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A Framework to Design and Evaluate Green Contract Mechanisms for Forestry Supply Chains

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Abstract: Green contracting mechanisms are utilized to integrate sustainable and environmentally protective goals into business objectives. This study proposes a framework for the design of green contract mechanisms in forestry supply chain management. We assumed that there was an applicant for harvesting timber in a forest, and that the owner tried to evaluate different scenarios to design a green contracting mechanism. We also assumed that the owner of a forest cared about green goals, such as carbon dioxide absorption, in the forest. We regarded the interests of the parties, such as the profit of the applicant as well as the green goals of the forest owner. We used multi-attribute decision-making techniques such as the weighted sum, normalized weighted sum, TOPSIS, and VIKOR to evaluate the various scenarios. In the literature, another approach was taken to solve a similar problem based on multi-objective techniques and the Pareto optimality concept. We compared the outcomes of the determined framework with the outputs of the previously employed methods. The recommended framework can provide more interpretable results since it considers the interests of different sides. The framework can assist businesses in designing contracts that promote sustainable operations and support compliance with the United Nations' Sustainable Development Goals.

Keywords: green contract mechanism; supply chain management; timber harvesting; TOPSIS; VIKOR; multi-attribute decision-making

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1. Introduction

Sustainability is a mainstay in a contemporary business environment [1]. Thus, the transformation of an organization's traditional supply chain management (SCM) approaches into sustainable practices has become paramount [1,2]. Compliance with the United Nations' Sustainable Development Goals (SDGs) is indispensable for achieving sustainable development and ensuring a better future [3]. One of the most vital tools for achieving these goals is a green contract mechanisms (GCM). GCMs provide a base for the implementation of environmentally sustainable practices in the various stages of a supply chain, including sourcing, production, transportation, and distribution [4,5].

Planning timber harvesting is one of the essential phases in the forestry supply chain, and it seriously impacts income and leads to significant environmental issues, such as carbon dioxide emissions. Influential studies have been conducted on this problem, with authors proposing alternative models to maximize profit, carbon dioxide absorption, and harvesting from trees of different sizes [6–8]. In real life, however, the different parties in this problem, such as the harvester and the forest owner, are neglected. Therefore, it may be helpful to regard this problem in terms of the contract mechanisms. Nevertheless, this problem has not been evaluated from this perspective. In addition, in the literature, the outputs of this problem were interpreted based on the Pareto optimality, conceptually, and multi-attribute decision-making (MADM) techniques, which could be more appropriate for this purpose.

Integrating GCMs and MADM techniques in timber harvesting planning can significantly contribute to the sustainable development of the forestry supply chain. This integration can lead to a shared responsibility for sustainable practices among all the parties involved. Furthermore, the application of the MADM techniques can enable a more comprehensive evaluation of the different attributes of timber harvesting beyond only profit or carbon absorption. The MADM techniques can facilitate more informed and sustainable decision-making by considering multiple points. Ultimately, combining GCMs and MADM techniques can lead to a more sustainable and inclusive forestry supply chain, contributing to achieving the SDGs related to responsible consumption and production, climate action, and partnerships for sustainable development. In this study, this is indicated by numerical outcomes. This paper addresses the shortcomings of the previous research on timber harvesting planning by examining the problem through the lens of contract mechanisms, an underexplored area in the literature. By integrating GCMs and MADM techniques, the proposed framework offers a more comprehensive approach for evaluating the different attributes of timber harvesting. This approach facilitates more informed and sustainable decision-making, contributing to the sustainable development of the forestry supply chain.

In the other sections of this work, following a literature review on the subject, the problem is defined and the proposed framework is explained. In the experimental results section, the usefulness of the proposed framework is shown through an example. The conclusion and future works comprise the final part of the study.

2. Literature Review

In recent years, there has been growing concern about the impact of business activities on the environment. As a result, there has been an increased focus on integrating sustainable practices into various business functions. One area of particular interest has been SCM, which involves coordinating activities across various organizations to ensure the delivery of goods and services to customers [1,2].

The development of SCM has paved the way for the emergence of green SCM, which aims to integrate environmental concerns into the inter-organizational practices of SCM. Green SCM practices include green supply, ecological purchasing, environmental operations management, and reverse logistics. These practices have been found to positively impact ecological performance, measured by outcomes such as reducing waste and emissions, consuming resources and toxic materials, and compliance with environmental standards [9,10].

Green SCM benefits businesses and the environment and contributes to achieving the United Nations Sustainable Development Goals (SDGs). This aligns with several SDGs, including SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). For example, by reducing waste and emissions, green SCM practices contribute to SDG 12 and SDG 13 while promoting sustainable consumption and production. Furthermore, green SCM practices can enhance the reputation of organizations that align with the SDGs and demonstrate their commitment to sustainable development. Thus, integrating green SCM practices can be beneficial for achieving the SDGs and creating a more sustainable future [3].

GCMs can play a crucial role in the implementation of green SCM operations. GCMs, provide a legally binding agreement between two or more parties that outlines the terms and conditions for implementing environmentally sustainable practices in the supply chain. By characterizing each party's expectations and responsibilities, GCMs can help ensure sustainable practices are implemented consistently and effectively [9]. One study by Gao et al. [10] realized that GCMs could lead to improved environmental performance in the supply chain as well as increased efficiency and cost savings. The authors suggested that using such contracts can help create a "win–win" situation for both the contracting parties and the environment. Another study by Wang et al. [11] investigated the role of GCMs in promoting sustainable SCM. The authors identified that such contracts could help align the interests of different stakeholders in the supply chain and promote trust and cooperation between the suppliers and buyers.

Some challenges to implementing GCMs in the supply chain have also been identified in the literature. For instance, a study by Agyemang et al. [12] found that the lack of standardization and clear definitions of "green" practices can make it challenging for companies to create effective contracts. Further, the authors noted that the high costs associated with implementing sustainable practices could hinder the widespread adoption of GCMs.

In this context, various models and decision-making frameworks have been developed to support the implementation of such contracts. For example, one study by Yin and Zhang [13] proposed a multi-criteria decision-making model to help companies evaluate the feasibility and benefits of GCMs. The model considers factors such as environmental performance, cost savings, and legal compliance in the decision-making process. Another study by Li et al. [14] suggested a game-theoretic model analyze the negotiation process of GCMs between the suppliers and buyers. The authors found that using such a model can help identify the optimal contract terms for both parties, considering the factors such as the costs of implementing sustainable practices and the potential benefits of improved environmental performance. A study by Wang et al. [15] proposed a decision-making framework for GCMs based on the analytic hierarchy process (AHP). The framework considers multiple criteria, such as the environmental performance, cost savings, legal compliance, economic benefit, and negotiation process to help companies make informed decisions about adopting and implementing GCMs. The work of Wu et al. [16] used the Stackelberg game model to establish the optimal contract price and planting area for agricultural cooperatives and proposed a contract coordination mechanism that enhanced the green innovation level and profits of the cooperatives and enterprise. Benez-Secanho et al. [17] utilized optimization models to compare the economic value of the ecosystem services provided by alternative land allocations for conservation. The study adopted boundary penalties to determine the trade-offs of choosing higher connectivity among parcels regarding the economic values provided by carbon storage, wildlife habitat, and water quality. Martin et al. [18] utilized linear programming to prioritize areas for protection based on multiple conservation objectives and examined how prioritizing multiple, competing objectives affected the individual outcomes.

However, there is a lack of deep understanding in the interest of the different stakeholders and the contractual part of the agreement, which is key to designing effective GCMs that align with the sustainability goals of all the parties involved.

Collaboration among the partners in the supply chain is increasingly vital for the success of a sustainable supply chain. Research has shown that cooperation can enhance the sustainable performance of a supply chain by facilitating the integration of the internal and external resources that can benefit sustainability [15].

Another important aspect that has been extensively explored in other industries but neglected in forestry is the incorporation of price differentiation strategies within GCMs. Price differentiation is a pricing strategy that involves charging different prices for the same product or service based on various factors, such as customer demographics, purchase history, and demand [19].

GCMs with price differentiation can promote sustainable forestry practices that reduce environmental impacts and support social responsibility. For example, GCMs can propose lower prices to suppliers who adopt sustainable practices, such as reduced deforestation, biodiversity conservation, and social responsibility. Price differentiation can also be used to incentivize sustainable practices by offering lower prices or financial rewards for meeting specific environmental or social performance targets [19].

Effective GCMs with price differentiation require the identification of relevant environmental and social performance indicators, the establishment of performance targets and benchmarks, the design of incentive mechanisms, and the monitoring and verification of their performance. By using a GCM framework, suppliers can be incentivized to adopt sustainable practices that align with global sustainability goals. By incorporating environmental and social considerations into contractual relationships and using price differentiation to incentivize sustainable practices, the forestry industry can become more sustainable, reduce its environmental impact, and contribute to achieving the global sustainability goals [19]. This research integrates all these components into the MADM model. Table 1 presents a summary of the main contributions.

Table 1. Literature review summary.

	Environmental Benefits	Stakeholders	Contracts	Differentiated Cost Sharing	Legal Issues
Benez-Secanho et al. [18]	x				
Li et al. [14]	x				
Martin et al. [17]	x				
Wang et al. [15]	x				x
Wu et al. [16]	x				
Yin and Zhang [13]					x
This paper	x	x	x	x	

3. Problem Definition

There are trees of S sizes in a forest and harvests are conducted in T periods. The index of the sizes and related heights are denoted as s and d_s. The number of trees of size s in period t is indicated by $x_{s,t}$ while the amount of the harvest is $h_{s,t}$. During each period t, the fraction of trees that grows to the next size class s + 1 is denoted as $\alpha_{s,t}$ while the fraction of trees that die during this period is shown as $\mu_{s,t}$. The natural regeneration in period t is shown as ϕ_t, which is the number of trees entering the smallest size class. The number of trees at different sizes in period t is represented by Equations (1) and (2). Additionally, Constraints (3), (4), and (5) are valid.

This section provides a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

$$x_{1,t+1} = \phi_t + [1 - \alpha_{1,t} - \mu_{1,t}]x_{1,t} - h_{1,t}, \forall t = 1, \ldots, T \tag{1}$$

$$x_{s+1,t+1} = \alpha_{st}x_{st} + [1 - \alpha_{s+1,t} - \mu_{s+1,t}]x_{s+1,t} - h_{s+1,t}, \forall s = 1, \ldots, S-1, \forall t = 1, \ldots, T \tag{2}$$

$$0 \le h_{s,t} \le x_{s,t}, \forall s = 1, \ldots, S, \forall t = 1, \ldots, T \tag{3}$$

$$0 \le \alpha_{s,t} \le 1, \forall s = 1, \ldots, S, \forall t = 1, \ldots, T \tag{4}$$

$$0 \le \mu_{s,t} \le 1, \forall s = 1, \ldots, S, \forall t = 1, \ldots, T \tag{5}$$

When an applicant applies to the owner of the forest for a harvest, the best contract mechanism is sought, considering different goals. In each period t, the applicant's profit is calculated using Equation (6) where ps, r_s, c_s, cs_s are, respectively, the share given to the owner from the total profit, the obtained revenue, the cost, and the amount given by the owner for the cost-sharing purposes for each size s.

$$p^t = (1 - ps)\sum_{s=1}^{S} (r_s - c_s + cs_s)h_{s,t}, \forall t = 1, \ldots, T \tag{6}$$

In each period, a balanced amount of different sizes from the harvest is desired. This is satisfied by Equation (7) where $\overline{x}_t$ is calculated using Equation (8).

$$de^t = \sqrt{\frac{1}{S}\sum_{s=1}^{S}(x_{s,t} - \overline{x}_t)^2}, \forall t = 1, \ldots, T \tag{7}$$

$$\overline{x}_t = \frac{1}{S}\sum_{s=1}^{S} x_{s,t}, \forall t = 1, \ldots, T \tag{8}$$

The amount of carbon dioxide absorption by a tree in size s is shown as e_s. Therefore, the carbon dioxide absorption amount in period t is calculated using Equation (9).

$$em^t = \sum_{s=1}^{S} e_s x_{s,t+1}, \forall t = 1, \ldots, T \tag{9}$$

As defined in Equation (10), the owner's cost in period t consists of the investment for the natural regeneration and the cost share with the applicant for the harvest. Cf is the unit cost for the natural regeneration.

$$CG^t = Cf\phi_t + \sum_{s=1}^{S} cs_s h_{s,t}, \forall t = 1, \ldots, T \tag{10}$$

The owner's profit is calculated using Equation (11).

$$PG^t = ps\sum_{s=1}^{S} (r_s - c_s + cs_s)h_{s,t} - CG^t, \forall t = 1, \ldots, T \tag{11}$$

The contract's criteria are defined using Equations (12)–(15). Cr_2 should be minimized, while the others should be maximized.

$$Cr_1 = \sum_{t=1}^{T} PG^t \tag{12}$$

$$Cr_2 = \sum_{t=1}^{T} de^t \tag{13}$$

$$Cr_3 = \sum_{t=1}^{T} em^t \tag{14}$$

$$Cr_4 = \sum_{t=1}^{T} p^t \tag{15}$$

It is assumed that Cr_1, Cr_2, and Cr_3 are the owner's goals, while Cr_4 is the applicant's purpose.

3.1. Alternatives for Contracts Mechanisms

To make a contract, the owner considers nine alternatives and anticipates their consequences, which are as follows.

Al_1: Maximizing the profit of the applicant and revenue sharing. The objective function is shown in Equation (16).

$$maxCr_4 \tag{16}$$

The owner doesn't share any cost of the harvest with the applicant, which is stated as $cs_s = 0, \forall s = 1, \ldots, S$.

Al_2: Fixed cost sharing, maximizing the profit of the applicant, and revenue sharing. The objective function is shown in Equation (16). The owner shares a fixed cost of the harvest of all sizes, which is denoted as $cs_s = cs, \forall s = 1, \ldots, S$.

Al_3: Differentiated cost sharing, maximizing the profit of the applicant, and revenue sharing. The objective function is shown in Equation (16). The owner shares a distinct cost with the applicant for the harvest of each size.

Al_4: Maximizing the goals of the owner and revenue sharing. The objective function is shown in Equation (17).

$$max w_2 Cr_1 + w_3 Cr_2 w_4 Cr_3 \tag{17}$$

Al_5: Fixed cost sharing, maximizing the goals of the owner, and revenue sharing. The objective function is shown in Equation (17).

Al_6: Differentiated cost sharing, maximizing the goals of the owner, and revenue sharing. The objective function is shown in Equation (17).

Al_7: Maximizing the goals of the owner as well as maximizing the profit of the applicant and revenue sharing. The objective function is shown in Equation (18).

$$max w_1 Cr_1 - w_2 Cr_2 + w_3 Cr_3 + w_4 Cr_4 \tag{18}$$

Al_8: Fixed cost sharing, maximizing the goals of the owner as well as maximizing the profit of the applicant and revenue sharing. The objective function is shown in Equation (18).

Al_9: Differentiated cost sharing, maximizing the goals of the owner as well as maximizing the profit of the applicant and revenue sharing. The objective function is shown in Equation (18).

3.2. Alternatives Ranking

We used different ranking methods to evaluate the performance of the different parties in meeting the requirements of the GCMs. They are as follows.

- The WS (weighted sum) method evaluates the performance of each party based on a set of predefined criteria and assigned weights—see Kim and De Weck [20].
- The NWS (normalized weighted sum) method is similar to the WS method but normalizes the scores to ensure that all the criteria are on the same scale—see Kim and De Weck [20].
- The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method evaluates the performance of each party based on the similarity of their characteristics to an ideal solution—see Khazaen et al. [21].
- The VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method, a multi-criteria decision-making method, considers both the benefits and drawbacks of each alternative—see Akram et al. [22].

In all the methods mentioned above, the weights are required for the criteria. We created a pairwise comparison matrix for the criteria weights for this aim. The elements of the matrix were normalized using Equation (19). Using the normalized matrix, we acquired the weights of each criterion. For example, in a pairwise comparison matrix with O criteria, the weight of the first criterion was calculated using Equation (20).

$$nw_{1,1} = \frac{w_{1,1}}{\sum_{o=1}^{O} w_{o,1}}, o = 1, \ldots, O \tag{19}$$

$$w_1 = \frac{nw_{1,1} + \ldots + nw_{1,O}}{O} \tag{20}$$

3.3. WS

In the WS method, the decision matrix is created in which each element e_{ao} is the value of alternative a, according to criterion o. Then, to be used in the ranking, the value of each alternative was calculated as $\sum_{o=1}^{O} w_o \times e_{a,o}, a = 1, \ldots, A$.

3.4. NWS

The NWS method is very similar to the WS method, but instead of $e_{a,o}$, it uses $ne_{a,o}$, which is the element of the normalized decision matrix for alternative a, according to criterion o.

3.5. TOPSIS

In the TOPSIS method, the ideal and anti-ideal values were obtained for each criterion using Equations (21) and (22), respectively.

$$id_o^+ = max_a\{ne_{a,o} \times w_o\}, \forall = 1, \ldots, O \tag{21}$$

$$id_o^- = \min_a\{ne_{a,o} \times w_o\}, \forall = 1, \ldots, O \tag{22}$$

The distances of the alternative a from the ideal and anti-ideal points were calculated using Equations (23) and (24), respectively.

$$d_a^+ = \sqrt{\sum_{o=1}^{O} e_{a,o} - id_o^+}, a = 1, \ldots, A \tag{23}$$

$$d_a^- = \sqrt{\sum_{o=1}^{O} e_{a,o} - id_o^-}, a = 1, \ldots, A \tag{24}$$

To be included in the ranking, the value of the alternative a in the TOPSIS method was achieved using Equation (25).

$$d_a = \frac{d_a^-}{d_a^- + d_a^+}, a = 1, \ldots, A \tag{25}$$

3.6. VIKOR

In the VIKOR method, the distances of the alternative a from the ideal and anti-ideal points were calculated using Equations (26) and (27).

$$d_a^+ = \sum_{o=1}^{O} w_o \frac{id_o^+ - e_{a,o}}{id_o^+ - id_o^-}, a = 1, \ldots, A \tag{26}$$

$$d_a^- = max_o\left\{w_o \frac{id_o^+ - e_{a,o}}{id_o^+ - id_o^-}\right\}, a = 1, \ldots, A \tag{27}$$

Denoted as d_{max}^+, d_{min}^+, d_{max}^-, d_{min}^-, the maximum and minimum distances from the ideal and anti-ideal points for all the alternatives were calculated.

To be used in the ranking, alternative a's value in the VIKOR method was obtained using Equation (28).

$$d_a = v\left[\frac{d_a^+ - d_{min}^+}{d_{max}^+ - d_{min}^+}\right] + (1 - v)\left[\frac{d_a^- - d_{min}^-}{d_{max}^- - d_{min}^-}\right], a = 1, \ldots, A \tag{28}$$

where v in Equation (28) is the adjustment parameter in the interval [0, 1].

4. Experimental Results

Similar to the literature, a benchmark was used, as shown in Table 2. The related details and a similar instance are available in references [6,8,22]. As shown in Table 2, there were five sizes and periods in the problem. It was presumed that the natural regeneration value and its unit cost for all the periods were 500 and 1, respectively. In this benchmark, the sizes that provided more revenue had a higher carbon dioxide absorption. Therefore, there was a conflict between Cr_3 and Cr_4. The values of d_s and e_s were denoted in meters and tones.

Table 2. The used benchmark.

s	d_s	r_s	c_s	e_s	$\mu_s(x_1)$	$\alpha_s(x_1)$	$\mu_s(x_2)$	$\alpha_s(x_2)$	$\mu_s(x_3)$	$\alpha_s(x_3)$	$\mu_s(x_4)$	$\alpha_s(x_4)$	$\mu_s(x_5)$	$\alpha_s(x_5)$
1	0.25	150	125	0.025	0.1	0.08	0.1	0.09	0.1	0.1	0.08	0.1	0.08	0.1
2	0.75	175	100	0.075	0.1	0.09	0.1	0.08	0.1	0.1	0.1	0.1	0.1	0.1
3	1.25	200	75	0.125	0.1	0.1	0.1	0.1	0.1	0.08	0.09	0.1	0.1	0.09
4	1.75	225	50	0.175	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5	2.25	250	25	0.225	0.09	0.1	0.07	0.1	0.1	0.1	0.1	0.08	0.1	0.1

We determined Equations (1), (2), and (6)–(15) and Constraints 3–5 using functions in Excel sheets, while the optimization of 16–18 was conducted using the solver in Excel. Since the solver was not favorably efficient, we also generated 1000 random solutions and selected the best one according to the objective functions. We implemented Equations (19)–(28) by employing the Excel functions. We utilized Microsoft Excel 2013 on a system with an Intel Core i5 processor, 2.4 GHz, with 12 GB of RAM.

To balance the ideal and anti-ideal points, the value of v in Equation (28) was supposed to be 0.5. The pairwise comparison matrix in Table 3 was operated to calculate the weights of the criteria. The values in this table were assigned hypothetically. The resulting weights were $w_1 = 0.1, w_2 = 0.3, w_3 = 0.5, w_4 = 0.1$.

Table 3. Pairwise comparison matrix between the criteria.

	$\boldsymbol{Cr_1}$	$\boldsymbol{Cr_2}$	$\boldsymbol{Cr_3}$	$\boldsymbol{Cr_4}$
$\boldsymbol{Cr_1}$	1	0.33	0.2	1
$\boldsymbol{Cr_2}$	3	1	0.6	3
$\boldsymbol{Cr_3}$	5	1.67	1	5
$\boldsymbol{Cr_4}$	1	0.33	0.2	1

The acquired results are shown in Table 4. The results in this table were all non-dominated. Therefore, if the concept of Pareto optimality was employed for this problem, as utilized in the literature, they could be considered identical.

Table 4. The values of the criteria according to the alternatives.

	$\boldsymbol{Cr_1}$	$\boldsymbol{Cr_2}$	$\boldsymbol{Cr_3}$	$\boldsymbol{Cr_4}$
$\boldsymbol{Al_1}$	280,686.64	1386.93	189.92	293,186.64
$\boldsymbol{Al_2}$	201,163.02	1235.83	248.00	362,813.02
$\boldsymbol{Al_3}$	223,598.40	978.45	190.10	485,410.76
$\boldsymbol{Al_4}$	278,488.86	955.41	189.30	290,988.86
$\boldsymbol{Al_5}$	206,063.79	1775.04	210.40	359,788.79
$\boldsymbol{Al_6}$	74,804.38	2515.04	500.75	441,429.38
$\boldsymbol{Al_7}$	279,695.16	1122.37	170.33	292,195.16
$\boldsymbol{Al_8}$	203,669.87	1131.64	148.85	366,919.87
$\boldsymbol{Al_9}$	11,809.00	1440.49	190.65	538,734.00

The methods ranked the results from Table 4, whose outputs are displayed in Table 5 and Figure 1.

Table 5. The rank of each alternative according to the different methods.

	WS	**NWS**	**TOPSIS**	**VIKOR**
Al_1	2	6	6	6
Al_2	7	2	2	2
Al_3	1	3	4	3
Al_4	5	4	3	4
Al_5	6	8	9	8
Al_6	9	1	1	1
Al_7	3	5	5	5
Al_8	4	7	7	9
Al_9	8	9	8	7

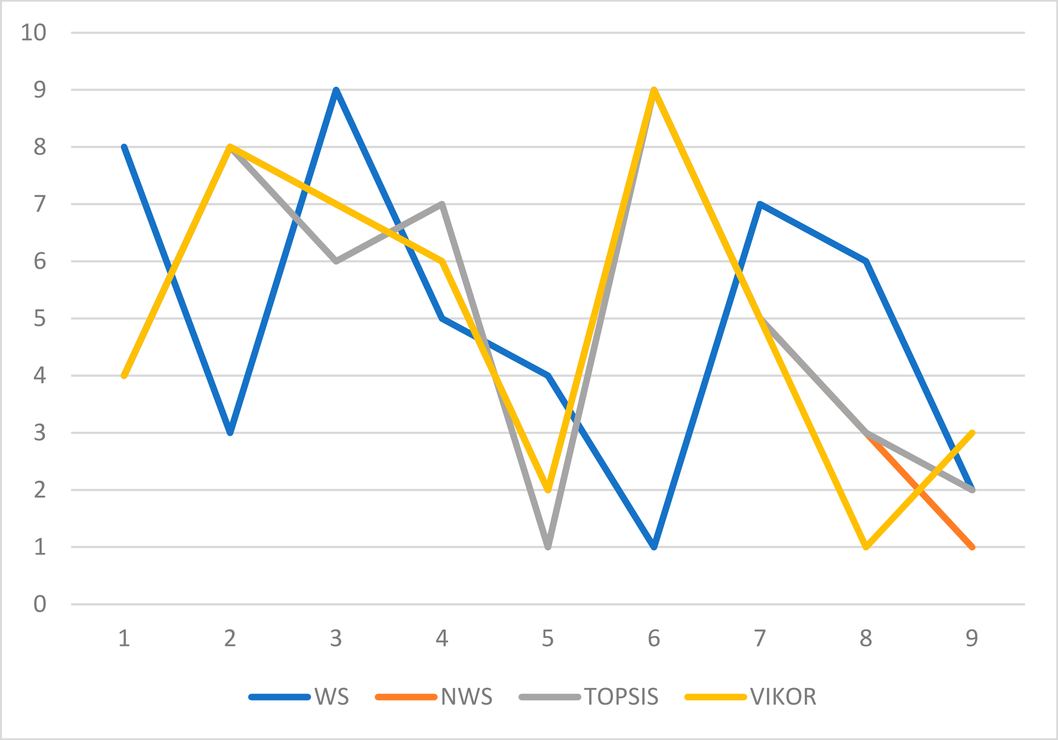

Figure 1. Visualization of the rank of the alternatives according to the used methods.

The acquired rankings, according to all the methods except for WS, were similar. It was concluded that the concepts such as the normalization and the distance from the ideal and anti-ideal points could be useful in comparison. Mostly, the approach of differentiated cost sharing, maximizing the owner's goals, and revenue sharing was ranked as the best. These approaches also provided significant managerial benefits.

As mentioned earlier in the benchmark, the sizes that provided more revenue had a higher carbon dioxide absorption. Consequently, there was a conflict between maximizing the revenue and carbon dioxide absorption objectives. In this case, differentiated cost sharing was more appropriate for the green goals.

This study constituted a novel example of the use of MADM methods for sustainable forest management. However, the comparison between the MADM methods should be conducted based on a large number of benchmarks derived from the different values for the parameters and criteria in Tables 2 and 3 and utilize the statistical experimental design.

Overall, we outlined that, while this work discussed a specific benchmark, the results were generalizable and there were managerial implications. We especially emphasize that the application of differentiated cost sharing and considering the different stakeholders' interests based on contract mechanisms are beneficial for sustainable forest management. It should be noted that the different values in Tables 2 and 3 did not affect these managerial inferences.

5. Managerial Implications

This study presented several managerial implications. First, this study emphasized the importance of integrating green goals, such as carbon dioxide absorption, into forestry supply chain management. This implies that businesses should incorporate these goals into their business objectives. By doing so, businesses can ensure that their operations are environmentally sustainable and supportive of the broader global sustainability objectives.

Secondly, this study emphasized the importance of considering the interests of different parties involved in the forestry supply chain management, including the forest owner and the applicant. This implies that businesses should design contracts that consider the interests of all the parties involved. By doing so, businesses can ensure that their contracts are fair, sustainable, and promote long-term relationships with their stakeholders.

Thirdly, this study compared the outcomes of the recommended framework with the outputs of a previously employed method based on multi-objective techniques and the Pareto optimality concept. This suggests that businesses should evaluate different approaches for designing green contracts to determine the most effective method for achieving their sustainability goals. By comparing the different approaches, businesses can identify the best approach for designing contracts that promote sustainable operations and minimize their environmental impact.

Finally, this study recommended that businesses use the framework to design contracts that promote sustainable operations and support compliance with the United Nations' Sustainable Development Goals. The framework can promote social responsibility and equity in the supply chain, contributing to SDG 10: Reduced Inequalities. The study's acknowledgement of the need for financial incentives and government regulations for environmentally friendly practices is also relevant to SDG 12: Responsible Consumption and Production. Additionally, by using the framework, businesses can design environmentally sustainable and fair contracts that support the broader global sustainability objectives.

6. Conclusions and Future Works

This paper suggested a framework based on MADM for designing green contract mechanisms for the forestry supply chain, in which, despite other fields of supply chain management, contract mechanisms still need to be sufficiently investigated. Unlike similar works in the literature, this study provided a more comprehensive approach to the design of GCMs and enabled the consideration of diverse perspectives from different stakeholders. We showed that for the presented problem evaluating the outcomes based on the Pareto optimality concept was not suitable. Furthermore, we demonstrated that methods such as the WS that do not utilize normalization or do not consider distances from the ideal and anti-ideal points are not beneficial in ranking the results of this problem.

In the defined benchmark, there was a conflict between the maximization of carbon dioxide absorption and profit. Usually, this is valid for real-life problems, and consequently, the model can be generalized for diverse applications. We demonstrated that in this situation, cost sharing, mainly differentiated cost sharing, can provide better outputs. It was reported in the literature that differentiated pricing, subsidization, and cost sharing can provide satisfactory outcomes in service systems [23]. Still, this topic has yet to be explored in the forestry supply chain.

The owner is supposed to be environmentally friendly. However in real life, financial incentives are generally expected in return for the reduction in carbon dioxide emissions, which is ignored in this study. Governments can employ tools such as tax deductions along with green financial incentives [24–27]. In addition, governments can assemble restrictions for businesses by enacting regulations toward green purposes [28,29]. In future studies, is the authors plan to design of a more comprehensive model for considering these situations.

As seen in Table 1, the legal issues were not discussed in this study, whereas this subject is inevitable for sustainable practices [30]. We plan to conduct elaborative work on this subject in future studies.

In this study, advanced optimization tools were not used, which could be viewed as a shortcoming. In future studies, we plan to design a heuristic wide version of the model, incorporating different forestry policies into the problem. In future studies, we plan to develop an algorithm for solving the model of this article by combining neural networks and variable neighborhood searches [31].

Furthermore, we will enclose more MADM methods in the model and compare them in future studies. Applying the model to a real-world context using empirical data can be a promising avenue for future research. Moreover, the generalizability of our findings was limited by the fact that we conducted experiments using only one benchmark. Thus, future research should incorporate additional benchmarks to further validate the effectiveness of the proposed framework as the parameters used to derive the benchmark affected the results. For example, the value of the v parameter in Equation (28) was defined as equal to 0.5. The reason for this can be explained as follows. The VIKOR method aimed to maximize the group utility and minimize the individual regret. The consensus between these goals was achieved when $v = 0.5$ [32]. However, for all the parameters, several values should be tested. In addition, statistical methods, such as an analysis of variance (ANOVA) and Tukey's test, should be performed to detect the differences between the results of the different methods [33]. The possible stages are summarized in Figure 2.

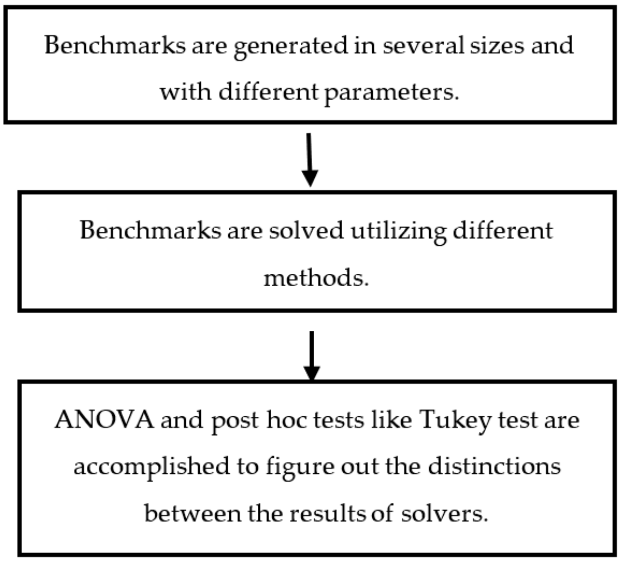

Figure 2. A framework for extracting more general implications.

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