Multi-Criteria Group Decision Making for Green Supply Chain Management under Uncertainty

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Abstract: This paper presents a multi-criteria group decision making model for effectively evaluating the performance of green supply chain management (GSCM) practices under uncertainty in an organization. The subjective assessments of individual decision makers are appropriately represented with the use of intuitionistic fuzzy numbers for better tackling the uncertainty existent. An algorithm is developed to assist individual decision makers in evaluating the performance of alternative GSCM practices across all the evaluation criteria. An example is presented for demonstrating the applicability of the proposed model in solving similar problems in the real-world setting.

Keywords: green supply chain management; multi-criteria analysis; group decision making; uncertainty modeling

1. Introduction

The importance of sustainability development is being recognized increasingly across the world in individual organizations [1]. This is due to the rapid development of the world economy for consuming non-renewable resources and the increasingly deteriorating world environment [2,3]. With this increasing recognition, organizations have started to adopt various sustainability development practices including green supply chain management (GSCM) in their operations to strengthen the green image of their organizations and to protect the environment along the whole supply chain while actively seeking the improvement of the competitiveness of the organization [4–6].

GSCM is about the effective consideration of sustainability development along the whole supply chain in an organization [7]. This involves redesigning the business processes in an organization for satisfying the customer of the supply chain while considering the issue of sustainability development [8,9]. GSCM focuses on minimizing the wastage in the operations of an organization along the supply chain through specific activities such as product design, material resourcing, product delivery, and management of the end-of-life of products [10]. It involves coordinating the activities along the supply chain for improving the sustainability development of an organization [11,12]. Effective GSCM helps organizations improve their competitiveness through: (a) reducing pollution and waste; (b) working with environmental-friendly suppliers; (c) developing green products and services; and (d) reducing emissions related to the transportation and delivery of products and services [13].

Evaluating the performance of GSCM practices is challenging. Multiple decision makers are often involved. Often, multiple and conflicting evaluation criteria exist. Furthermore, uncertainty is always present due to the use of subjective assessments in the evaluation process. To adequately

solve this problem, the development of structured models capable of comprehensively evaluating the performance of individual GSCM practices is, therefore, desirable.

Much research has been done, and various models have been developed for solving the problem of evaluating the performance of GSCM practices from different perspectives [14–16]. Such models can be classified usually from two perspectives: multi-criteria evaluation and multi-objective optimization [17,18]. They have shown their respective merits in addressing this problem in organizations in various circumstances.

Multi-criteria evaluation models formulate the performance evaluation process as a discrete optimization problem with the development of specific algorithms for facilitating the performance evaluation process while adequately considering multiple, usually conflicting evaluation criteria. Kannan et al. [15], for example, combined interpretive structural modeling and analytic hierarchy process [19] for evaluating GSCM practices. Interpretive structural modeling is used for studying the interaction between criteria, leading to the determination of the weights of the evaluation criteria. The analytical hierarchy process is then applied for determining the suitable GSCM practice in organizations. Awasthi et al. [14] developed a fuzzy model for assessing GSCM practices in organizations. Linguistic assessments are used for better modeling the uncertainty in the evaluation process. The technique for order preference by similarity to ideal solutions (TOPSIS) is adopted for aggregating these linguistic assessments in determining the performance index value for all the alternatives across the evaluation criteria [20]. Shen et al. [16] extended the TOPSIS model for evaluating GSCM practices in the Taiwanese electronic industry. Linguistic variables are used for assessing the weights of the evaluation criteria and the performance rating of each alternative with respect to each criterion. A weighted decision matrix is constructed on which a closeness coefficient is calculated for ranking all the GSCM practices across all the evaluation criteria.

Multi-objective optimization models treat the performance evaluation process as a continuous optimization problem with the focus on the tangible benefits and costs in the decision process. Roghanian et al. [21], for example, proposed a multi-objective optimization model for planning green supply chains in organizations. Torabi and Hassini [22] presented a multi-objective model for designing multi-echelon supply chains. Pinto-Varela et al. [23] developed a mixed-integer programming model for designing green supply chains with respect to the economic and environmental consideration of an organization. Liu and Papageorgiou [24] constructed a linear programming model for evaluating green supply chains.

In summary, these models have shown their merits in evaluating GSCM practices from different perspectives. They are, however, not completely satisfactory for effectively addressing this problem due to: (a) the need for adequately considering the interest of multiple decision makers; (b) the presence of uncertainty; and (c) the demand on decision makers in the evaluation process.

This paper presents a group decision making model for evaluating GSCM practices in an organization. To adequately model the uncertainty in decision-making, intuitionistic fuzzy numbers are used for representing the assessment of the decision maker. To effectively aggregate the subjective assessment, an algorithm is developed for determining the overall performance of GSCM practices with respect to the sustainability criteria. An example is presented that shows the proposed model is effective in solving similar problems in the real world setting.

In what follows, the problem of evaluating GSCM practices are first formulated as a multi-criteria group decision making problem. An algorithm is then developed for effectively solving this problem, followed by an example.

2. Evaluating the Performance of GSCM Practices

Conserving resources and protecting environments are becoming increasingly important nowadays, thereby exerting pressures on organizations worldwide. These pressures have forced individual organizations to improve their environmental performance while maintaining their competitiveness in the marketplace [25]. As a result, organizations are looking for the adoption

of specific GSCM practices [5]. To ensure that the best GSCM practice is implemented, evaluating individual GSCM practices across various evaluation criteria by different stakeholders is necessary.

There are numerous studies on investigating the criteria for affecting the performance of GSCM practices in organizations [25–30]. These criteria can usually be classified into four perspectives: (a) green design; (b) green purchasing; (c) green manufacturing; and (d) green marketing.

Green design is about the active consideration of the impact of products and services on the environment while designing these products and services [9,10]. In designing a specific product or service, it is critical for organizations to adequately consider the impact of the whole lifecycle of that product. Such a practice is often referred to as eco-design. It can improve the environmental outcome and reduce the costs of the operations in an organization [31].

The role of green design in effective GSCM has been explored in the literature. Diabat and Govindan [10], for example, stated that green design must be considered when evaluating GSCM practices in organizations. This is because green design emphasizes on sustainable practices of reusing and recycling materials in the daily operations of an organization. Arena et al. [32] showed that green design should consider the impact of products and services along their life cycles [33]. Zhu et al. [25] believed that organizations need to adequately consider the design of products for possible reuse. This is because green design not only allows the product and its components to be easily reused, but also helps to replace products with greener substitutes in specific circumstances.

Green design is important for evaluating GSCM practices. It is equally critical to balance the consideration between green design and the practicality of the product function. Rao and Holt [34] and Azevedo et al. [35], for example, showed that it is critical for organizations to adopt a balanced view between green design and product functions. Hu and Hsu [36] and Barari et al. [26] found that it is necessary to consider various factors in designing a product or service in an environmentally sustainable manner including: (a) avoiding utilizing toxic substances; (b) reducing the use of energy; (c) meeting the requirement for disassembly, reuse, and recycling; and (d) increasing innovation capabilities of an organization. Sarkis [37] and Shen et al. [16] proved that green design can help organizations to minimize waste and improve the environmental performance by designing the functionality of products and minimizing the environmental impact. Mangla et al. [38] believed that green design can minimize the ecological effect of a new product throughout the entire lifecycle of the product without compromising on the functionality. Overall green design can be approached from several perspectives including: (a) environmental risk management; (b) pollution prevention; (c) resource conservation; (d) product safety; and (e) waste management.

Green purchasing is related to the ability of an organization to procure products and services that minimize the negative environmental impact over the lifecycle of the product and services [16]. It involves identifying, selecting and purchasing products and services with less adverse environmental impacts than competing products and services. Green purchasing considers the environmental characteristics of a product in all stages of the life-cycle [34]. It enables organizations to establish environmental standards in their purchasing policies for improving GSCM.

The importance of green purchasing is well recognized in existing literature. Sarkis [37], for example, believed that green purchasing is about waste reduction, environmental material substitution, and hazardous material minimization. Vachon and Klassen [12] stated that the performance of green supply chains is dependent on the ability of an organization to adopt green design and green purchasing. Shen et al. [16] indicated that green purchasing significantly eliminates waste, therefore improving the performance of GSCM. Lee et al. [39] pointed out that organizations need to improve green purchasing initiatives for better achieving the economic and operational goals. Luthra et al. [40] emphasized the importance of green purchasing for achieving a positive outcome of GSCM practices. An investigation of the related literature shows that green purchasing is usually measured by: (a) green competencies; (b) green image; and (c) green management abilities of individual suppliers.

Green manufacturing is the production of products that can minimize the natural resources use and improve recycling and reusing [9]. It focuses on utilizing greener sources of energy via the adoption of latest technologies in the daily operations of an organization. Furthermore, green manufacturing is about reducing pollution and wastes while improving the efficiency of the operations of an organization [25]. Azevedo et al. [35] and Barari et al. [26], for example, showed that green manufacturing should consider the willingness of an organization to develop green products while reducing the negative environmental impact of the manufacturing process. Chen et al. [41] pointed out that green manufacturing is directly related to the selection and use of the right materials in an organization. Thanki et al. [17] believed that green manufacturing can enhance the market share, the competitive advantage and the green image of an organization. Govindan et al. [8] stated that effective green manufacturing helps to improve business performance of an organization in a dynamic global market. In general, green manufacturing is reflected by: (a) the green energy utilization; (b) the degree of green energy; (c) the reduction of hazardous waste; and (d) the reuse of hazardous waste.

Green marketing is about the initiative that an organization takes for promoting the green characteristics of its products and services for reducing the negative environmental impact [25]. It is a strategic activity in an organization that involves in green logistics and green alliances through manipulating segmenting, targeting, and positioning in addition to the traditional marking principles such as product, price, place, and promotion [26]. Ginsberg and Bloom [42], for example, pointed out that it is important for organizations to implement green marketing strategies by continuously: (a) interacting with customers; and (b) increasing the credibility of products and services. Carter and Ellram [43] believed that organizations need to continuously interact with government, suppliers, customers, and even competitors for improving the sustainability development of the supply chain. Zhu et al. [25] claimed that the cooperation with suppliers and customers is critical for organizations to close the supply chain loop towards sustainability development. Linton et al. [44] and Zhu et al. [45] stated that GSCM practices should be evaluated based on the effective communication of an organization with suppliers and customers on sustainability development in the delivery of products and services. Fang and Zhang [46] believed that organizations need to collaborate with customers to reduce the total cost, decrease the lead time and improve the satisfaction of customers. In general, green marketing is measured by: (a) the use of information and communication technologies; (b) the transparency of the disclose of environmental information of products and services; (c) the willingness of extending producers' responsibility; and (d) the provision of education and training on the benefits of green products and services. A summary of the critical criteria for determining the performance of GSCM practices in an organization is shown in Table 1.

Table 1. Criteria for Determining the Performance of GSCM Practices.

Criteria	References
Green design	[9,10,14,16,25,26,31,34–38,44]
Green purchasing	[10,12,16,34,37,39,40]
Green manufacturing	[8,9,14,17,25,26,41]
Green marketing	[25,26,42,43,45–47]

In selecting the most appropriate GSCM practice in an organization, every available GSCM practice has to be comprehensively evaluated with respect to the criteria and their associated sub-criteria in a holistic manner for determining their overall performance across all the evaluation criteria in a specific situation. Furthermore, various stakeholders are presented in such an evaluation process due to the nature of the GSCM process and the existence of uncertainty. To effectively solve this problem, the next section presents an interactive fuzzy multi-criteria group decision making model for evaluating the performance of GSCM practices in an organization.

3. A Fuzzy Multi-Criteria Group Decision Making Model

Multi-criteria group decision making involves several decision makers in prioritizing and ranking available alternatives with respect to multiple, often conflicting criteria [17,48–51]. Evaluating and selecting specific GSCM practices in an organization usually consists of several activities. First, all the alternatives and the evaluation criteria have to be identified. The performance rating of the GSCM practice alternatives and the weight of the evaluation criteria and their associated sub-criteria if existent then have to be determined. Finally, the alternative rating and the criteria weight have to be aggregated for determining the overall performance index value for each alternative across all the criteria, on which the best alternative can be selected.

Uncertainty is always present in human decision making. It is usually existent due to the presence of subjectiveness and imprecision [1]. To better model the uncertainty, intuitionistic fuzzy numbers [52,53] are used for representing the assessments of the decision maker. This is due to: (a) the appropriateness of intuitionistic fuzzy numbers in tackling the uncertainty in decision-making; and (b) the simplicity of representing subjective assessments with the use of membership degree and non-membership degree [54,55].

The proposed model starts with assessing the performance rating of each GSCM practice alternative A_i ($i = 1, 2, \ldots, n$) with respect to each criterion C_j ($j = 1, 2, \ldots, m$). To facilitate the subjective assessment process, intuitionistic preference relations $y_{ij}^k = (\mu_{ij}^k, v_{ij}^k)$ are used to represent the assessment of the decision maker D_k ($k = 1, 2, \ldots, s$) with respect to criterion C_j in which $0 \leq \mu_{ij}^k + v_{ij}^k \leq 1$, $\mu_{ij}^k = v_{ij}^k, v_{ij}^k = \mu_{ij}^k = 0.5$. In this situation, μ_{ij}^k indicates the degree that alternative A_i satisfies criterion C_j, while v_{ij}^k describes the degree that alternative A_i does not satisfy criterion C_j. As a result, the decision matrix for each decision maker in this problem can be determined as follows

$$y_{ij}^k = \begin{bmatrix} \mu_{11}^k, v_{11}^k & \mu_{12}^k, v_{12}^k & \cdots & \mu_{1m}^k, v_{1m}^k \\ \mu_{21}^k, v_{21}^k & \mu_{22}^k, v_{22}^k & \cdots & \mu_{2m}^k, v_{2m}^k \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{n1}^k, v_{n1}^k & \mu_{n2}^k, v_{n2}^k & \cdots & \mu_{nm}^k, v_{nm}^k \end{bmatrix} \tag{1}$$

With the determination of the subjective assessments as above, the consensus among the decision makers needs to be assessed [56]. In this situation, a distance-based similarity measure is proposed [1,56]. It is used to describe the closeness between the fuzzy assessments of a decision maker and the group fuzzy assessments for all the alternatives. This leads to the determination of the degree of consensus between a decision maker' assessments r_{ij}^k and the group assessments m_{ij} for alternative performance ratings on each criterion as follows

$$S_i^k = \left| r_{ij}^k - m_{ij} \right| \tag{2}$$

where $r_{ij}^k = (\mu_{ij}^k, v_{ij}^k)$, $m_{ij} = (\mu_{ij}, v_{ij})$, $\mu_{ij} = \dfrac{\sum\limits_{k=1}^{s} \mu_{ij}^k}{s}$, and $v_{ij} = \dfrac{\sum\limits_{k=1}^{s} v_{ij}^k}{s}$ ($i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; k = 1, 2, \ldots, s$).

To determine whether a decision maker has reached the group consensus, a consensus threshold value δ can be used. If $S_i^k \geq \delta$, this means that the decision maker must change the assessments. Through such interactive changes and modifications, the consensus value of individual decision makers can be lower than the specified consensus threshold, and therefore the consensus development process can stop.

The relative importance of the criteria can be determined subjectively by the decision maker using intuitionistic fuzzy numbers represented as $w_j^k = (\mu_j^k, v_j^k)$. μ_j^k indicates the degree to which criterion C_j is considered as important. v_j^k describes the degree to which criterion C_j is deemed to

be unimportant. To facilitate the decision-making process, the criteria weight w_j can be normalized as follows

$$w_j = \frac{E(w_j^k)}{\sum_{j=1}^{m} E(w_j^k)} \tag{3}$$

where

$$E(w_j^k) = \frac{\mu_j^k + v_j^k}{2}. \tag{4}$$

To prioritize and rank all the alternatives, the subjective assessments should be aggregated. To facilitate the aggregation process, the intuitionistic fuzzy hybrid geometric averaging (IFHGA) operator [56] is introduced for determining the overall intuitionistic fuzzy performance r_i of the alternative A_i, shown as in Equation (5).

$$r_i = (\mu_{ri}, v_{ri}) = IFHGA(a_1, a_2, \ldots, a_n) = \left\langle 1 - \prod_{i=1}^{n} (1 - \mu_{r_{ij}})^{w_i}, \prod_{i=1}^{n} (1 - \mu_{r_{ij}})^{w_i} - \prod_{i=1}^{n} (1 - \mu_{r_{ij}} - v_{r_{ij}})^{w_i} \right\rangle \tag{5}$$

With the use of the score function [57], the performance index value of each alternative with respect to all the criteria can be determined as

$$S(r_i) = \mu_{r_i} - v_{r_i} \tag{6}$$

where $S(r_i) \in [-1, 1]$. The larger the $S(r_i)$ is, the more preferred the alternative is.

The procedure for the proposed model as above can be summarized as follows.

Step 1   Obtain the decision matrix from each decision maker as expressed in Equation (1).
Step 2   Assess the consensus among the decision makers by Equation (2).
Step 3   Determine the relative importance of the criteria as expressed in Equations (3) and (4).
Step 4   Calculate the performance of each alternative from all decision makers as in Equation (5).
Step 5   Compute the performance index value for each alternative across criteria by Equation (6).
Step 6   Rank the alternatives in descending order of their performance index values.

4. An Example

This section presents an example of evaluating the available GSCM practices for ensuring that the best GSCM practice can be selected in an organization.

Due to the intense competition and the presence of the networked market, a reputable company in Taiwan is considering a green supply chain initiative for improving its performance [10]. The company is one of the largest professional printed circuit board manufacturers in Taiwan. It is developing the next generation of technology for enhancing its competitiveness. Due to the increasing market pressure, the company needs to develop green products for satisfying the changing market situation. This leads to the consideration of the implementation of a proper GSCM practice in the organization.

Three top managers from three functional departments within the organization are involved in assessing the GSCM practices represented as D_1, D_2, and D_3. A series of meetings have been held. This leads to the identification of four criteria for evaluating the four GSCM practices in an organization. These criteria include the Green Design (C_1), Green Manufacturing (C_2), Green Purchasing (C_3), and Green Marketing (C_4). The hierarchical structure of GSCM practice evaluation is shown in Figure 1.

Green Design (C_1) is related to the capability of an organization to reduce the negative impact on the environment through product designs [4,57]. This is often measured by the ability of the organization to minimize using toxic substances, meet sustainability principles, increase innovation capabilities, and reduce energy use in the operations of the organization.

Green manufacturing (C_2) considers the enhancement of the production processes for reducing the generation of toxic matter [58]. It requires an organization to produce products with less waste and less pollution. This is often measured by the amount of resources used, the greenness of the energy, and the reduction of hazardous waste [11,59].
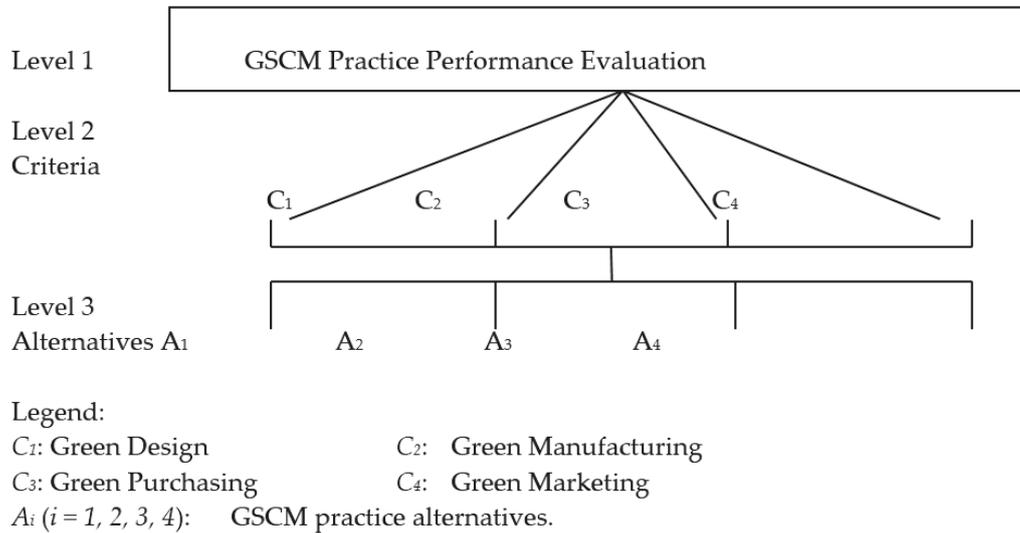
Level 1   GSCM Practice Performance Evaluation

Level 2
Criteria

C_1 C_2 C_3 C_4

Level 3
Alternatives A_1 A_2 A_3 A_4

Legend:
C_1: Green Design C_2:   Green Manufacturing
C_3: Green Purchasing C_4:   Green Marketing
A_i (*i = 1, 2, 3, 4*):   GSCM practice alternatives.

Figure 1. The Hierarchical Structure of GSCM Practice Evaluation.

Green Purchasing (C_3) is about the practice of sourcing and purchasing products and services that are less damaging to the environment than their substitutes [6]. Several factors including the green image, the green competency, and the green management ability are usually considered in this regard [12,26].

Green Marketing (C_4) is about promoting the green characteristics of products and services that are safe for individuals and environments [60]. This is often measured through the adoption of information and communication technologies in marketing and the provision of education and training on the benefits of green products and services [10,60].

With the determination of the alternatives and the criteria as above, the performance rating of all available alternatives with respect to each criterion from decision makers D_1, D_2, and D_3 can be determined as in Table 2.

Table 2. Performance Assessments of GSCM Practices.

	Alternative A_1			Alternative A_2			Alternative A_3			Alternative A_4		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
C_1	(0.91, 0.05)	(0.48, 0.43)	(0.58, 0.27)	(0.57, 0.27)	(0.60, 0.32)	(0.57, 0.34)	(0.43, 0.48)	(0.57, 0.27)	(0.67, 0.16)	(0.70, 0.17)	(0.62, 0.32)	(0.62, 0.32)
C_2	(0.70, 0.24)	(0.75, 0.16)	(0.75, 0.18)	(0.95, 0.03)	(0.77, 0.14)	(0.75, 0.18)	(0.62, 0.32)	(0.65, 0.29)	(0.18, 0.74)	(0.57, 0.27)	(0.75, 0.18)	(0.71, 0.19)
C_3	(0.55, 0.37)	(0.67, 0.16)	(0.60, 0.32)	(0.62, 0.32)	(0.42, 0.52)	(0.63, 0.34)	(0.48, 0.39)	(0.71, 0.19)	(0.57, 0.27)	(0.48, 0.39)	(0.86, 0.04)	(0.60, 0.32)
C_4	(0.49, 0.36)	(0.63, 0.34)	(0.42, 0.52)	(0.84, 0.11)	(0.84, 0.14)	(0.62, 0.32)	(0.15, 0.83)	(0.55, 0.37)	(0.48, 0.39)	(0.75, 0.22)	(0.67, 0.16)	(0.42, 0.52)

In this situation, the consensus threshold is set at 0.65. Based on all the information provided, the similarity between individual decision makers' assessments and the group assessments can be calculated by Equation (2). The results are shown in Table 3.

Table 3. The Degree of Similarity of Individual Decision Makers.

Alternatives	Decision Makers	Degree of Similarity
	D_1	0.32
A_1	D_2	0.57
	D_3	0.49
	D_1	0.48
A_2	D_2	0.51
	D_3	0.34
	D_1	0.53
A_3	D_2	0.31
	D_3	0.52
	D_1	0.39
A_4	D_2	0.42
	D_3	0.51

Table 3 shows that the familiarity values of individual decision makers are lower than the threshold value of 0.65. As a result, there is no need for developing consensus further. With the achievement of the consensus, the weights of the criteria need to be determined by the decision maker. Table 4 shows the results.

Table 4. Criteria Weights.

Criteria	Weights
C_1	(0.67, 0.21)
C_2	(0.80, 0.11)
C_3	(0.37, 0.48)
C_4	(0.60, 0.30)

Based on this information, the criteria weight vector w_j can be calculated using Equations (3) and (4). The resulted criteria weights are determined as W_j = (0.2451, 0.2563, 0.2422, 0.2564).

With the use of Equations (5) and (6), the performance index value of each alternative with respect to all the criteria and its corresponding ranking can be determined. Table 5 shows the results. It shows that alternative A_2 has the best performance with the highest performance index value of 0.675.

Table 5. The Performance Index Value and the Ranking of GSCM Practices Alternatives.

Alternative	Performance Index Value	Ranking
A_1	0.608	3
A_2	0.675	1
A_3	0.587	4
A_4	0.642	2

To demonstrate the merits of the proposed model, a comparative study is conducted. Five other models [47,61–66] are used. The results shown in Table 6 reveal that the proposed model produces consistent ranking results as compared to other comparable models. This demonstrates that the proposed model is effective due to its simplicity in concept and its efficiency in computation.

Table 6. An Overview of the Comparative Study.

Models	Ranking
Hung and Yang [61]	$A_4 > A_2 > A_3 > A_1$
Lin et al. [44]	$A_4 > A_2 > A_3 > A_1$
Xia and Xu [64]	$A_2 > A_4 > A_3 > A_1$
Wibowo and Deng [63]	$A_2 > A_4 > A_1 > A_3$
Ren and Liang [62]	$A_2 > A_4 > A_1 > A_3$
The proposed algorithm	$A_2 > A_4 > A_1 > A_3$

5. Conclusions

Evaluating the performance of available GSCM practices in an organization is not an easy task. This is because such an evaluation involves several decision makers and multiple criteria with the presence of uncertainty in the group decision making process. This paper has presented a multi-criteria group decision making model for effectively evaluating the performance of GSCM practices in an organization. The uncertainty of the evaluation process is adequately modeled by using intuitionistic fuzzy numbers. A fuzzy multi-criteria group decision making model is developed for evaluating the performance of GSCM practices in an organization. The example presented shows that this developed model is capable of effectively and efficiently solving the multi-criteria group decision making problem. It can help organizations to better understand the performance of GSCM practices for improving their overall sustainability development performance.

There are several limitations in this study. One is to do with the dependency of the decision outcome on the inputs of the decision maker. This is to do with the way that this problem is formulated. Another is about the need for considering tangible and intangible benefits and costs together in evaluating the available GSCM practices. Future research can be carried out to better deal with these two issues through the proper use of organizational data and knowledge in the evaluation and the development of continuous optimization models for addressing the performance evaluation problem.

References

1. Deng, H. Multicriteria analysis for benchmarking sustainability development. *Benchmark. Int. J.* **2015**, *22*, 791–807. [CrossRef]
2. Gallego, I. The use of economic, social and environmental indicators as a measure of sustainable development in Spain. *Corp. Soc. Responsib. Environ. Manag.* **2006**, *13*, 78–97. [CrossRef]
3. Magee, L.; Scerri, A.; James, P.; Thom, J.A.; Padgham, L.; Hickmott, S.; Cahill, F. Reframing social sustainability reporting: Towards an engaged approach. *Environ. Dev. Sustain.* **2013**, *15*, 225–243. [CrossRef]
4. Lin, R.J. Using fuzzy DEMATEL to evaluate the green supply chain management practices. *J. Clean. Prod.* **2013**, *40*, 32–39. [CrossRef]
5. Tseng, M.L. Green supply chain management with linguistic preferences and incomplete information. *Appl. Soft Comput.* **2011**, *11*, 4894–4903. [CrossRef]
6. Tseng, M.L.; Chiu, A.S.F. Grey-entropy analytical network process for green innovation practices. *Proced. Soc. Behav. Sci.* **2012**, *57*, 10–21. [CrossRef]
7. Sarkis, J. A boundaries and flows perspective of green supply chain management. *Supply Chain Manag. Int. J.* **2012**, *17*, 202–216. [CrossRef]

8.   Govindan, K.; Rajendran, S.; Sarkis, J.; Murugesan, P. Multi criteria decision making approach for green supplier evaluation and selection: A literature review. *J. Clean. Prod.* **2015**, *98*, 66–83. [CrossRef]

9.   Sharma, V.K.; Chandna, P.; Bhardwaj, A. Green supply chain management related performance indicators in agro industry: A review. *J. Clean. Prod.* **2017**, *141*, 1194–1208. [CrossRef]

10. Diabat, A.; Govindan, K. An analysis of the drivers affecting the implementation of green supply chain management. *Resour. Conserv. Recycl.* **2011**, *55*, 659–667. [CrossRef]

11. Ahi, P.; Searcy, C. A comparative literature analysis of definitions for green and sustainable supply chain management. *J. Clean. Prod.* **2013**, *52*, 329–341. [CrossRef]

12. Vachon, S.; Klassen, D. Extending green practices across the supply chain: The impact of upstream and downstream integration. *Int. J. Oper. Prod. Manag.* **2006**, *26*, 795–821. [CrossRef]

13. Dwivedy, M.; Mittal, R.K. Willingness of residents to participate in e-waste recycling in India. *Environ. Dev.* **2013**, *6*, 48–68. [CrossRef]

14. Azevedo, S.G.; Carvalho, H.; Machado, V.C. The influence of green practices on supply chain performance: A case study approach. *Transp. Res. Part E Logist. Transp. Rev.* **2011**, *47*, 850–871. [CrossRef]

15. Kannan, G.; Pokharel, S.; Kumar, P.S. A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. *Resour. Conserv. Recycl.* **2009**, *54*, 28–36. [CrossRef]

16. Shen, L.; Olfat, L.; Govindan, K.; Khodaverdi, R.; Diabat, A. A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. *Resour. Conserv. Recycl.* **2013**, *74*, 170–179. [CrossRef]

17. Thanki, S.; Govindan, K.; Thakkar, J. An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. *J. Clean. Prod.* **2016**, *135*, 284–298. [CrossRef]

18. Wibowo, S.; Deng, H. Intelligent decision support for effectively evaluating and selecting ships under uncertainty in marine transportation. *Expert Syst. Appl.* **2012**, *39*, 6911–6920. [CrossRef]

19. Deng, H. Multicriteria analysis with fuzzy pairwise comparison. *Int. J. Approx. Reason.* **1999**, *21*, 215–231. [CrossRef]

20. Yeh, C.H.; Deng, H.; Chang, Y.H. Fuzzy multicriteria analysis for performance evaluation of bus companies. *Eur. J. Oper. Res.* **2000**, *126*, 1–15. [CrossRef]

21. Roghanian, E.; Sadjadi, S.J.; Aryanezhad, M.B. A probabilistic bi-level linear multiobjective programming problem to supply chain planning. *Appl. Math. Comput.* **2007**, *188*, 786–800.

22. Torabi, S.A.; Hassini, E. An interactive possibilistic programming approach for multiple objective supply chain master planning. *Fuzzy Sets Syst.* **2008**, *159*, 193–214. [CrossRef]

23. Pinto-Varela, T.; Barbosa-Povoa, A.P.; Novais, A.Q. Bi-objective optimization approach to the design and planning of supply chains: Economic versus environmental performances. *Comput. Chem. Eng.* **2011**, *35*, 1454–1468. [CrossRef]

24. Liu, S.; Papageorgiou, L.G. Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry. *Omega* **2013**, *41*, 369–382. [CrossRef]

25. Zhu, Q.; Sarkis, J.; Lai, K. Confirmation of a measurement model for green supply chain management practices implementation. *Int. J. Prod. Econ.* **2008**, *111*, 261–273. [CrossRef]

26. Barari, S.; Agarwal, G.; Zhang, W.J.; Mahanty, B.; Tiwari, M.K. A decision framework for the analysis of green supply chain contracts: An evolutionary game approach. *Expert Syst. Appl.* **2012**, *39*, 2965–2976. [CrossRef]

27. Bowen, F.E.; Cousins, P.D.; Lamming, R.C.; Faruk, A.C. The role of supply management capabilities in green supply. *Prod. Oper. Manag.* **2001**, *10*, 174–189. [CrossRef]

28. Mumtaz, U.; Ali, Y.; Petrillo, A. A linear regression approach to evaluate the green supply chain management impact on industrial organizational performance. *Sci. Total Environ.* **2018**, *624*, 162–169. [CrossRef] [PubMed]

29. Wu, G.C. The influence of green supply chain integration and environmental uncertainty on green innovation in Taiwan's IT industry. *Supply Chain Manag. Int. J.* **2013**, *18*, 539–552. [CrossRef]

30. Zhu, Q.; Sarkis, J. Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *J. Oper. Manag.* **2004**, *22*, 265–289. [CrossRef]

31. Sheu, J. Buyer behavior in quality-dominated multi-sourcing recyclable material procurement of green supply chains. *Prod. Oper. Manag.* **2016**, *25*, 477–497. [CrossRef]

32. Arena, U.; Mastellone, M.L.; Perugini, F. The environmental performance of alternative solid waste management options: A lifecycle assessment study. *Chem. Eng. J.* **2003**, *96*, 207–222. [CrossRef]

33. Kopicki, R.; Berg, M.J.; Legg, L.; Dasppa, V.; Maggioni, C. *Reuse and Recycling-Reverse Logistics Opportunities*; Council of Logistics Management: Oak Brook, IL, USA, 1993.

34. Rao, P.; Holt, D. Do green supply chains lead to competitiveness and economic performance? *Int. J. Oper. Prod. Manag.* **2005**, *25*, 898–916. [CrossRef]

35. Awasthi, A.; Chauhan, S.S.; Goyal, S.K. A fuzzy multicriteria approach for evaluating environmental performance of suppliers. *Int. J. Prod. Econ.* **2010**, *126*, 370–378. [CrossRef]

36. Hu, H.; Hsu, C.W. Critical factors for implementing green supply chain management practice: An empirical study of electrical and electronics industries in Taiwan. *Manag. Res. Rev.* **2010**, *33*, 586–608. [CrossRef]

37. Sarkis, J. *Greening Supply Chain Management*; GMI 35 Autumn; Greenleaf Publishing: Melbourne, Australia, 2001.

38. Mangla, S.; Govindan, K.; Luthra, S. Critical success factors for reverse logistics in Indian industries: A structural model. *J. Clean. Prod.* **2016**, *129*, 608–621. [CrossRef]

39. Lee, V.H.; Ooi, K.B.; Chong, A.Y.; Seow, C. Creating technological innovation via supply chain management: An empirical analysis. *Expert Syst. Appl.* **2014**, *41*, 6983–6994. [CrossRef]

40. Luthra, S.; Garg, D.; Haleem, A. Green supply chain management: Implementation and performance—A literature review and some issues. *J. Adv. Manag. Res.* **2014**, *11*, 20–46. [CrossRef]

41. Chen, C.C.; Shih, H.S.; Shyur, H.J.; Wu, K.S. A business strategy selection of green supply chain management via an analytic network process. *Comput. Math. Appl.* **2012**, *64*, 2544–2557. [CrossRef]

42. Ginsberg, J.M.; Bloom, P.N. Choosing the right green marketing strategy. *MIT Sloan Manag. Rev.* **2004**, *46*, 79–84.

43. Carter, C.R.; Ellram, L.M. Reverse logistics: A review of the literature and framework for future investigation. *J. Bus. Logist.* **1998**, *19*, 85–102.

44. Lin, L.; Yuan, X.H.; Xia, Z.Q. Multicriteria fuzzy decision-making methods based on intuitionistic fuzzy sets. *J. Comput. Syst. Sci.* **2007**, *73*, 84–88. [CrossRef]

45. Zhu, Q.; Sarkis, J.; Lai, K. Institutional-based antecedents and performance outcomes of internal and external green supply chain management practices. *J. Purchas. Supply Manag.* **2013**, *19*, 106–117. [CrossRef]

46. Fang, C.; Zhang, J. Performance of green supply chain management: A systematic review and meta analysis. *J. Clean. Prod.* **2018**, *183*, 1064–1081. [CrossRef]

47. Linton, J.D.; Klassen, R.; Jayaraman, V. Sustainable supply chains: An introduction. *J. Oper. Manag.* **2007**, *25*, 1075–1082. [CrossRef]

48. Park, J.H.; Cho, H.J.; Kwun, Y.C. Extension of the VIKOR method to dynamic intuitionistic fuzzy multiple attribute decision making. *Comput. Math. Appl.* **2013**, *65*, 731–744. [CrossRef]

49. Qin, J.; Liu, X.; Pedrycz, W. An extended TODIM multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment. *Eur. J. Oper. Res.* **2017**, *258*, 626–638. [CrossRef]

50. Wibowo, S.; Deng, H. Consensus-based decision support for multicriteria group decision making. *Comput. Ind. Eng.* **2013**, *66*, 625–633. [CrossRef]

51. Yeh, C.H.; Deng, H.; Wibowo, S.; Xu, Y. Fuzzy multicriteria decision support for information systems project selection. *Int. J. Fuzzy Syst.* **2010**, *12*, 170–179.

52. Chen, Z.; Yang, W. A new multiple attribute group decision making method in intuitionistic fuzzy setting. *Appl. Math. Model.* **2011**, *35*, 4424–4437. [CrossRef]

53. Tan, C.; Deng, H. A multi-criteria group decision making procedure using interval-valued intuitionistic fuzzy sets. *J. Comput. Inf. Syst.* **2010**, *6*, 855–863.

54. Wang, W.; Liu, X. The multi-attribute decision making method based on interval-valued intuitionistic fuzzy Einstein hybrid weighted geometric operator. *Comput. Math. Appl.* **2013**, *66*, 1845–1856. [CrossRef]

55. Zhao, H.; Xu, Z.S.; Ni, M.F.; Liu, S.S. Generalized aggregation operators for intuitionistic fuzzy sets. *Int. J. Intell. Syst.* **2010**, *25*, 1–30. [CrossRef]

56. Herrera-Viedma, E.; Alonso, S.; Chiclana, F.; Herrera, F. A consensus model for group decision making with incomplete fuzzy preference relations. *IEEE Trans. Fuzzy Syst.* **2007**, *15*, 863–877. [CrossRef]

57. Chen, S.M.; Tan, J.M. Handling multicriteria fuzzy decision making problems based on vague set theory. *Fuzzy Sets Syst.* **1994**, *67*, 163–172. [CrossRef]

58. Yang, M.G.; Hong, P.; Modi, S.B. Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms. *Int. J. Prod. Econ.* **2011**, *129*, 251–261. [CrossRef]

59.　Gualandris, J.; Kalchschmidt, M. Customer pressure and innovativeness: Their role in sustainable supply chain management. *J. Purchas. Supply Manag.* **2014**, *20*, 92–103. [CrossRef]

60.　Glover, J.L.; Champion, D.; Daniels, K.J.; Dainty, A.J.D. An institutional theory perspective on sustainable practices across the dairy supply chain. *Int. J. Prod. Econ.* **2014**, *152*, 102–111. [CrossRef]

61.　Hung, W.L.; Yang, M.S. Similarity measures of intuitionistic fuzzy sets based on Hausdorff distance. *Pattern Recogn. Lett.* **2004**, *25*, 1603–1611. [CrossRef]

62.　Ren, J.; Liang, H. Multi-criteria group decision-making based sustainability measurement of wastewater treatment processes. *Environ. Impact Assess. Rev.* **2017**, *65*, 91–99. [CrossRef]

63.　Wibowo, S.; Deng, H. Multi-criteria group decision making for evaluating the performance of e-waste recycling programs under uncertainty. *Waste Manag.* **2015**, *40*, 127–135. [CrossRef] [PubMed]

64.　Xia, M.; Xu, Z. Hesitant fuzzy information aggregation in decision making. *Int. J. Approx. Reason.* **2011**, *52*, 395–407. [CrossRef]

65.　Chen, S.M.; Chang, C.H. Fuzzy multiattribute decision making based on transformation techniques of intuitionistic fuzzy values and intuitionistic fuzzy geometric averaging operators. *Inf. Sci.* **2016**, *352–353*, 133–149. [CrossRef]

66.　Beske, P.; Land, A.; Seuring, S. Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature. *Int. J. Prod. Econ.* **2014**, *152*, 131–143. [CrossRef]