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GREEN SUPPLY CHAIN OPTIMIZATION WITH FUZZY MCDM FOR ECONOMIC GROWTH

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Abstract
An in-depth investigation into Green Supply Chain Management (GSCM) practices is presented, delineating their economic impact. The research applies fuzzy logic within a Multi-Criteria Decision-Making (MCDM) framework to systematize the evaluation and advancement of green practices in supply chains. The integration of fuzzy logic with MCDM is posited to refine the precision of evaluations. The approach centres on the assessment of green suppliers using a linear programming-based fuzzy Multi-Attributive Border Approximation area Comparison (MABAC) method. The study advances the discourse on GSCM by quantifying the economic merits, namely cost efficiency, market productivity enhancement, and brand image improvement. Evidence from practical applications substantiates the dual benefits of GSCM in bolstering environmental sustainability and generating significant economic gains.
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Key Words: GSCM, Economic Benefits, MCDM, MABAC, Fuzzy Logic, Linear Programming

1. INTRODUCTION

The appraisal of GSCM emerges as a pivotal process that evaluates the ecological sustainability and operational efficacy of an organization's supply chain methodologies. This evaluation is conducted through systematic analysis of the supply chain's multifaceted components, aiming to pinpoint opportunities for environmental improvement and to scrutinize the effectiveness of extant sustainable practices. Such evaluations assist enterprises in harmonizing their supply chain operations with environmental objectives and regulations, thereby enhancing their competitive edge and reputation in an increasingly sustainability-conscious global market [1-12]. Critical to the GSCM appraisal is the thorough assessment of environmental impacts across the entire supply chain network. This comprehensive assessment spans the acquisition of raw materials, manufacturing processes, transportation, distribution operations, and product disposal. The assessment serves to identify potential enhancement areas and to quantify the supply chain's carbon footprint. Metrics such as greenhouse gas emissions, energy utilization, and water consumption are commonly applied to measure environmental impact quantitatively. Moreover, the environmental stewardship of suppliers and partners is rigorously evaluated in terms of performance [13]. Audits, surveys, and assessments are conducted to ascertain suppliers' adherence to sustainable practices and compliance with environmental standards. The evaluation of supplier performance is indispensable for aligning the supply chain with environmental sustainability goals. A variety of methodological frameworks are employed to facilitate proper GSCM evaluation, including Life Cycle Assessments (LCA), Environmental Impact Assessments (EIA), and eco-labelling. These instruments enable an all-encompassing analysis of the environmental impacts attributable to enterprise supply chain activities and assist in identifying areas amenable to improvement.

GSCM integrates environmentally sustainable practices within supply chains, aiming to optimize economic gains. The pivotal role of fuzzy logic in GSCM evaluation is acknowledged, particularly in highlighting economic outcomes. It is recognized that the assessment of environmental and economic performance is fraught with inherent uncertainty and ambiguity

[14]. The initial procedure in the application of fuzzy logic is the definition of linguistic variables, which epitomize criteria such as cost-efficiency and environmental friendliness [15]. Membership functions are then employed to ascribe degrees of association to these variables, enabling the evaluation of both qualitative and quantitative datasets. Subsequently, a fuzzy inference system is engaged to delineate the relationships among these criteria, culminating in a holistic evaluation that balances economic benefits against environmental impacts. The advantage of fuzzy logic lies in its flexibility to navigate complex real-world scenarios, providing a nuanced, context-sensitive analysis of GSCM activities. This flexibility affords organizations the capacity to incrementally refine their sustainability practices [16].

The integration of fuzzy logic into the MABAC method signifies a substantial advancement in the method's ability to process data characterized by imprecision, uncertainty, and ambiguity. Fuzzy logic provides a robust theoretical framework for the nuanced handling of linguistic assessments and the quantification of membership degrees, thereby increasing the MABAC method's applicability and robustness in decision-making scenarios. Fuzzy logic extends traditional binary logic, facilitating the modelling of imprecision and vagueness inherent in decision-making processes. Within the MABAC framework, linguistic terms or fuzzy sets are adopted as surrogates for precise numerical values, allowing for the performance evaluation of alternatives against multiple criteria. For instance, rather than assigning exact numerical scores to alternatives, descriptive adjectives such as "good," "very good," or "fair" are employed, capturing the subjective and non-precise nature of human judgment. The MABAC methodology, conceived by Pamučar and Ćirović [17], is predicated on calculating the distances between alternatives and a defined border approximation area. Each alternative is evaluated by determining the difference between these distances. The versatility of the MABAC method has been demonstrated through its application in diverse fields such as defence operations [18], web page evaluation [19], supplier selection [20], railway freight terminal and administration [21-23], windmill siting [24], and the assessment of power generation technologies [25].

The MABAC model has been the subject of scholarly acclaim, distinguished by its effectiveness in addressing complex decision-making challenges within various practical contexts. The scholarly discourse has witnessed a burgeoning interest in dissecting the manifold applications of this model. The research herein undertakes an examination of seminal contributions that have broadened and augmented the MABAC framework, thus introducing innovative perspectives and pragmatic applications across multiple sectors. Among the salient contributions is the study by Chakraborty et al. [26], which provides an exhaustive analysis of the MABAC model's application to the selection of healthcare suppliers amidst uncertain conditions. This study accentuates the model's adaptability and robustness, evidencing its potential to refine decision-making processes within the healthcare supply chain infrastructure. Additionally, the investigation by Jana et al. [27] elucidates the application of the MABAC model within the realm of MADM utilizing Pythagorean fuzzy information. This research delineates the model's adeptness in navigating complex and uncertain data landscapes. In the domain of waste management process selection, Mandal and Seikh have contributed significantly, propelling the model forward with the introduction of an interval-valued spherical fuzzy MABAC method that assimilates indeterminate attribute weights [28]. These empirical explorations attest to the MABAC model's flexibility in addressing a spectrum of problematics, particularly those characterized by inherent ambiguity and a lack of precision. Further to this, Tan et al. have enriched the MABAC framework through the integration of prospect theory and Fermatean fuzzy environments in the evaluation of risk-laden investments, thereby furnishing a comprehensive framework for the scrutiny of investment options under uncertain scenarios. Lastly, Jana et al. [27] have advanced the MABAC model's scope by presenting its application to logarithmic bipolar fuzzy MADM, with a concentrated focus on its utility in the sphere of supplier selection processes.

The structure of the current study is methodically delineated as follows: Section 2 offers an elucidation of the pivotal criteria underpinning GSCM. In Section 3, the exposition of the linear programming-based fuzzy MABAC method is presented. Section 4 articulates a detailed case study, replete with numerical examples, to illustrate the merits of the proposed methodology. Finally, Section 5 delivers a succinct synthesis of the salient insights gleaned from the research undertaken.

2. CRITERIA FOR GSCM WITH ECONOMIC BENEFIT

This chapter delineates the criteria pivotal to the economic benefits of GSCM. The strategy of GSCM is centrally concerned with infusing principles of environmental sustainability throughout supply chain operations. While the focus predominantly rests on environmental benefits, the economic advantages are also assessed to ensure the enduring viability of the enterprise.

Criterion 1: Cost reduction. The adoption of energy-efficient processes and technologies plays a vital role in diminishing operational costs and fostering sustainability. Energy audits are conducted to pinpoint inefficiencies, such as outdated equipment or lighting systems, which may be ameliorated by implementing energy-efficient appliances and machinery, yielding considerable savings over time. The potential for integrating renewable energy sources like solar panels or wind turbines is also explored, which may reduce reliance on conventional power systems. This shift towards energy efficiency not only curtails costs but also reflects a commitment to environmental protection, potentially enhancing the company's reputation and appealing to environmentally conscious consumers [29].

Criterion 2: Efficiency improvement. It encompasses efficiency enhancement, necessitating the optimization of supply chain management to curtail lead times and augment productivity. The initial phase involves a thorough analysis of the supply chain to identify inefficiencies contributing to delays. Process streamlining techniques are employed to minimize lead times by removing superfluous steps and simplifying procedures. Lean principles, including just-in-time (JIT) inventory management and continuous improvement initiatives, are applied to refine supply chain operations, reducing waste and elevating production efficiency. Continuous monitoring and adaptation of supply chain operations ensure organizational agility and competitiveness within the dynamic contemporary business landscape [30].

Criterion 3: Risk management. The dynamic business environment necessitates the integration of supply chain resilience to effectively navigate economic risks and maintain sustainability. Disruptions such as natural disasters and resource scarcity can significantly impede supply chain continuity, precipitating production delays and financial losses. It is recommended that enterprises implement supplier diversification strategies, establish alternative transportation routes as contingency plans, and maintain adequate inventory buffers to mitigate such risks [31]. Additionally, compliance with environmental regulations is paramount to avoid financial penalties and sanctions that could negatively impact financial performance. Adherence to these regulations not only mitigates legal liabilities but also fosters corporate responsibility and enhances public perception. Proactive engagement in sustainability projects can yield long-term financial benefits and strengthen relations with environmentally conscious consumers and stakeholders, underscoring the importance of developing an environmentally compatible supply chain as a core component of modern corporate strategy.

Criterion 4: Market and brand value. Positioning a company as socially responsible and environmentally aware can captivate an increasing demographic of eco-conscious consumers. These consumers tend to favour products and services from companies that resonate with their environmental ethos. Marketing environmentally-friendly practices not only attracts this consumer segment but also differentiates the brand in competitive markets. Marketing strategies should emphasize a commitment to sustainability, eco-friendly product features, and support for environmental causes. The key is authenticity; ensuring that practices align with promotional messages to build consumer trust. Over time, this approach can lead to increased sales as eco-conscious consumers actively seek and advocate for brands that reflect their values. This strategy also promotes lasting customer loyalty and brand advocacy [32].

Criterion 5: Continuous improvement. It emphasizes the imperative of continuous improvement within the field of GSCM. In an ever-changing business milieu, marked by swift market shifts and technological advancements, the ability to evolve becomes a cornerstone of success. It is advocated that organizations embrace a philosophy of incessant learning and enhancement concerning their GSCM approaches. The regular assessment and refinement of GSCM strategies empower organizations to remain agile and responsive to market transformations, technological progress, and progressive sustainability benchmarks. Such adaptability is instrumental in uncovering operational inefficiencies, reducing costs, elevating customer satisfaction, and lessening environmental impacts. A culture steeped in constant advancement positions organizations to secure a competitive advantage, maintain a forward-thinking posture, and ensure the robustness and efficacy of their supply chains in the face of future challenges. Commitment to excellence is a central pledge that propels sustained triumph in the global marketplace.

Criterion 6: Government incentives and tax benefits. It deals with the strategic utilization of government incentives and tax benefits to bolster eco-friendly initiatives, thus aligning financial prudence with sustainability goals. Governments worldwide offer a variety of incentives designed to foster environmentally sustainable practices, such as renewable energy adoption and energy-efficiency upgrades. Leveraging these benefits, companies can reduce operational costs while enhancing their environmental profile. Investments in renewable energy and efficient technologies not only curtail energy expenditures but also contribute to the diminution of greenhouse gas emissions, supporting broader environmental sustainability efforts. These initiatives often align with governmental sustainability targets, increasing the attractiveness of firms to eco-aware consumers and partners. To maximize these benefits, companies must be well informed about available incentives and ensure compliance with relevant regulations, achieving a harmonious balance between economic performance and environmental stewardship [16].

By considering these criteria for economic benefit alongside environmental objectives, firms can effectively integrate GSCM practices, thereby ensuring their long-term financial stability and competitive standing.

3. LINEAR PROGRAMMING BASED FUZZY MABAC METHOD

Assume that there are n alternatives given as $\mathrm{A} = \{\mathrm{A}_1, \dots, \mathrm{A}_i, \dots, \mathrm{A}_n\}$ $(n \geq 2)$ and $C = \{C_1, \dots, C_j, \dots, \mathrm{C}_m\}$ $(m \geq 2)$ that comprise the finite set of m criteria. The subsequent stages delineate the fuzzy MABAC method, which is founded upon linear programming.

Algorithm

Step 1: Obtain the fuzzy decision matrix from the decision-makers (DMs) as $\varphi = (\omega_{ij})_{n\times m}$.

Step 2: Using this fuzzy decision matrix as a basis Ω, a weighted sum of the scores of each alternate β_j is determined by:

$$\mathrm{Y}(\beta_j) = \sum_{i=1}^{m} \beta_i\,(\omega_{ij}), (j = 1, 2, \dots, n).$$

where, $\beta_1, \beta_2, \ldots, \beta_m$ represent the weighted values of the given criterion.

In a scenario where weights are deemed indeterminate, a subset of these weights shall be denoted as ¥. The assessment of these indeterminate weights is conducted through the application of the previously outlined mathematical formulation.

$$Maxg = \sum_{i=1}^{m} \text{Y}(\beta_j)$$

Given the stipulated conditions, the equation $\sum_{i=1}^{m} \beta_i = 1$ holds true. Utilizing this particular set of data, the weighted values are subjected to a normalization process. Within a linear programming paradigm, the weights attributed to the criteria are determined in compliance with predefined constraints.

Step 3: Eqs. (1) and (2) are employed to normalize the favourable and unfavourable characteristics of the decision matrix, correspondingly.

$$Z_{ij} = \frac{S(\omega_{ij}) - S(\omega_i)^-}{S(\omega_i)^+ - S(\omega_i)^-} \tag{1}$$

$$Z_{ij} = \frac{S(\omega_{ij}) - S(\omega_i)^+}{S(\omega_i)^- - S(\omega_i)^+} \tag{2}$$

Step 4: The "weighted normalized decision matrix" is derived from Eq. (3) by applying the weighted values $[\beta_1, \beta_2, \ldots, \beta_n]$ to the normalized decision matrix.

$$\theta_{ij} = \beta_j + Z_{ij} \times \beta_j \tag{3}$$

Step 5: The values utilized to calculate the border approximation area matrix are derived from Eq. (4).

$$g_j = \left(\prod_{i=1}^{m} \theta_{ij}\right)^{\frac{1}{m}} \tag{4}$$

Step 6: Eq. (5) is utilized to ascertain the distance of the alternatives from the border approximation area, taking into consideration the dimensions of the border approximation area matrix and the weighted normalized values of each attribute.

$$q_{ij} = \theta_{ij} - g_j \tag{5}$$

Step 7: The calculation of the total distances of each alternative from the border approximation region is conducted using Eq. (6).

$$S_i = \sum_{j=1}^{n} q_{ij}; \quad i = 1, \ldots, m \tag{6}$$

Step 8: In the preceding stage, the distances of the alternatives from the border approximation area are calculated and sequenced in descending order. Thereafter, the alternatives are prioritized according to these calculated distances.

Fig. 1 gives a visual representation of the proposed methodology.

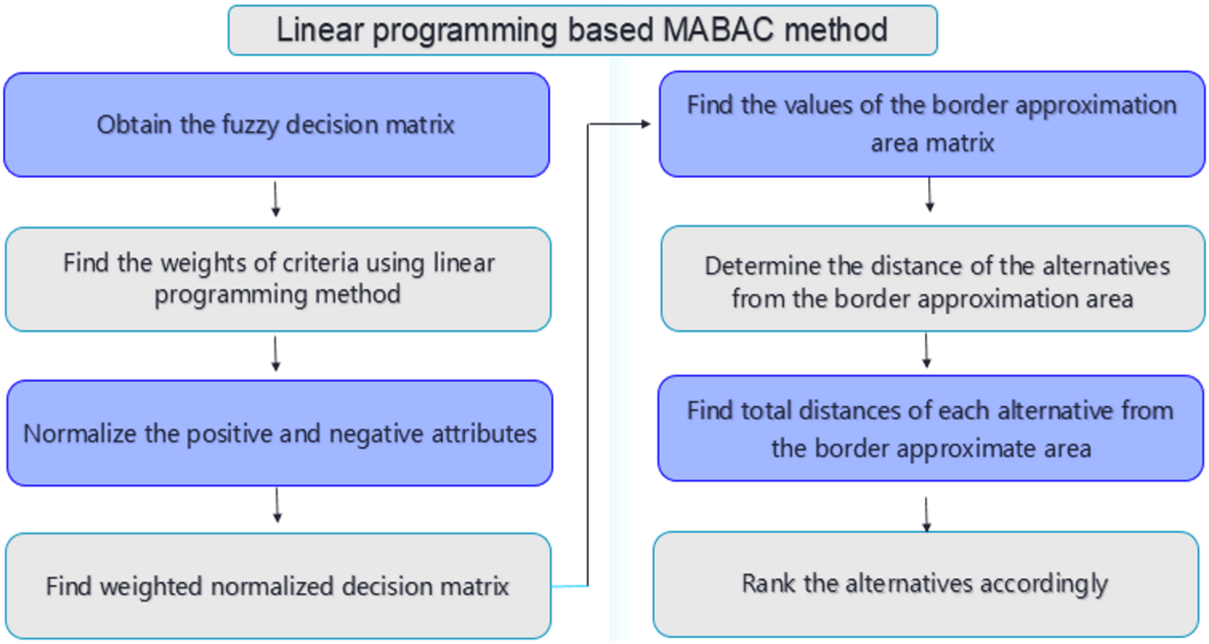

Figure 1: Visual representation of the suggested method.

4. PROBLEM STATEMENT

Within the domain of GSCM, critical influence is exerted on organizational efficiency, financial performance, and consumer satisfaction in modern commercial enterprises. This case study scrutinizes the supply chain tribulations faced by a multinational entity specializing in the manufacture of electronic consumer goods, exploring various strategies and criteria to augment the efficacy of their supply chain operations. Operating in a fiercely competitive industry that prioritizes innovation, cost efficiency, and timely delivery, the company has recently grappled with disruptions, escalated costs, and dwindling customer satisfaction due to multifaceted challenges within its supply chain. These issues have compelled a comprehensive reassessment and refinement of its supply chain management practices.

The corporation's supply chain is beleaguered by challenges, notably inefficient inventory management. Encounters with both excess and insufficient inventory levels have precipitated increased carrying costs and stockout incidents. Prolonged lead times for procuring raw materials and components have resulted in manufacturing delays and unmet delivery commitments. Supplier performance inconsistency, marked by quality and delivery reliability fluctuations, has impeded the company's ability to satisfy client demands. Additionally, the discourse encompasses the costs associated with transportation, where rising expenses and logistical inefficiencies have impacted the overall cost structure. The enterprise recognizes the imperative of sustainability and is committed to embedding environmentally friendly practices within its supply chain. Presented are 10 alternatives (companies) denoted as $A = \{A_1, A_2, A_3, \ldots, A_{10}\}$, and six criteria identified as $C = \{C_1, C_2, C_3, \ldots, C_6\}$, wherein cost reduction (C_1), efficiency improvement (C_2), risk management (C_3), continuous improvement (C_4), government incentives and tax benefits (C_5), and market and brand value (C_6).

Algorithm

Step 1: Obtain the fuzzy decision matrix from the DMs as $\varphi = (\omega_{ij})_{n\times m}$. It is provided in Table I.

Table I: Fuzzy decision matrix.

Alternatives	Criterion					
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.350	0.650	0.150	0.250	0.150	0.700
A_2	0.150	0.150	0.250	0.300	0.750	0.650
A_3	0.800	0.200	0.350	0.150	0.100	0.750
A_4	0.650	0.250	0.700	0.300	0.900	0.500
A_5	0.150	0.600	0.350	0.500	0.200	0.800
A_6	0.600	0.450	0.550	0.700	0.350	0.400
A_7	0.550	0.350	0.200	0.850	0.300	0.250
A_8	0.750	0.700	0.100	0.200	0.650	0.550
A_9	0.250	0.850	0.950	0.650	0.800	0.900
A_{10}	0.950	0.500	0.750	0.400	0.350	0.200

Step 2: Assume that the DMs offer the partial weight information regarding the attribute weights shown below:

$\partial = 0.15 \leq \beta_1 \leq 0.55,\ 0.25 \leq \beta_2 \leq 0.35,\ 0.15 \leq \beta_3 \leq 0.50,\ 0.55 \leq \beta_4 \leq 0.85,\ 0.25 \leq \beta_5 \leq 0.55,\ 0.20 \leq \beta_6 \leq 0.85.$

Relying on this data, the following optimization framework can be developed:

$Max\,g = 0.350\ \beta_1 + 0.150\ \beta_1 + 0.800\ \beta_1 + 0.650\ \beta_1 + 0.150\ \beta_1 + 0.600\ \beta_1 + 0.550\ \beta_1 + 0.750\ \beta_1 + 0.250\ \beta_1 + 0.950\ \beta_1$

$0.650\ \beta_2 + 0.150\ \beta_2 + 0.200\ \beta_2 + 0.250\ \beta_2 + 0.600\ \beta_2 + 0.450\ \beta_2 + 0.350\ \beta_2 + 0.700\ \beta_2 + 0.850\ \beta_2 + 0.500\ \beta_2$

$0.150\ \beta_3 + 0.250\ \beta_3 + 0.350\ \beta_3 + 0.700\ \beta_3 + 0.350\ \beta_3 + 0.500\ \beta_3 + 0.200\ \beta_3 + 0.100\ \beta_3 + 0.950\ \beta_3 + 0.750\ \beta_3$

$0.250\ \beta_4 + 0.300\ \beta_4 + 0.150\ \beta_4 + 0.300\ \beta_4 + 0.500\ \beta_4 + 0.700\ \beta_4 + 0.850\ \beta_4 + 0.200\ \beta_4 + 0.650\ \beta_4 + 0.400\ \beta_4$

$0.150\ \beta_5 + 0.750\ \beta_5 + 0.100\ \beta_5 + 0.900\ \beta_5 + 0.200\ \beta_5 + 0.350\ \beta_5 + 0.300\ \beta_5 + 0.650\ \beta_5 + 0.800\ \beta_5 + 0.350\ \beta_5$

$0.700\ \beta_6 + 0.650\ \beta_6 + 0.750\ \beta_6 + 0.500\ \beta_6 + 0.800\ \beta_6 + 0.400\ \beta_6 + 0.250\ \beta_6 + 0.550\ \beta_6 + 0.900\ \beta_6 + 0.200\ \beta_6$

Such that,

$\beta_1 + \beta_2 + \beta_3 + \beta_4 + \beta_5 + \beta_6 = 1,\ \ \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 \geq 0.$

By solving this model we get, $\beta_1 = 0.20$, $\beta_2 = 0.15$, $\beta_3 = 0.12$, $\beta_4 = 0.13$, $\beta_5 = 0.20$, $\beta_6 = 0.20$.

Step 3: Find the normalized decision matrix by using Eqs. (1) and (2), given in Table II.

Table II: Normalized decision matrix.

0.7500	0.2857	0.9412	0.8571	0.9375	0.2857
0.0000	1.0000	0.8235	0.7857	0.1875	0.3571
0.1875	0.9286	0.7059	1.0000	1.0000	0.2143
0.3750	0.8571	0.2941	0.7857	0.0000	0.5714
0.0000	0.3571	0.7059	0.5000	0.8750	0.1429
0.4375	0.5714	0.4706	0.2143	0.6875	0.7143
0.5000	0.7143	0.8824	0.0000	0.7500	0.9286
0.2500	0.2143	1.0000	0.9286	0.3125	0.5000
0.8750	0.0000	0.0000	0.2857	0.1250	0.0000
0.0000	0.5000	0.2353	0.6429	0.6875	1.0000

Step 4: Evaluate the weighted normalized decision matrix given in Table III.

Table III: Weighted normalized decision matrix.

0.3500	0.1929	0.2329	0.2414	0.3875	0.3857
0.4000	0.3000	0.2188	0.2321	0.2375	0.4071
0.2375	0.2893	0.2047	0.2600	0.4000	0.3643
0.2750	0.2786	0.1553	0.2321	0.2000	0.4714
0.4000	0.2036	0.2047	0.1950	0.3750	0.3429
0.2875	0.2357	0.1765	0.1579	0.3375	0.5143
0.3000	0.2571	0.2259	0.1300	0.3500	0.5786
0.2500	0.1821	0.2400	0.2507	0.2625	0.4500
0.3750	0.1500	0.1200	0.1671	0.2250	0.3000
0.2000	0.2250	0.1482	0.2136	0.3375	0.6000

Step 5: The values of the border approximation area matrix are obtained from Eq. (4), given in Table IV.

Table IV: Border approximation area matrix.

g_1	g_2	g_3	g_4	g_5	g_6
0.0900	0.0513	0.0355	0.0414	0.0917	0.1860

Step 6: The distance of the alternatives from the border approximation area is determined by using Eq. (5) given in Table V.

Table V: Distance from the border approximate area.

0.2599	0.1416	0.1974	0.2001	0.2958	0.1997
0.3099	0.2487	0.1833	0.1908	0.1458	0.2211
0.1475	0.2380	0.1692	0.2186	0.3083	0.1782
0.1850	0.2273	0.1198	0.1908	0.1083	0.2854
0.3099	0.1523	0.1692	0.1536	0.2833	0.1568
0.1975	0.1845	0.1410	0.1165	0.2458	0.3283
0.2100	0.2059	0.1904	0.0886	0.2583	0.3925
0.1600	0.1309	0.2045	0.2093	0.1708	0.2640
0.2850	0.0987	0.0845	0.1258	0.1333	0.1140
0.1100	0.1737	0.1127	0.1722	0.2458	0.4140

Step 7: The total distances of each alternative from the border approximate area is determined as in Eq. (6), given in Table VI.

Table VI: Total distances from the border approximate area.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
0.2945	1.2997	1.2598	1.1165	1.2252	1.2134	1.3456	1.1394	0.8412	1.2284

Step 8: The ranking of alternatives based on total distance of each alternative from the border approximate area is given as follows.

$$A_7 > A_2 > A_1 > A_3 > A_{10} > A_5 > A_6 > A_8 > A_4 > A_9$$

The pictorial view of ranking of alternatives is given in Fig. 2.

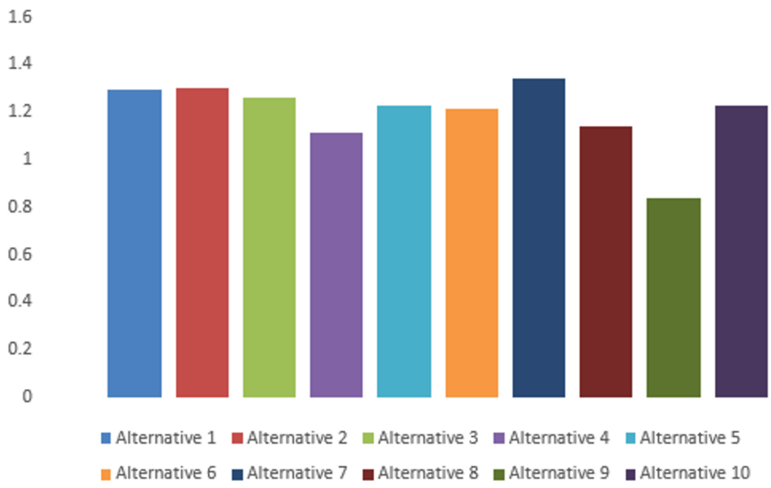

Figure 2: Ranking of alternatives.

4.1 Comparison analysis

In this section, the efficacy of the newly proposed methodology will be evaluated through comparison with established techniques. Table VII succinctly delineates the comparative assessment, providing an incisive examination of the performance of the suggested approach vis-à-vis existing methods. This comparison is instrumental in gauging the proposed methodology's ability to augment efficiency and credibility within the field. Table VII serves as a tool for assessing the relative performance of the introduced approach against entrenched methodologies.

Table VII: Comparison analysis of the proposed approach.

Method	Ranking of alternatives
Fuzzy TOPSIS [22]	$A_7 > A_2 > A_1 > A_3 > A_{10} > A_5 > A_6 > A_4 > A_8 > A_9$
Fuzzy VIKOR [23]	$A_7 > A_2 > A_1 > A_9 > A_4 > A_5 > A_6 > A_8 > A_{10} > A_3$
Fuzzy MOORA [24]	$A_7 > A_8 > A_4 > A_3 > A_{10} > A_5 > A_6 > A_2 > A_1 > A_9$
Fuzzy EDAS [25]	$A_7 > A_2 > A_1 > A_9 > A_4 > A_5 > A_6 > A_8 > A_{10} > A_3$
Fuzzy DEMATEL [26]	$A_7 > A_2 > A_1 > A_9 > A_4 > A_5 > A_6 > A_8 > A_{10} > A_3$
Proposed	$A_7 > A_2 > A_1 > A_3 > A_{10} > A_5 > A_6 > A_8 > A_4 > A_9$

5. CONCLUSION

The study culminates by presenting a novel methodology for the evaluation and enhancement of GSCM practices, with a focus on their economic implications. Through the application of fuzzy logic combined with MCDM methods, a systematic framework has been developed for the assessment and improvement of eco-friendly initiatives within supply chains, highlighting the critical role of economic factors in promoting sustainable practices. The integration of fuzzy logic into the MCDM has been shown to facilitate a more precise evaluation of eco-friendly practices and their associated economic benefits. The practicality of the proposed approach is exemplified by the assessment of green suppliers using a fuzzy MABAC method grounded in linear programming. This contribution enriches the academic discourse on GSCM, offering empirical evidence that sustainable practices can indeed result in tangible economic benefits. Organizations that incorporate GSCM can achieve cost savings, improved market productivity, and a bolstered brand image. The research underscores the growing interplay between environmental responsibility and economic gain in today's evolving business landscape, advocating for the widespread adoption of GSCM strategies to maintain competitiveness in the market.

REFERENCES

[1] Yang, S. Y.; Tan, C. (2022). Blockchain-based collaborative management of job shop supply chain, *International Journal of Simulation Modelling*, Vol. 21, No. 2, 364-374, doi:10.2507/IJSIMM21-2-CO10

[2] Ahmed, A. M.; Zafer Sayar, A. R. (2023). An empirical study on the factors influencing the implementation of blockchain-based supply chain traceability system, *Journal of Logistics, Informatics and Service Science*, Vol. 10, No. 1, 280-297, doi:10.33168/LISS.2023.0116

[3] Riaz, M.; Farid, H. M. A. (2023). Enhancing green supply chain efficiency through linear Diophantine fuzzy soft-max aggregation operators, *Journal of Industrial Intelligence*, Vol. 1, No. 1, 8-29, doi:10.56578/jii010102

[4] Khan, M. H.; Muktar, S. N. (2021). What's next for green human resource management: insights and trends for sustainable development, *International Journal of Sustainable Development and Planning*, Vol. 16, No. 1, 181-194, doi:10.18280/ijsdp.160119

[5] Ahmed, A. M.; Mohamed, A. A. (2023). Inbound, outbound disturbances and supply chain vulnerability of firms operating in post-conflict zones: the case of Somalia, *Journal of System and Management Sciences*, Vol. 13, No. 3, 352-363, doi:10.33168/JSMS.2023.0324

[6] Grznar, P.; Gregor, M.; Gaso, M.; Gabajova, G.; Schickerle, M.; Burganova, N. (2021). Dynamic simulation tool for planning and optimisation of supply process, *International Journal of Simulation Modelling*, Vol. 20, No. 3, 441-452, doi:10.2507/IJSIMM20-3-552

[7] Zheng, Y. R.; Bulatenko, M.; Bykov, A.; Sakulyeva, T.; Bozhko, L. (2022). Effective dairy supply chain management in big cities, *Journal of System and Management Sciences*, Vol. 12, No. 6, 131-146, doi:10.33168/JSMS.2022.0609

[8] Čerkauskienė, A.; Meidute-Kavaliauskiene, I. (2023). The aspects of supply chain risk management in the healthcare industry, *Journal of Logistics, Informatics and Service Science*, Vol. 10, No. 1, 1-19, doi:10.33168/JLISS.2023.0101

[9] Wei, D. (2020). Modeling and simulation of a multi-agent green supply chain management system for retailers, *Journal Européen des Systèmes Automatisés*, Vol. 53, No. 4, 549-557, doi:10.18280/jesa.530414

[10] Andry, J. F.; Hadiyanto; Gunawan, V. (2023). Critical factors of supply chain based on structural equation modelling for Industry 4.0, *Journal Européen des Systèmes Automatisés*, Vol. 56, No. 2, 187-194, doi:10.18280/jesa.560202

[11] Albhirat, M. M.; Zulkiffli, S. N. A.; Salleh, H. S.; Zaki, N. A. M. (2023). The moderating role of social capital in the relationship between green supply chain management and sustainable business performance: evidence from Jordanian SMEs, *International Journal of Sustainable Development and Planning*, Vol. 18, No. 6, 1733-1747, doi:10.18280/ijsdp.180609

[12] Guo, F. F.; Wu, Z.; Liu, C. J.; Fu, W. S.; Du, J. Q. (2023). Operation strategies of green supply chain members with short-sighted and far-sighted behavior: a differential game theory approach, *Journal of Green Economy and Low-Carbon Development*, Vol. 2, No. 2, 49-57, doi:10.56578/jgelcd020201

[13] Sahu, N. K.; Datta, S.; Mahapatra, S. S. (2012). Establishing green supplier appraisement platform using grey concepts, *Grey Systems: Theory and Application*, Vol. 2, No. 3, 395-418, doi:10.1108/20439371211273276

[14] Rao, P. (2002). Greening the supply chain: a new initiative in South East Asia, *International Journal of Operations & Production Management*, Vol. 22, No. 6, 632-655, doi:10.1108/01443570210427668

[15] Zadeh, L. A. (1965). Fuzzy sets, *Information and Control*, Vol. 8, No. 3, 338-353, doi:10.1016/S0019-9958(65)90241-X

[16] Bhutta, K. S.; Huq, F. (2002). Supplier selection problem: a comparison of the total cost of ownership and analytic hierarchy process approaches, *Supply Chain Management: An International Journal*, Vol. 7, No. 3, 126-135, doi:10.1108/13598540210436586

[17] Pamučar, D.; Ćirović, G. (2015). The selection of transport and handling resources in logistics centers using Multi-Attributive Border Approximation area Comparison (MABAC), *Expert Systems with Applications*, Vol. 42, No. 6, 3016-3028, doi:10.1016/j.eswa.2014.11.057

[18] Božanić, D. I.; Pamučar, D. S.; Karović, S. M. (2016). Application the MABAC method in support of decision-making on the use of force in a defensive operation, *Tehnika*, Vol. 71, No. 1, 129-136, doi:10.5937/tehnika1601129B
[19] Pamučar, D.; Stević, Ž.; Zavadskas, E. K. (2018). Integration of interval rough AHP and interval rough MABAC methods for evaluating university web pages, *Applied Soft Computing*, Vol. 67, 141-163, doi:10.1016/j.asoc.2018.02.057
[20] Stević, Ž.; Pamučar, D.; Vasiljević, M.; Stojić, G.; Korica, S. (2017). Novel integrated multi-criteria model for supplier selection: case study construction company, *Symmetry*, Vol. 9, No. 11, Paper 279, 34 pages, doi:10.3390/sym9110279
[21] Milosavljević, M.; Bursać, M.; Tričković, G. (2018). Selection of the railroad container terminal in Serbia based on multi criteria decision making methods, *Decision Making: Applications in Management and Engineering*, Vol. 1, No. 2, 1-15, doi:10.31181/dmame1802001m
[22] Sharma, H. K.; Roy, J.; Kar, S.; Prentkovskis, O. (2018). Multi criteria evaluation framework for prioritizing Indian railway stations using modified rough AHP-MABAC method, *Transport and Telecommunication Journal*, Vol. 19, No. 2, 113-127, doi:10.2478/ttj-2018-0010
[23] Vesković, S.; Stević, Ž.; Stojić, G.; Vasiljević, M.; Milinković, S. (2018). Evaluation of the railway management model by using a new integrated model DELPHI-SWARA-MABAC, *Decision Making: Applications in Management and Engineering*, Vol. 1, No. 2, 34-50, doi:10.31181/dmame1802034v
[24] Gigović, L.; Pamučar, D.; Božanić, D.; Ljubojević, S. (2017). Application of the GIS-DANP-MABAC multi-criteria model for selecting the location of wind farms: a case study of Vojvodina, Serbia, *Renewable Energy*, Vol. 103, 501-521, doi:10.1016/j.renene.2016.11.057
[25] Adar, T.; Ok, Y.; Delice, E. K. (2017). Selection of on-site energy generation technology with a new MCDM approach using MABAC & AHP, *Proceedings of the 2017 International Conference on Industrial Engineering and Technology Management*, 126-143
[26] Chakraborty, S.; Raut, R. D.; Rofin, T. M.; Chatterjee, S.; Chakraborty, S. (2023). A comparative analysis of multi-attributive border approximation area comparison (MABAC) model for healthcare supplier selection in fuzzy environments, *Decision Analytics Journal*, Vol. 8, Paper 100290, 15 pages, doi:10.1016/j.dajour.2023.100290
[27] Jana, C.; Garg, H.; Pal, M. (2023). Multi-attribute decision making for power Dombi operators under Pythagorean fuzzy information with MABAC method, *Journal of Ambient Intelligence and Humanized Computing*, Vol. 14, No. 8, 10761-10778, doi:10.1007/s12652-022-04348-0
[28] Mandal, U.; Seikh, M. R. (2023). Interval-valued spherical fuzzy MABAC method based on Dombi aggregation operators with unknown attribute weights to select plastic waste management process, *Applied Soft Computing*, Vol. 145, Paper 110516, 26 pages, doi:10.1016/j.asoc.2023.110516
[29] Lee, A. H. I.; Kang, H.-Y.; Hsu, C.-F.; Hung, H.-C. (2009). A green supplier selection model for high-tech industry, *Expert Systems with Applications*, Vol. 36, No. 4, 7917-7927, doi:10.1016/j.eswa.2008.11.052
[30] Chen, H. M. W.; Chou, S.-Y.; Luu, Q. D.; Yu, T. H.-K. (2016). A fuzzy MCDM approach for green supplier selection from the economic and environmental aspects, *Mathematical Problems in Engineering*, Vol. 2016, Paper 8097386, 10 pages, doi:10.1155/2016/8097386
[31] Yazdani, M. (2014). An integrated MCDM approach to green supplier selection, *International Journal of Industrial Engineering Computations*, Vol. 5, No. 3, 443-458, doi:10.5267/j.ijiec.2014.3.003
[32] Dobos, I.; Vörösmarty, G. (2014). Green supplier selection and evaluation using DEA-type composite indicators, *International Journal of Production Economics*, Vol. 157, 273-278, doi:10.1016/j.ijpe.2014.09.026