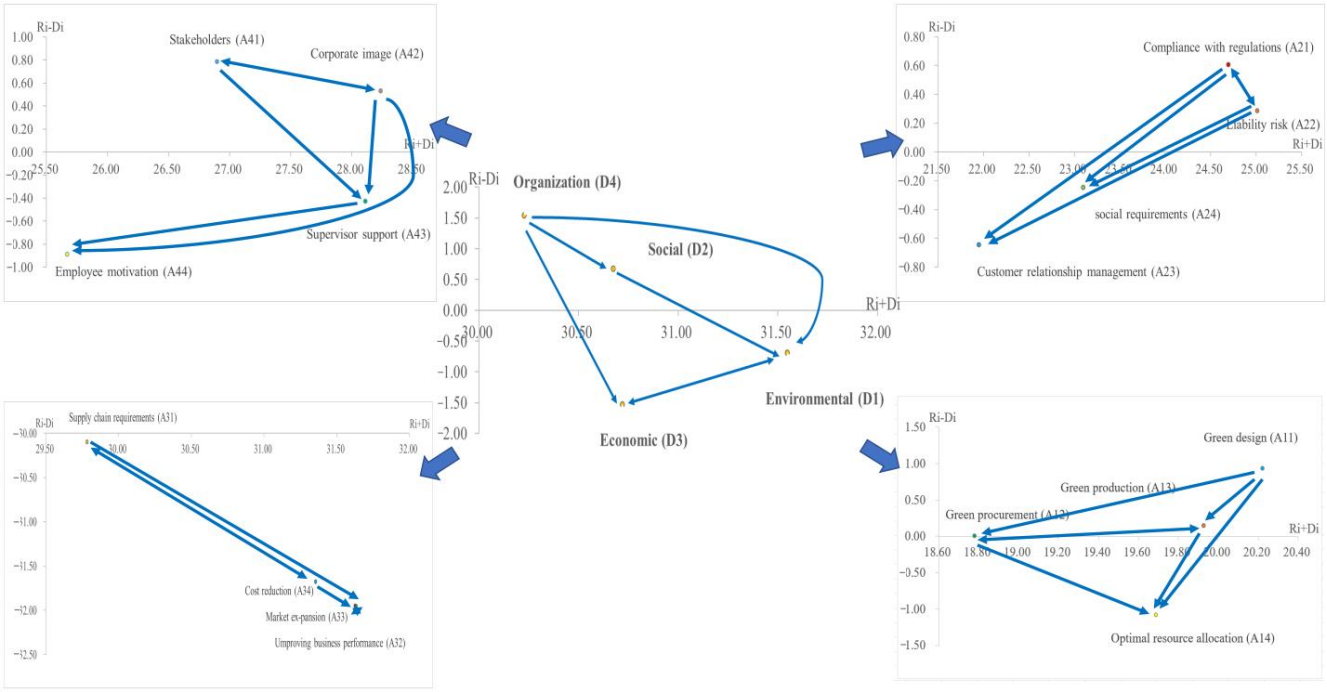

Figure 1. Influential network relationship map.

In dimension D_1, green design (A_{11}) influences green procurement (A_{12}), green production (A_{13}), and optimal resource allocation (A_{14}). Green design can have a number of benefits, including reduced resource consumption, lower greenhouse gas emissions, and improved overall environmental performance. Green design can support optimal resource allocation by identifying and prioritizing sustainable resources and minimizing resource consumption.

In dimension D_4, corporate image (A_{42}) influences stakeholders (A_{41}), supervisor support (A_{43}), and employee motivation (A_{44}). For GSCM, a company's corporate image and the support provided by supervisors both play important roles in influencing employee motivation. A positive corporate image and supportive supervisors can create a positive work environment that encourages employees to be motivated and engaged, while a negative corporate image and lack of support result in the opposite effect. In terms of the economic dimension (D_3), the relationships between the four criteria are relatively weak, but supply chain requirements (A_{31}), market expansion (A_{33}), and cost reduction (A_{34}) all affect improving business performance (A_{32}). Improving business performance is a very important criterion for GSM being of the most concern to people, and it is easily affected by the other elements. GSC can help alleviate resource wastage, enhance corporate social responsibility, and expand product markets [53]. Production savings in raw materials reduces the life-cycle cost of the final product, providing end consumers with safer and more environmentally friendly products at a lower price. Cost reduction (A_{34}) also influences market expansion (A_{33}). By reducing costs, a business offers its products or services at a lower price than its competitors, making it more competitive in the market and helping it attract new customers. Reducing costs also helps a business increase its profitability, which can provide the financial resources needed to expand into new markets. Reducing costs can also help a business improve its sustainability by decreasing its environmental impact and resource consumption. This can be particularly important in markets where consumer sustainability is crucial.

GSCM can vastly improve the corporate work environment. Not only can it improve employees' health and work safety and reduce unnecessary expenditure, but it also helps employees feel comfortable and encourages personal initiatives and work efficiency, gener-

ating increased profits. Furthermore, GSCM can create a better corporate social image and provide additional intangible assets.

4.2. Data Analysis of Dimension and Criterion Weights

The influence weight values and ranking of each attribute were obtained after the limit of the weighted supermatrix was sorted and analyzed. The results in Table 7 show that, based on overall weight, essential criteria among the 16 evaluation criteria were optimal resource allocation (A_{14}) (0.0690), market expansion (A_{33}) (0.0664), green production (A_{13}) (0.0659), and cost reduction (A_{34}) (0.0655).

Table 7. Analysis of the importance weights of each dimension and criterion.

Dimension	Criteria	Global Weight	Rank	Dimension Local Weight	Criteria Local Weight
Environmental	Green design	0.0645	6	0.262	0.2460
	Green procurement	0.0626	8		0.2388
	Green production	0.0659	3		0.2517
	Optimal resource allocation	0.0690	1		0.2635
Social	Compliance with regulations	0.0621	9	0.244	0.2545
	Liability risk	0.0637	7		0.2610
	Customer relationship management	0.0581	14		0.2382
	Social requirements	0.0601	11		0.2463
Economic	Supply chain requirements	0.0637	7	0.261	0.2442
	Improving business performance	0.0653	5		0.2503
	Market expansion	0.0664	2		0.2544
	Cost reduction	0.0655	4		0.2510
Organization	Stakeholders	0.0559	13	0.233	0.2399
	Corporate image	0.0593	12		0.2546
	Supervisor support	0.0610	10		0.2619
	Employee motivation	0.0568	15		0.2436

Optimal resource allocation (A_{14}) was the most critical criterion for GSCM. When companies manage the supply chain, they mainly focus on issues such as cost and quality. However, they do not fully consider the environmental impact of resources used throughout the industrial chain. In the face of increasingly severe resource and environmental challenges and the context of green development becoming a global concern, environmental regulation and continuous innovation in management methods have become increasingly important to reduce the ecological and environmental impacts created by economic and social development. Resource workloads must be tracked for optimal performance and results to avoid over- and under-provisioning. In the context of GSCM, optimal resource allocation is a critical criterion because it can help organizations reduce waste, improve efficiency, and enhance the sustainability of their supply chain operations. There are several factors that can affect optimal resource allocation in GSCM, including the availability and quality of resources, the effectiveness of logistics and transportation systems, and the overall sustainability of the supply chain. By focusing on optimal resource allocation, organizations can improve the performance and efficiency of their supply chain and reduce their environmental impact.

Second, in terms of market expansion (A_{33}), GSC is an innovative market-based approach to environmental management. It relies on the supplier relationship between

upstream and downstream companies. With core companies as the focus, green requirements are transmitted to upstream and downstream companies through green supplier management, green procurement, and other related efforts. This helps encourage relevant companies to participate in green development work. In turn, the green level of the entire industry chain will continue to improve. Implementing GSCM is a relatively effective way to achieve sustainable development with an equal emphasis on environmental awareness and economic development.

The results of this study show that green production (A_{13}) is also an important criterion. The traditional supply chain was a kind of linear management model, where requests from core companies often only flowed in one direction, upstream or downstream, along the supply chain, even if they reached the end of the industrial chain. Additionally, they often lack environmental protection considerations. This model makes it challenging to push related products into a new cycle. GSC involves the integration of environmental considerations into all aspects of the supply chain, from the sourcing of raw materials and the design of products to the distribution and disposal of finished goods. The goal of GSC is to create a more sustainable and efficient supply chain that reduces waste, conserves resources, and minimizes environmental impacts. Green production involves the use of technologies, practices, and materials that minimize environmental impacts, such as pollution, waste, and resource depletion. In the context of GSCM, green production is an important criterion because it can help organizations reduce their environmental footprint and improve the sustainability of their operations. By adopting green production practices, organizations can reduce their energy and resource consumption, minimize waste and pollution, and improve the overall sustainability of their products and services.

GSC is based on the idea that organizations can benefit from incorporating environmental considerations into their supply chain operations. By adopting GSC practices, organizations can improve their environmental performance, enhance their reputation and credibility, and gain a competitive advantage in the market. Additionally, GSC can help organizations reduce costs, improve efficiency, and increase the sustainability of their supply chain.

When manufacturers invest resources to establish GSC, they should consider ecological and environmental problems when addressing customers' requirements for using restricted substances. This means that manufacturers should carefully consider the potential impacts of the substances they use on the environment and human health, and take steps to minimize or eliminate any harmful effects. For example, if a customer requests that a manufacturer use a certain restricted substance in their product, the manufacturer should carefully evaluate the potential impacts of that substance on the environment and human health. If the substance is found to be harmful, the manufacturer should consider alternative substances that are less harmful or non-toxic, and propose these alternatives to the customer. Doing so helps establish a more stable and reliable relationship with upstream and downstream suppliers, which may enhance the green competitiveness of the industry. Such developments hint toward a future of green products. There should nevertheless be a continued focus on product life-cycle research and development, especially those products that meet specific environmental protection requirements, are harmless to the human body, and have no or minimal impact on the environment, while retaining their functionality and service life.

5. Discussion

GSCM helps organizations reduce their environmental impact. By implementing waste reduction, energy efficiency, and sustainable sourcing practices, organizations can minimize their environmental impact and reduce their carbon footprint. Organizations can save money and improve their bottom line by reducing waste and inefficiency in their supply chains. By demonstrating a commitment to sustainability and environmental responsibility, organizations can improve their relationships with stakeholders and enhance their reputation in the eyes of customers, employees, investors, and other stakeholders. Many countries

have regulations and laws requiring organizations to reduce their environmental impact, and GSCM practices can help organizations comply with these requirements. GSCM has the potential to be better than other supply chain management approaches in terms of reducing environmental impact, reducing costs, improving reputation, and complying with legal requirements.

As indicated in past research [2], green production is an essential criterion for GSCM. By considering the environmental impact of production processes and making efforts to minimize that impact, organizations can reduce their overall environmental footprint and improve the sustainability of their operations. Green production is therefore seen as an essential criterion for GSCM, as it can help organizations to meet their environmental responsibility goals and improve their overall performance.

The management implications of GSCM practices can be significant for organizations. Some of the key implications of GSCM for managers and decision-makers are as follows. GSCM may require changes to how organizations operate and manage their supply chains. Implementing green practices may require organizations to redesign their processes, change their sourcing strategies, and invest in new technologies, among other things. GSCM could require organizations to trade between different objectives and priorities. For example, implementing green practices may involve a higher initial investment, which may conflict with the organization's short-term financial goals. Managing these trade-offs and balancing different objectives can be challenging for managers.

Recent article discusses how small and medium-sized enterprises can use big data to innovate and sustain their supply chain operations in the post-COVID-19 scenario [1]. The core competencies of contractors in the post-COVID-19 world may vary, depending on the WCI in which they operate [54]. Compared to the literature [5,9], this study reveals that some core competencies for contractors in the WCI to consider in this environment include the ability to adapt quickly and effectively to changing circumstances and market conditions, which is likely crucial for contractors in the post-COVID-19 world. As businesses increasingly shift towards digital tools and platforms, contractors with strong digital skills and expertise may be in high demand. Moreover, with the continued focus on preventing the spread of COVID-19 and other infectious diseases, contractors with expertise in health and safety protocols may be particularly valuable [4]. Effectively planning and managing projects, including virtual and remote work, will likely be essential for contractors in the post-COVID-19 environment. Finally, as concerns about climate change and sustainability continue to grow, contractors focusing on these issues may be well positioned in the post-COVID-19 market.

The effectiveness of various GSCM strategies and practices has yet to be fully explored in the current literature [21]. In this study, we discuss that GSCM should require organizations to engage with external stakeholders and build partnerships. For example, organizations may need to work with suppliers, customers, and other stakeholders to develop and implement sustainable practices, and to generate support for their green initiatives. GSCM should require organizations to monitor and evaluate their performance and adjust as needed. Organizations will need to track their progress on their green initiatives, measure their environmental impact, and change their practices to improve their performance over time [30]. Meanwhile, our results indicate that liability risk is a crucial consideration in GSCM, as it can significantly impact an organization's financial and reputational health [55]. If harm occurs, the company may be held legally liable for the damages, which can result in high financial costs and a negative impact on the company's reputation. To mitigate liability risk, companies may take various precautions, such as implementing safety measures to prevent accidents or spills, properly storing and handling hazardous materials, and having insurance coverage to protect against potential liabilities. By taking these steps, companies can reduce the likelihood of incidents occurring and minimize the potential damage.

Recent research has focused on how to mitigate challenges that come from the GSCM [19]. GSCM has important implications for managers and decision-makers, who

need to consider the potential challenges and opportunities of implementing these practices and take a strategic and systematic approach to managing their organization's green initiatives [20,21]. There may be possible barriers to implementing better GSCM solutions. The potential barriers and challenges to implementing GSCM have not been fully explored in existing research. While there is some focus on the process of supplier selection [25,32], the challenges organizations may face when attempting to implement GSCM practices and how these challenges can be overcome have not been fully addressed.

Some of the key barriers that organizations may face when trying to implement GSCM practices include the following:

- Financial barriers: Implementing GSCM practices may require a significant investment of time and resources, which can be a barrier for organizations facing financial constraints or not willing to make the necessary investment;
- Cultural barriers: Organizations may face resistance from employees or other stakeholders who are not supportive of green initiatives, or who may be skeptical about the benefits of GSCM. Overcoming this resistance and building support for green initiatives can be challenging;
- Technical barriers: Implementing GSCM practices may require organizations to invest in new technologies and systems, and to develop new skills and expertise. This can be a barrier for organizations that do not have the necessary technical resources or capabilities;
- Regulatory barriers: Organizations may face barriers in the form of regulations or other legal requirements that limit their ability to implement GSCM practices. For example, some countries may have regulations that restrict the use of certain materials or technologies or require organizations to meet certain environmental standards. For GSM, and organizations may need to overcome these barriers to successfully implement these practices.

6. Conclusions

This study incorporated the concept of environmental quality into the original supply chain. The operation structure, management system, and management information of GSC were discussed from the perspective of GSCM. This allows for maintaining operational stability at each stage of the product life cycle, which allows the product to meet environmental protection standards continuously. Green consumption is an important step in achieving global sustainable development goals. Establishing a green procurement alliance to promote green products has become an international trend. Increasing emphasis has been placed on consuming low-pollution, recyclable, and resource-saving commodities to reduce environmental damage. Overall, using MCDM methods in sustainability-related decision-making can provide organizations with a structured and systematic approach to analyzing complex problems and making informed decisions. By applying advanced MCDM methods, organizations can evaluate and compare alternatives based on multiple criteria, making more strategic and practical decisions that support their sustainability goals.

Selecting the best green supplier is one of the critical tasks in improving service levels in the supply chain and environmental protection performance [56]. This study proposed a green supplier evaluation model that was simpler and more complete than the one used in the industry. Traditionally, suppliers were selected based on low cost, good quality, and punctual deliveries. Currently, the focus is on GSCM. A more direct approach is to use sustainability indicators as supplier selection criteria. This study added an organization dimension to the evaluation criteria, building upon previous sustainability frameworks. The results of this study indicate that change beginning with the organization dimension would bring about the most significant benefits among the four dimensions, as improving it would also enhance the other three dimensions. Among the 16 evaluation criteria, optimal resource allocation and market expansion were the most important.

This study used 4 dimensions and 16 evaluation criteria as research subjects and the DEMATEL research method to analyze the causal relationship between the dimensions and

the criteria. The DANP research method was applied to analyze the importance weights of each dimension and criterion. Subsequent studies can conduct supplier evaluations with different research methods. A causal-based improvement strategy was proposed to closely align with sustainability-oriented benefits through a structural model evaluation system. For further research, the strategies and practices that are effective for reducing the environmental impact and improving sustainability can be explored in more depth. Additionally, the impact of different sizes of organizations (e.g., small businesses vs. large corporations) on the effectiveness of GSCM practices or the role of government policies and regulations in promoting the adoption of GSCM can be investigated. Therefore, a thorough understanding of the issues related to GSCM can be developed.

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