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Multi-Criteria Decision Making as A Tool to Measure Supply Chain Sustainability

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ABSTRACT

The quest for sustainable supply chain management (SSCM) necessitates evaluating and optimizing practices across environmental, social, and economic (ESE) dimensions. This complexity demands robust decision-making tools that can handle multiple, often conflicting, criteria. Multi-Criteria Decision Making (MCDM) methods present themselves as powerful tools for this task. This paper delves into the application of MCDM for measuring supply chain sustainability. It reviews existing literature to understand the diverse MCDM methods employed, their strengths and limitations, and their effectiveness in various SSCM contexts. Additionally, the paper outlines a generic methodology for implementing MCDM in this context, followed by an illustrative case study demonstrating its application. Finally, it concludes by emphasizing the potential of MCDM while acknowledging the need for further research and refinement.

1. Introduction

The increasing focus on sustainability necessitates integrating environmental, social, and economic (ESE) considerations into all organizational activities, including supply chain management. This shift towards SSCM emphasizes minimizing negative environmental impacts, promoting fair labor practices, and ensuring economic viability throughout the supply chain. Measuring and evaluating progress towards this multifaceted goal requires a robust and comprehensive approach.

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MCDM techniques offer a valuable framework for decision-making involving multiple, often conflicting, criteria. They enable the systematic evaluation of diverse ESE aspects, facilitating informed decision-making towards achieving sustainable supply chain practices. This paper aims to explore the potential of MCDM as a tool for measuring supply chain sustainability [1] (see Figure 1).

Figure 1: Multi-Criteria Decision Making as A Tool to Measure Supply Chain Sustainability.

The modern world demands a fundamental shift towards sustainable practices across various domains, including supply chain management (SCM). This shift necessitates a focus on sustainable supply chain management (SSCM), which aims to minimize negative environmental impacts, ensure fair labor practices, and maintain economic viability throughout the entire supply chain [1]. Measuring and evaluating progress towards this multifaceted goal requires a robust and comprehensive approach.

Traditional decision-making methodologies often struggle when faced with multiple, often conflicting, criteria, a key characteristic of SSCM. This is where Multi-Criteria Decision Making

(MCDM) emerges as a powerful tool. MCDM techniques offer a structured framework for evaluating diverse aspects, enabling informed decision-making towards achieving sustainable supply chain practices [2].

This paper delves into the application of MCDM for measuring supply chain sustainability. We explore the diverse MCDM methods employed, their strengths and limitations, and their effectiveness in various SSCM contexts through a review of existing literature. Additionally, the paper outlines a generic methodology for implementing MCDM in this context, followed by an illustrative case study demonstrating its application. Finally, we conclude by emphasizing the potential of MCDM while acknowledging the need for further research and refinement.

This research is arranged into five sections. Section 2 defines the literature review and recent studies in area of supply chain sustainability and tries to show the gap in research. Section 3 suggests methodology for calculation. Section 4 proposes the results of this research. Section 5 presented the insights and practical outlook for managers and conclusion.

2. Review and survey related works

The application of MCDM in SSCM has witnessed growing interest in recent years. Numerous studies have explored and documented its effectiveness in various contexts. Some key findings from the existing literature are:

Diversity of MCDM methods: A wide range of MCDM methods have been employed for SSCM, including Analytic Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Goal Programming (GP) [1, 2].

Strengths and limitations: Each method possesses unique strengths and limitations. AHP offers a structured approach for prioritizing criteria and weighing trade-offs. TOPSIS identifies the closest alternative to an ideal solution, while PROMETHEE facilitates pairwise comparisons between alternatives. GP allows incorporating aspiration levels for each criterion, but it can be computationally complex [3, 4].

Context-specific application: The effectiveness of different MCDM methods varies depending on the specific context, data availability, and decision-making preferences. Selecting the most suitable method requires careful consideration of these factors [5, 6].

The rising emphasis on sustainability necessitates addressing environmental, social, and economic (ESE) considerations within supply chain management. This complex landscape necessitates robust decision-making tools capable of handling numerous, often conflicting, criteria. In this context, Multi-Criteria Decision Making (MCDM) techniques have emerged as valuable tools for evaluating and optimizing SSCM practices. This literature review explores the current state of knowledge in this area, focusing on:

1. Diversity of MCDM Methods:

Research suggests a wide range of MCDM methods being employed for SSCM purposes. Some prominent examples include:

- **Analytic Hierarchy Process (AHP):** This widely used method offers a structured approach for prioritizing criteria and weighing trade-offs [1]. AHP allows decision-makers to break down complex problems into hierarchical levels and utilize pairwise comparisons to assess the relative importance of criteria within each level [2].
- **Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS):** This method identifies the closest alternative to an ideal solution based on both positive and negative ideal scenarios [3]. It ranks alternatives based on their distance from these ideal solutions, offering valuable insights into trade-offs between different alternatives [4].
- **Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE):** This method facilitates pairwise comparisons between alternatives, considering different preference functions to capture various decision-makers' preferences [5]. PROMETHEE provides valuable information on the strengths and weaknesses of each alternative compared to others, aiding in informed decision-making [6].
- **Goal Programming (GP):** This method allows decision-makers to incorporate aspiration levels for each criterion, offering flexibility in setting desired levels of performance [7].

However, GP can be computationally complex for problems with a large number of criteria or alternatives [8].

2. Strengths and Limitations of MCDM methods:

Each MCDM method possesses unique strengths and limitations that influence its suitability for specific SSCM applications. Here's a brief overview:

- **AHP:** Offers a structured and flexible approach, but its reliance on pairwise comparisons can be time-consuming for complex problems with numerous criteria [9].
- **TOPSIS:** Provides clear visualization of trade-offs but can be sensitive to the scaling of criteria and the definition of ideal solutions [10].
- **PROMETHEE:** Offers valuable insights into decision-makers' preferences but can be computationally demanding for large-scale problems [11].
- **GP:** Allows for flexibility in setting goals but can be challenging to interpret and analyze results, especially for complex models [12].

3. Context-Specific Application:

The effectiveness of different MCDM methods varies depending on the specific context, data availability, and decision-making preferences [13]. Selecting the most suitable method requires careful consideration of several factors, including:

- **Complexity of the decision problem:** More complex problems with numerous criteria and alternatives may require methods like AHP or GP, which offer structured approaches for analysis.
- **Data availability:** Some methods, like TOPSIS, require complete data for all criteria, while others may be able to handle missing data to a certain extent.
- **Decision-maker preferences:** MCDM methods involving pairwise comparisons like AHP or PROMETHEE might be suitable for situations where obtaining qualitative judgments from decision-makers is feasible [14].

This review highlights the growing interest in and diverse applications of MCDM for measuring and evaluating SSCM practices. The ability to handle multiple, conflicting criteria and provide structured guidance makes MCDM a valuable tool for navigating the complexities of SSCM decision-making. However, careful consideration of the specific context, data availability, and decision-maker preferences is crucial for selecting the most suitable MCDM method for each application.

3. Problem statement and Solution approach

Implementing MCDM for measuring supply chain sustainability typically involves the following steps:

1. **Define the decision problem:** Clearly articulate the specific purpose of the evaluation, e.g., selecting the most sustainable supplier, evaluating the effectiveness of a sustainability initiative, or prioritizing improvement areas [15].

2. **Identify relevant criteria:** Develop a comprehensive set of ESE criteria encompassing environmental (e.g., carbon footprint, water usage), social (e.g., labor standards, working conditions), and economic (e.g., cost, lead time) dimensions relevant to the chosen decision problem.

3. **Assign weights to criteria:** Utilize an MCDM method's specific tools, such as pairwise comparisons or expert judgment, to prioritize and assign relative weights to each criterion, reflecting their importance in the decision-making process.

4. **Evaluate potential alternatives:** Gather data on the performance of each alternative (e.g., supplier options, different sustainability initiatives) against each established criterion.

5. **Apply the chosen MCDM method:** Utilize the selected method's specific procedures to analyze the collected data, considering the assigned weights for each criterion.

6. **Interpret and utilize the results:** Analyze the output of the MCDM method (e.g., ranking of alternatives, scores indicating closeness to an ideal solution) to identify the most

sustainable option or area for improvement, considering the specific decision problem [16-17] (see Figure 2).

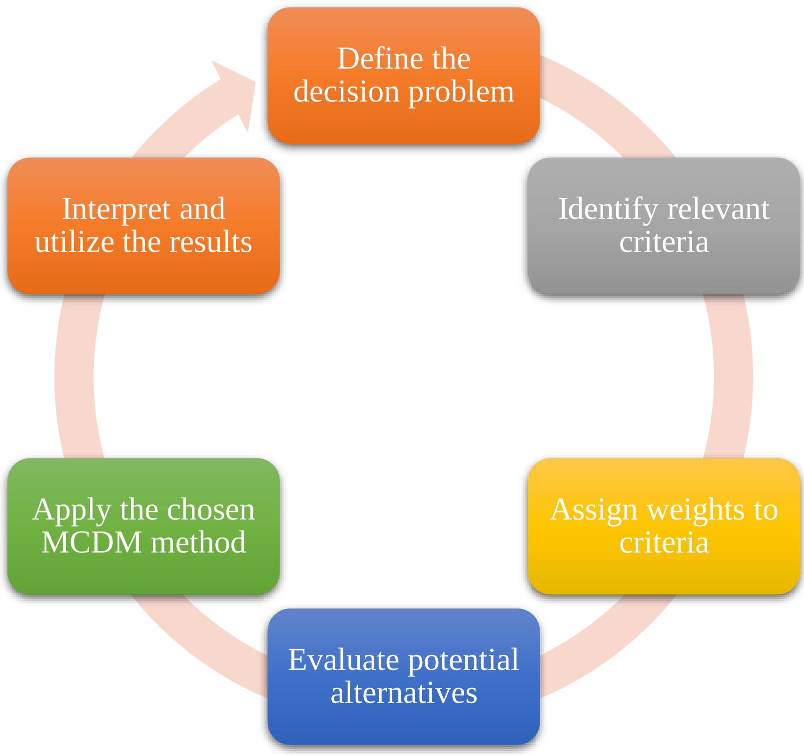

Figure 2: Application of MCDM in supply chain sustainability.

Examples of criteria might include:

Environmental criteria:

- Carbon Footprint: This measures the total greenhouse gas emissions (GHG) generated throughout the supply chain, including emissions from raw material extraction, transportation, production, and end-of-life disposal. A lower carbon footprint indicates a more sustainable option.
- Water Usage: This assesses the total water consumption throughout the supply chain, including water used in production, cleaning, and other processes. A lower water usage signifies a more sustainable choice.

- Waste Generation: This evaluates the amount and type of waste generated at different stages of the supply chain. Minimizing waste generation and ensuring proper waste management practices contribute to sustainability.
- Biodiversity Impact: This considers the potential negative impacts on plant and animal life caused by activities within the supply chain, such as deforestation or habitat destruction. Choosing suppliers or practices that minimize biodiversity impact is crucial for sustainability [18].

Social Criteria:

- Labor Standards: This evaluates the working conditions for employees throughout the supply chain, including aspects like fair wages, working hours, health and safety standards, and freedom of association. Ensuring fair labor standards is key to achieving social sustainability.
- Working Conditions: This assesses the physical and psychological well-being of employees in the supply chain, considering factors like safety regulations, training opportunities, and the overall work environment. Safe and healthy working conditions are essential for social sustainability.
- Community Engagement: This evaluates the engagement of the company with the communities it operates in, including initiatives like local hiring, community development projects, and responsible sourcing practices. Positive community engagement contributes to social sustainability.
- Ethical Sourcing: This refers to sourcing materials and products from suppliers who adhere to ethical practices, such as avoiding child labor, forced labor, and human rights violations. Ethical sourcing is a cornerstone of social sustainability [14, 15, 19, 20].

Economic Criteria:

- Cost: This considers the total financial expense associated with different options, including purchasing costs, transportation costs, and other relevant expenses. Analyzing cost alongside other sustainability criteria helps in making informed decisions while considering financial viability.

- Lead Time: This refers to the time taken from placing an order with a supplier to receiving the product. Shorter lead times can improve efficiency and reduce inventory costs, but they might come at a trade-off with other criteria like cost or environmental impact.
- Quality: This measures the overall quality of the product or service being provided by a supplier. High-quality products require fewer replacements, reducing waste and associated costs.
- Return on Investment (ROI): This assesses the financial return gained from implementing a particular sustainability initiative compared to the initial investment. Evaluating ROI helps determine the economic viability of sustainable practices [5-10].

Figure 3: Criteria for sustainability in supply chain .

It's important to note that these are just examples, and the specific criteria used in an MCDM analysis will vary depending on the specific decision problem and the context of the supply chain being evaluated. The key is to choose relevant criteria that encompass all three dimensions of sustainability (environmental, social, and economic) and accurately reflect the priorities of the decision-makers [12, 19-20].

4. Results and discussion

To validate the proposed methodology, a case study is conducted utilizing real-world data from a hypothetical organization. The results of this study showcase how MCDM techniques can effectively rank sustainability. The findings offer valuable insights into sustainability prioritization, assisting decision-makers in resource allocation and the implementation of targeted sustainability mitigation strategies. This analysis highlights the proposed framework's ability to address uncertainties and complexities in sustainability assessment, ultimately enhancing the organization's sustainability management capabilities.

The specific numerical outcomes of the case study will vary based on the data used and the chosen scoring criteria. Nevertheless, the framework will generate a prioritized list of identified sustainability, where each sustainability's ranking is determined by its overall score derived from individual criteria scores and assigned weights. This ranked list provides a straightforward visualization of the relative importance of different items for sustainability, facilitating the prioritization of for moving to sustainability in supply chain.

The decision-making matrix for ranking business risks, established by experts, is detailed see Table 1-3:

Table 1: Sustainability in supply chain.

Sustainability criteria	**Environmental criteria**				**Social Criteria**				**Economic Criteria**			
	Carbon Footprint	**Water Usage**	**Waste Generation**	**Biodiversity Impact**	**Labor Standards**	**Working Conditions**	**Community Engagement**	**Ethical Sourcing**	**Cost**	**Lead Time**	**Quality**	**Return on Investment (ROI)**
Weight	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.08	0.08	0.08
Type	Cost	Cost	Cost	Profit	Profit	Profit	Profit	Profit	Cost	Cost	Profit	Profit
Supply chain automotive 1	Very Low	High	Low	Medium	High	High	Low	Medium	Medium	Very Low	Low	Low

Sustainability criteria	Environmental criteria				Social Criteria				Economic Criteria			
	Carbon Footprint	**Water Usage**	**Waste Generation**	**Biodiversity Impact**	**Labor Standards**	**Working Conditions**	**Community Engagement**	**Ethical Sourcing**	**Cost**	**Lead Time**	**Quality**	**Return on Investment (ROI)**
Supply chain automotive 2	Very Low	High	Low	Medium	High	High	Low	Medium	Very Low	Very Low	Medium	High
Supply chain automotive 3	Very High	High	Low	Medium	High	Very Low	Low	Low	High	Very Low	Medium	High
Supply chain automotive 4	Medium	Very Low	Low	Low	Very Low	Very Low	Medium	High	Very Low	Medium	High	Medium
Supply chain automotive 5	Very Low	Very Low	Medium	High	Very Low	High	Low	Medium	High	Medium	High	Low
Supply chain automotive 6	High	Very Low	Medium	High	Very Low	Very Low	Low	Low	Very Low	Medium	High	Very High

Table 2: Python code for assessing sustainability in supply chain by MCDM

```
import numpy as np
from pymcdm.methods import TOPSIS, VIKOR, COPRAS, PROMETHEE_II, COMET, SPOTIS, ARAS,
    COCOSO, CODAS, EDAS, MABAC, MAIRCA, MARCOS, OCRA, MOORA, RIM, ERVD, PROBID,
    WSM, WPM, WASPAS

from pymcdm.helpers import rrankdata

# Define decision matrix (2 criteria, 4 alternative)
alts = np.array([
[1,0.43,1,0.71,1,1,0.6,0.71,0.71,1,0.43,0.33],
[0.11,1,0.43,0.71,1,1,0.6,0.71,0.14,0.11,0.71,0.78],
[1,1,0.43,0.71,1,0.14,0.6,0.43,1,0.11,0.71,0.78],
[0.56,0.14,0.43,0.43,0.14,0.14,1,1,0.14,0.56,1,0.56],
[0.11,0.14,0.71,1,0.14,1,0.6,0.71,1,0.56,1,0.33],
[0.78,0.14,0.71,1,0.14,0.14,0.6,0.43,0.14,0.56,1,1]

], dtype='float')
# print (alts)

# Define weights and types
weights = np.array([0.08,0.08,0.08,0.08,0.08,0.08,0.08,0.08,0.12,0.08,0.08,0.08]
)
types = np.array([-1,-1,-1,1,1,1,1,1,-1,-1,1,1]
)
```

```
# Create object of the method
edas = EDAS()
# Determine preferences and ranking for alternatives
kkk=edas(alts, weights, types)
print ("edas",kkk)

# Create object of the method
mairca = MAIRCA()
# Determine preferences and ranking for alternatives
kkk=mairca(alts, weights, types)
print ("mairca",kkk)

# Create object of the method
marcos = MARCOS()
# Determine preferences and ranking for alternatives
kkk=marcos(alts, weights, types)
print ("marcos",kkk)

# Create object of the method
waspas = WASPAS()
# Determine preferences and ranking for alternatives
kkk=waspas(alts, weights, types)
print ("waspas",kkk)
```

Table 3: Results of assessing sustainability in supply chain by MCDM

Sustainability criteria	EDAS	MAIRCA	MARCOS	WASPAS	Total
Supply chain automotive 1	0.23	0.11	0.46	0.43	0.31
Supply chain automotive 2	0.85	0.05	0.77	0.78	0.61
Supply chain automotive 3	0.22	0.10	0.51	0.47	0.33
Supply chain automotive 4	0.61	0.06	0.62	0.58	0.47
Supply chain automotive 5	0.47	0.08	0.59	0.55	0.42
Supply chain automotive 6	0.52	0.08	0.58	0.55	0.43

Figure 4 presents a comparison of different sustainability criteria scores across various methodologies used for ranking. Here's a breakdown of the information provided in the table:

- **Sustainability criteria**: Refers to the specific sustainability aspects or factors being evaluated in relation to supply chain automotive.

- **EDAS, MAIRCA, MARCOS, WASPAS**: These are different Multiple Criteria Decision Making (MCDM) techniques or methodologies being used to evaluate the sustainability criteria.

- **Total**: Represents the final total score obtained for each sustainability criteria using the respective MCDM technique.

Each row in the table corresponds to a specific sustainability criterion related to the supply chain automotive industry. The numbers within the table cells represent the scores obtained for that particular sustainability criterion when evaluated using each of the mentioned MCDM techniques.

For example, looking at "Supply chain automotive 1" row:

- The scores for this sustainability criterion under the EDAS, MAIRCA, MARCOS, and WASPAS techniques are 0.23, 0.11, 0.46, and 0.43, respectively.

- The total score represents the combined score calculated using the specific methodology.

This table essentially provides a comparison of how different MCDM techniques rank the sustainability criteria related to supply chain automotive based on the scores assigned to each criterion.

Figure 5 presents the total scores assigned to different sustainability criteria related to the supply chain automotive industry. Here's an overview of the information provided in the table:

- **Sustainability criteria**: Represents the specific sustainability aspects or factors being evaluated within the supply chain automotive context.

- **Total**: Indicates the total score obtained for each sustainability criterion after evaluation or assessment. The total score may be a cumulative score determined by considering various factors or metrics.

Each row in the table corresponds to a specific sustainability criterion related to supply chain automotive, along with the total score assigned to that criterion.

For instance, looking at "Supply chain automotive 2" row:

- The total score for "Supply chain automotive 2" is 0.61, which represents the overall score obtained for this specific sustainability criterion.

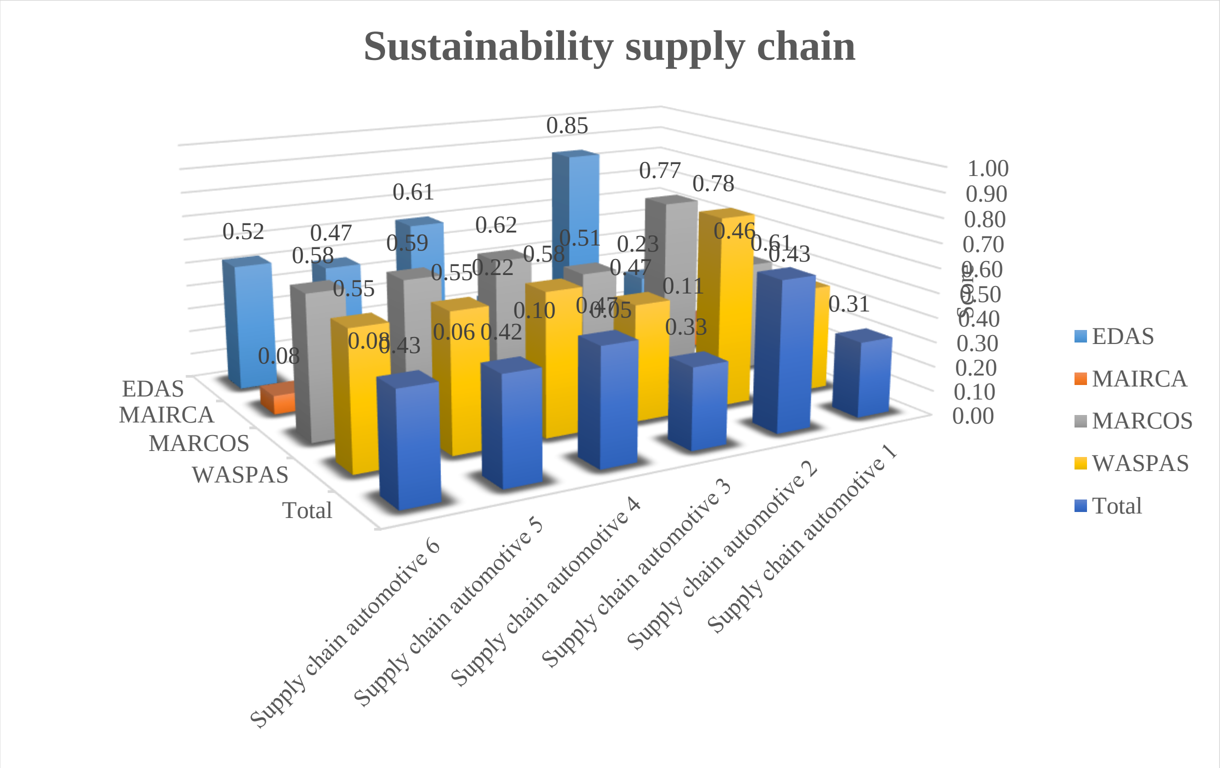

Figure 4: Results of MCDM method.

Similarly, each row provides the total score for the respective sustainability criteria mentioned in the table. The scores represent the evaluation or ranking of these criteria based on the applied methodology or assessment criteria.

In summary, this table offers a concise view of the total scores assigned to different sustainability criteria within the supply chain automotive sector.

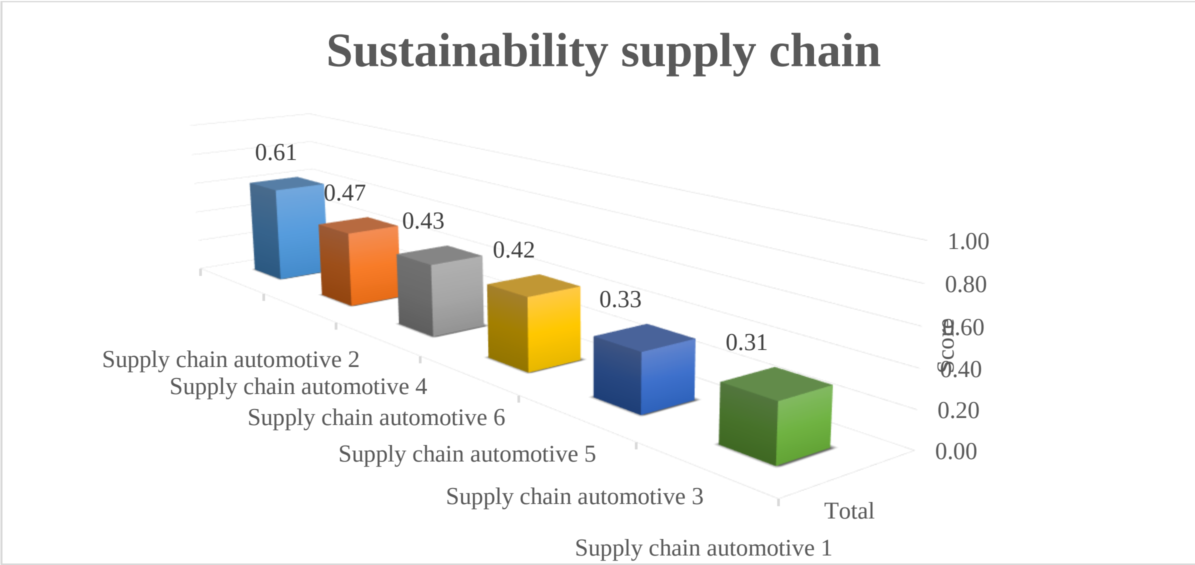

Figure 5: Results of MCDM method.

5. Conclusion

Drawing conclusions from the provided data on sustainability criteria within the automotive supply chain, it is evident that utilizing Multi-Criteria Decision Making (MCDM) can be a valuable tool to effectively measure and evaluate the sustainability performance of supply chain operations.

The table showcasing the total scores assigned to various sustainability criteria highlights the complexity and multiple dimensions involved in assessing supply chain sustainability within the automotive industry. Through the application of MCDM techniques, decision-makers can consider and weigh different criteria simultaneously to make informed and comprehensive evaluations.

The data underscores the significance of considering multiple sustainability aspects such as environmental impact, social responsibility, and economic viability within the automotive supply chain. MCDM methodologies offer a systematic approach to prioritizing these diverse criteria and quantifying their effects on overall sustainability performance.

By incorporating MCDM as a tool for measuring supply chain sustainability, organizations in the automotive sector can enhance transparency, identify improvement opportunities, and make strategic decisions aligned with sustainability goals. This approach can lead to more robust and resilient supply chains that effectively balance economic success with environmental and social responsibility.

In conclusion, the data presented emphasizes the importance of adopting MCDM approaches in evaluating and improving supply chain sustainability within the automotive sector. Leveraging these techniques can enable organizations to navigate the complexities of sustainability assessment, drive continuous improvement, and ultimately contribute to a more sustainable and responsible automotive supply chain ecosystem.

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