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Biodiversity Protection Practices in Supply Chain Management: A Novel Hybrid Grey Best–Worst Method/Axial Distance-Based Aggregated Measurement Multi-Criteria Decision-Making Model

Mladen Krstić [1,2,3,*], Snežana Tadić [2], Pier Paolo Miglietta [4] and Donatella Porrini [1,3]

1 Department of Economic Sciences, University of Salento, Via Monteroni snc, 73100 Lecce, Italy; donatella.porrini@unisalento.it
2 Logistics Department, Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305, 11000 Belgrade, Serbia; s.tadic@sf.bg.ac.rs
3 National Biodiversity Future Center (NBFC), 90133 Palermo, Italy
4 Department of Biological and Environmental Sciences and Technologies, University of Salento, Via Monteroni snc, 73100 Lecce, Italy; pierpaolo.miglietta@unisalento.it
* Correspondence: mladen.krstic@unisalento.it

Abstract: Biodiversity, from genes to entire ecosystems, is crucial for a healthy planet. However, human activities, including business practices, are causing rapid biodiversity loss. This study focuses on selecting and integrating biodiversity protection practices into the supply chain, offering a chance to make positive changes for the environment and future generations. A new hybrid grey multi-criteria decision-making (MCDM) model is proposed in this paper, which combines the grey Best–Worst Method (BWM) for obtaining criteria weights and the grey Axial Distance-based Aggregated Measurement (ADAM) method for ranking alternatives (practices). The applicability of the proposed model for solving the defined problem was demonstrated by ranking nine practices according to seven criteria. The most effective supply chain management practices in the context of biodiversity conservation were supply chain policies (with a score of 0.044), biodiversity goal setting, monitoring, reporting, and transparency (0.039), and education and awareness raising (0.037). These practices are the best because they combine clear frameworks, measurable goals, and long-term cultural change for effective biodiversity conservation. The lowest ranked practice is compliance with legislation (0.006) since it represents a baseline, reactive approach rather than a proactive or innovative strategy for biodiversity conservation. This study provides a comprehensive framework and hybrid MCDM model that enhances theoretical knowledge and can serve as a basis for developing a practical tool for integrating, assessing, and prioritizing biodiversity-focused practices in supply chains. The main novelties of this paper are the extension of the ADAM method in the grey environment, the development of a new hybrid MCDM model that combines the grey BWM and grey ADAM method, the identification of biodiversity-oriented business strategies in supply chains and the criteria for their evaluation, and a framework for practice evaluation and selection.

Keywords: biodiversity conservation in supply; multi-criteria decision-making (MCDM) for sustainability assessment; best–worst method (BWM); axial distance-based aggregated measurement (ADAM)

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1. Introduction

Biodiversity represents the diversity of living organisms at all levels—from genes within species to the ecosystems that surround them [1]. This diversity is vital to the health of our planet and to sustaining life on it. Healthy ecosystems provide basic conditions for life, such as clean air and water, climate regulation, pollination of crops, and much more. However, human activities, including those related to business practices, are leading to a rapid loss of biodiversity [2].

Modern business practices, through all stages of the supply chain and in all industries, have a deep impact on biodiversity [3]. Intensive agricultural management with monocultures and the excessive use of pesticides and fertilizers destroy habitats, deplete soil, and pollute water [4]. Unsustainable logging, mining, and fishing lead to resource scarcity, habitat fragmentation, and the extinction of numerous plant and animal species [5]. Industrial pollution, by releasing harmful substances into the air, water, and soil, causes acidification, eutrophication, and many other problems that threaten the health of the ecosystem [6]. Mass consumption, emphasizing short-lived goods, excessive packaging, and a wasteful attitude towards resources, increases demand for raw materials and generates huge amounts of waste [7]. This series of negative impacts is leading to a loss of biodiversity at an alarming rate, with incalculable consequences for the planet and humanity. Biodiversity preservation is becoming an increasingly urgent task, and responsible business is a key element in finding a solution.

Due to their complexity and global reach, supply chains represent a significant opportunity for positive changes in biodiversity protection [8]. Incorporating biodiversity considerations into supply chain management is crucial for corporate responsibility, as it ensures sustainable resource use, protects ecosystems, and fosters long-term environmental stewardship [9]. By defining and ranking supply chain management practices that promote sustainability, business flows can be directed toward activities that protect natural ecosystems and ensure a healthier planet for future generations.

The main motivation behind this study is to investigate how businesses can integrate biodiversity conservation into their supply chain operations. This includes examining strategies, policies, and initiatives employed to minimize the negative impact on biodiversity throughout supply chains. This study seeks to identify best practices, assess the effectiveness of current approaches, and explore opportunities for improvement. Ultimately, the goal is to promote sustainable business practices that contribute to biodiversity conservation while also meeting company and stakeholder needs.

Given this motivation, the study addresses two main research questions:

RQ1: Which practices generate the most positive effects on biodiversity, considering the feasibility and complexity of their application?

RQ2: Can a universally applicable framework and methodological approach for evaluating and ranking biodiversity-oriented supply chain management practices be defined?

To answer these questions, this study begins with a detailed literature review to provide foundational insights into biodiversity-oriented practices in supply chains. These practices, identified from existing studies, are diverse in their impact on biodiversity and vary in terms of complexity and feasibility of application. To address RQ1, a robust framework was developed to evaluate and rank these practices based on a set of carefully defined criteria. Addressing RQ2, the study proposes a new hybrid MCDM model combining the grey Best–Worst Method (BWM) and the grey ADAM method. This model provides a methodological approach to identify practices that offer the most significant benefits for biodiversity conservation while accounting for practical implementation challenges.

The applicability of the proposed model was demonstrated through a case study that ranked nine practices according to seven criteria. The results indicate that the most favorable practices are supply chain policies, biodiversity goal setting, monitoring, reporting, and transparency, and education and awareness raising, which collectively provide actionable insights for integrating biodiversity conservation into supply chain management.

The main contributions of this study are the definition of applicable supply chain management practices that positively affect biodiversity conservation, the definition of a framework and set of criteria for their evaluation, and the establishment of a new hybrid MCDM model.

The following section describes the background of the problem through a review of the literature on all the main aspects of the study and the identification of research gaps that this study covers. After that, the structure of the problem is described, i.e., identified practices and criteria for their evaluation and ranking. This is followed by a section with a detailed explanation of the methodology and the steps of its application. The fifth section provides insight into the results of solving the defined problem and sensitivity analysis, followed by a discussion of the results, implications, and study limitations. Concluding considerations and directions for future research are given in the last section.

2. Theoretical Framework

Following the main goal and to deepen the motivation behind the study and identify the main research gaps, it is necessary to investigate the research background and provide a clearer picture of biodiversity alongside business strategies and practices oriented towards its protection, with a special emphasis on supply chain management. Given the nature of the problem and the methodology developed for solving it, the following section also provides an overview of the applied methods, the motivation, and justification for their application.

2.1. Biodiversity-Oriented Supply Chain Management Practices

Biodiversity represents a complex ecological system comprising living organisms, their habitats, and the environmental processes that sustain them [10]. Its significance has been underscored globally since the establishment of Natura 2000 in 1992 [11] and the signing of the Convention on Biological Diversity (CBD) at the Rio de Janeiro Summit. Biodiversity has become a cornerstone of sustainable development, a concept explicitly reflected in the Sustainable Development Goals (SDGs) [12]. In particular, SDG 15 (Life on Land) and SDG 14 (Life Below Water) emphasize the urgent need to protect terrestrial and marine ecosystems, aligning closely with biodiversity conservation efforts. Biodiversity research has traditionally centered on several key directions, each with direct relevance to the SDGs. One significant focus is the assessment and monitoring of species and ecosystems, which aligns with SDG 15's targets on halting biodiversity loss. Research efforts in this area often include documenting species, understanding ecosystem dynamics, and monitoring changes in populations and ecosystem health over time (e.g., [13]). By providing the data necessary for informed conservation actions, such studies contribute to SDG 15's emphasis on protecting and restoring life on land.

Another essential strand of research explores the causes and dynamics of biodiversity loss, addressing threats such as climate change, habitat destruction, pollution, and invasive species (e.g., [14,15]). This aligns with SDG 13 (Climate Action), which seeks to mitigate climate change impacts and enhance resilience. Understanding these threats provides critical insights for designing interventions that reduce biodiversity loss and enhance ecosystem resilience, fostering a symbiotic relationship between climate action and biodiversity preservation.

Research on ecosystem services—the benefits nature provides to humanity, such as clean air, water, food, and climate regulation—illustrates the link between biodiversity and sustainable development. This area of study supports multiple SDGs, including SDG 6

(Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 15. Ecosystem services are fundamental to human well-being, and understanding their dependence on biodiversity is critical for ensuring their sustainability (e.g., [16]).

The preservation and restoration of biodiversity through strategies such as establishing protected areas, promoting sustainable agricultural practices, and developing innovative conservation solutions also align with SDG 2 (Zero Hunger) and SDG 15. These efforts ensure that ecosystems can continue to provide essential services, even in the face of growing human demands and environmental pressures (e.g., [17]).

Additionally, biodiversity research highlights its connection to human health, a focus that intersects with SDG 3 (Good Health and Well-Being). Studies show that ecosystems with high biodiversity contribute to better health outcomes, including reducing the risk of infectious disease outbreaks, while biodiversity loss can exacerbate health vulnerabilities (e.g., [18]). This underscores the interconnectedness of ecological and human systems within the sustainable development framework.

Despite its importance, the relationship between biodiversity and economic activities has been less explored. This gap is particularly significant given the emphasis of SDG 8 (Decent Work and Economic Growth) and SDG 12 on sustainable production and consumption patterns. While some studies have examined the economic valuation of biodiversity and ecosystem services, highlighting the costs of biodiversity loss (e.g., [19–21]), there is limited research on the integration of biodiversity considerations into business practices.

Modern business trends, including the principles of social responsibility, circular economy, and green logistics, reflect an increasing recognition of biodiversity's value (e.g., [22]). Companies are beginning to evaluate their operational impacts on biodiversity, leading to research on sustainable business practices that minimize negative impacts and even create positive contributions to ecosystem health (e.g., [23]). These practices are pivotal for aligning business operations with SDG 12's targets on responsible consumption and SDG 9 (Industry, Innovation, and Infrastructure), which emphasizes building resilient and sustainable infrastructure.

A critical gap exists in understanding the specific biodiversity-oriented practices that businesses in various sectors can adopt. Most existing research focuses on primary sectors such as agriculture and extractive industries (e.g., [24,25]), with limited attention to secondary sectors like manufacturing [26] or tertiary sectors such as logistics and supply chain management. Addressing this gap is vital for realizing SDG 17 (Partnerships for the Goals), which calls for multi-stakeholder collaboration to achieve sustainable development.

The impacts of supply chains on biodiversity are profound and extend beyond the initial stages of resource extraction. Research indicates that biodiversity is affected throughout the supply chain, including in transportation, storage, processing, and distribution (e.g., [27,28]). This perspective highlights the relevance of SDG 11 (Sustainable Cities and Communities), as urban logistics systems often intersect with biodiversity-rich areas.

Studies have explored integrating ecological principles into logistics, such as designing urban ecological corridors and optimizing micro-transit systems (e.g., [29–32]). These efforts contribute indirectly to biodiversity conservation by enhancing the sustainability of urban systems. However, explicit business practices tailored to reducing biodiversity impacts in logistics remain underexplored. This research gap limits the potential of logistics providers to align their operations with SDG 9 and SDG 15, thereby reducing their ecological footprint.

The responsibilities of various supply chain actors, including buyers, manufacturers, shippers, and transport operators, in managing biodiversity impacts are another area requiring further exploration. Research on supply chain management has often overlooked the implications for biodiversity, focusing instead on economic and operational efficiency (e.g., [8]). This study seeks to address this oversight by defining actionable practices that supply chain actors can adopt to align with the SDGs.

This literature review situates biodiversity research within the broader framework of the SDGs, emphasizing its relevance to multiple goals, including SDG 13, SDG 15, and SDG 17. By addressing gaps related to business practices, supply chain management, and tertiary sector impacts, this study contributes to advancing global sustainability objectives. It highlights the need for businesses to adopt biodiversity-oriented practices that align with SDG 12 and SDG 8. By integrating biodiversity considerations into their operations, companies can minimize negative impacts and create value for ecosystems, supporting both environmental and economic goals. Additionally, this study underscores the importance of incorporating biodiversity into supply chain management, aligning with SDG 9 and SDG 11. It proposes actionable strategies for logistics providers to enhance their ecological performance, reducing the sector's overall environmental footprint. Finally, this study emphasizes the interconnectedness of the SDGs, particularly the synergies between biodiversity conservation and other sustainability objectives. Fostering collaboration across sectors and disciplines advances the holistic approach needed to achieve the SDGs.

2.2. Methods Combined in the MCDM Model

Evaluating, ranking, and identifying practices of supply chains oriented toward the preservation of biodiversity, according to the requirements of different participants and a large number of conflicting criteria, represent a problem whose solution requires the application of MCDM methods. There are studies in the literature that have used MCDM methods to solve similar problems (e.g., [33]). This paper contributes to this field by proposing a new hybrid grey BWM–grey ADAM MCDM model.

The BWM [34] is a pairwise comparison method and is used to rank elements based on their relative importance or the ranker's preference. This method is used when different criteria are available to evaluate the different elements, and the goal is to select the best option or to rank the options according to the ranker's preference. In the literature, it is most often used to determine the weights of criteria in more complex MCDM models that combine several methods (e.g., [35]). When applying this method, respondents rank the elements according to their importance or preference; that is, they rate them as "best" and "worst" relative to the others, which enables a clear distinction between the most desirable and least desirable options. The main advantages of the method are precision, simplicity, transparency, and efficiency [36]. This method is characterized by high precision, i.e., sensitivity to small differences in preferences, which means that it can effectively identify subtle differences in the ranking of elements. The BWM method is often simpler to apply compared to other MCDM methods, such as the Analytic Hierarchy Process (AHP) or Analytic Network Process (ANP) techniques, because it requires a significantly smaller number of comparisons of decision elements. This method provides transparent insight into the respondents' preferences, as the best and worst elements are identified, which facilitates the interpretation of the results. In addition, the BWM method can quickly generate relevant information about preferences, which makes it efficient in situations where a quick decision needs to be made. The method also has some drawbacks. It may be less suitable for complex MCDM problems because it focuses on the direct ranking of elements rather than their mutual interaction. However, if there are no prominent mutual influences between the elements, as is the case with the problem in this study, this drawback is negligible. Another disadvantage is subjectivity. Like other multi-criteria decision-making methods, the BWM can be subject to subjective interpretations and biases, especially if respondents are insufficiently informed or have different perspectives. To mitigate this shortcoming, in this paper, a grey extension of the BWM method was used, which considers the uncertainty and ambiguity in the judgments of the decision-makers.

Apart from the advantages mentioned, the BWM method was used in the proposed model because of its proven applicability for solving problems in various fields and the possibility of effectively combining it with other MCDM methods. Particularly, the grey BWM method has previously been used to obtain criteria weights in hybrid MCDM models [37]. In recent years, the method has been used independently or in combination with other methods, in a conventional form or in a fuzzy, grey, or rough set environment, to solve problems such as the ranking of cloud services [35], the evaluation of business strategies in biomedical waste management [38], the performance evaluation of retail warehouses [39], the evaluation of sustainable energy systems in smart cities [40], the evaluation of agri-food circular-economy-based business models [41], supplier selection [42], etc.

The ADAM method [41] is a geometric MCDM method because ranking is based on determining the values of the volumes of complex polyhedra formed in three-dimensional space by the evaluation vectors of the alternatives according to the criteria and the evaluation of the weights of those criteria. Similarly to distance-based methods, such as the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [43], Multi-Criteria Optimization and Compromise Solution (VIKOR) [44], or Comprehensive Distance-Based Ranking (COBRA) [45], ADAM focuses on distances. However, unlike these methods, ADAM does this in a multi-dimensional space, thus forming complex geometric bodies that can be displayed graphically. Because of this, the results of applying this method are very intuitive; that is, the decision maker can identify the best alternative (the largest polyhedron, that is, the polyhedron with the largest volume) by simply looking at the graphical representations of the obtained polyhedra. So, ADAM might provide a clearer picture of how alternatives compare to each other on various criteria. Compared to pairwise comparison methods, another very popular group of MCDM methods whose best-known representatives are the Analytic Hierarchy Process (AHP) [46], the Analytic Network Process (ANP) [47], Step-wise Weight Assessment Ratio Analysis (SWARA) [48], etc., the ADAM method is much more efficient because it provides results with significantly less evaluation and consumption of resources (primarily time and humans). One of the main disadvantages of the ADAM method is that it requires the direct input of criteria weights and specific values of alternatives according to criteria. However, it can be very easily combined with other MCDM methods, which has already been proven in the literature (e.g., [49]), so the first drawback is easily overcome. The second drawback can also be overcome by extending the method to the environment of intuitive or interval sets. The ADAM method has so far been extended to the fuzzy environment [50] but not to the grey environment, which is another research gap that this paper covers. Although one of the newest MCDM methods, the applicability of the ADAM method has been widely proven by solving various problems, such as the ranking of drones from the perspective of their applicability in selecting tourism accommodation facilities [51], measuring the efficiency of logistics processes [52], ranking entrepreneurial systems in various European countries [53], selecting warehouse locations [54], evaluating and selecting city logistics concepts [55], evaluating strategies to achieve circularity in the agroindustry [56], etc.

Aside from the fact that the BWM and ADAM method have not been used to rank supply chain practices, they have also never been combined in a grey environment, which are also research gaps that this study covers. Grey sets, in contrast to fuzzy and rough sets, offer improved handling of partial data and the ability to merge vague or incomplete information into a single model [57]. Furthermore, grey sets can represent scenarios that cannot be captured by either fuzzy or rough sets [57].

3. Problem Statement

The problem addressed in this study involved identifying, evaluating, and ranking supply chain management practices that have the greatest potential for biodiversity conservation. In this procedure, a set of criteria was used that included different dimensions of environmental impact, enabling objective evaluation and ranking of the considered practices.

3.1. Supply Chain Management-Oriented Biodiversity Protection Practices

Biodiversity Impact Assessment(BIA) (P_1) is a systematic process of identifying, assessing, and understanding the potential impacts of business activities or projects on biodiversity [58]. This practice is often applied within supply chain management to ensure that company activities are carried out with minimal negative impact on local ecosystems. The BIA process includes several key steps. First, all relevant activities, project phases, or processes within the supply chain that may have potential impacts on biodiversity are identified. This may include an analysis of suppliers, manufacturing facilities, transportation, or other aspects of the business. After identification, it is necessary to assess the impact on biodiversity, i.e., to analyze how each identified activity or process will affect local species, habitats, and ecosystem services. This includes assessing direct and indirect impacts as well as cumulative effects over time. After the assessment, the company identifies strategies to mitigate the negative impacts and improve the positive aspects of biodiversity. This may include adjustments in product design, changes in waste management practices, or the adoption of sustainable production methods. The key value of a BIA practice lies in the information it provides to the business and its stakeholders. This enables informed decision-making and the identification of needed improvements and demonstrates a commitment to sustainable business. By implementing BIA, businesses can integrate biodiversity conservation into their business practices, achieving a balance between economic efficiency and responsibility towards nature [59]. This practice aligns with SDG 12, SDG 15, and SDG 9 through systematic evaluation and mitigation of the environmental impacts of business activities, ensuring the protection of ecosystems while supporting economic and operational sustainability.

Biodiversity goal setting, monitoring, reporting, and transparency (P_2) are aimed at achieving specific goals related to biodiversity conservation, monitoring progress in their achievement, reporting results, and transparently sharing information with stakeholders [60]. First, the company defines clear and measurable biodiversity goals. These can be quantified goals, such as reducing the ecological footprint or increasing support for local species and habitats. The targets should be in line with international biodiversity standards and specific local conditions. After setting goals, the company implements tracking systems to regularly measure its progress. This includes the collection of relevant data on the impact of business on biodiversity, as well as the implementation of metrics that allow for the accurate measurement of the achievement of goals. Reporting results is a key step in this practice. The company prepares annual or periodic reports on achieving biodiversity goals. These reports provide information on measurable results and the identification of challenges and improvements, which supports transparency and accountability to stakeholders. Transparency is essential, and a company should actively share information about its goals, achievements, and planned actions with stakeholders, including consumers, suppliers, investors, and local communities. Open dialogue with these parties can further support sustainability and contribute to a positive perception of the company. Through biodiversity target-setting, monitoring, reporting, and transparency, businesses integrate environmental responsibility into their business practices, creating more sustainable supply chains and contributing to the long-term conservation of biodiversity [61]. This practice aligns with SDG 12, SDG 17, and SDG 15 through measurable targets, accountability, and open stakeholder engagement that integrates environmental responsibility into business practices.

Education and awareness raising (P_3) of employees, suppliers, and service users aim to create a proactive and informed working community that understands the importance of biodiversity and contributes to its preservation [62]. First, the company establishes comprehensive training programs for its employees, emphasizing the importance of biodiversity, its role in business activities, and ways to reduce the negative impact on natural ecosystems. This education can include sector-specific information, expected practices, and concrete steps employees can take to contribute to biodiversity conservation. Additionally, collaboration with suppliers is vital. The company provides educational resources and programs for its suppliers, helping them understand biodiversity standards and expectations. This may include guidelines on sustainable resource use, emission reductions, and other practices that support biodiversity. Service users can also get involved through awareness campaigns and educational materials that provide information about the impact of products or services on biodiversity. This information can promote awareness of environmentally responsible behavior and influence consumer decisions. This practice not only informs but also motivates employees, suppliers, and users to take steps toward a more sustainable business. Through education and awareness, the company builds an engaged team of people who actively contribute to the preservation of biodiversity, creating more sustainable supply chains and a wider positive impact on society [63]. This practice aligns with SDG 4, SDG 12, and SDG 15 through empowering employees, suppliers, and service users with knowledge and practices that drive biodiversity preservation and sustainable behavior.

Stakeholder collaboration (P_4) involves active collaboration with authorities, local communities, non-governmental organizations (NGOs), and biodiversity experts to achieve the holistic and sustainable management of biodiversity in supply chains [64]. This practice reflects the company's commitment to achieving biodiversity goals through an inclusive process and synergy with relevant stakeholders. First, the company establishes dialogue with local authorities to understand the regulatory framework and environmental priorities in local communities. This allows business practices to adapt to local requirements, thereby enhancing sustainability and supporting local biodiversity conservation initiatives. Cooperation with local communities includes active involvement in projects and initiatives that contribute to nature conservation. This may include support for local education programs, sustainable employment, or joint initiatives to conserve natural resources. Partnership with NGOs in the field of biodiversity enables the exchange of expertise and access to the latest research and practices in biodiversity conservation. This collaboration also helps the company to identify areas for potential improvement in its operations and to implement best practices. Finally, cooperation with experts in the field of biodiversity contributes to the expertise and direction of the company according to the latest scientific knowledge. This includes consultations, workshops, or joint initiatives that promote innovation and improve biodiversity management strategies. This approach involving cooperation with stakeholders not only strengthens corporate social responsibility but also contributes to more effective biodiversity conservation through inclusiveness and synergy with relevant communities and experts [65]. This practice aligns with SDG 11, SDG 15, and SDG 17 through inclusive cooperation with authorities, local communities, NGOs, and experts to implement holistic biodiversity management strategies in supply chains.

The application of smart technologies (P_5) in supply chains improves the efficiency and sustainability of operations while contributing to nature conservation and other positive effects on biodiversity [66]. The application of sensors and Internet of Things (IoT) technology in logistics processes enables the monitoring of the transport and storage of goods, minimizing the negative impact on the environment. This tracking accuracy contributes to reduced emissions, the optimal use of resources, and more efficient supply chain management. Using data analytics and artificial intelligence, businesses can identify areas where sustainable practices can be implemented. These analysis systems enable the identification of ecological hot-spots, improving resource management and reducing negative impacts on biodiversity. Blockchain technology can be used for traceability and transparency in the supply chain, especially in industries that use natural resources. This helps prevent illegal trade and illegal exploitation, supporting the fair and sustainable use of resources. The integration of technologies such as drones and geographic information systems (GISs) enables the precise mapping of terrain, the identification of sensitive habitats, and monitoring of changes in ecosystems. These technological solutions contribute to the sustainable management of resources and a reduction in the negative impact on biodiversity. Essentially, technological innovations in supply chains not only increase business efficiency but also provide tools to actively reduce negative impacts on biodiversity, making sustainability an integral part of business operations [67]. This practice aligns with SDG 9, SDG 12, and SDG 15 through enhanced efficiency, transparency, and data-driven strategies that actively reduce environmental impacts and support biodiversity conservation.

The application of green technologies (P_6) in the context of logistics activities directly affects the reduction in negative impacts on ecosystems [68]. The use of energy-efficient means of transport, such as electric and hybrid trucks, contributes to reducing harmful gas emissions and minimizes the impact of transport on biodiversity. Tracking and transport management systems enable route optimization, reducing the need for additional journeys and reducing pressure on ecosystems. In warehouses, the application of green technologies includes the use of automated inventory management systems and temperature control systems. These systems not only increase storage efficiency but also reduce product losses, reducing the need for intensive agricultural practices that can negatively impact biodiversity. Handling and packaging management platforms also contribute to reducing waste and negative impacts on nature. Integrating recyclable and reusable materials into packaging reduces resource consumption and helps preserve natural habitats. Through all these applications of green technologies, supply chains become more sustainable, reducing their ecological footprint and contributing to the preservation of biodiversity. These innovations not only increase the efficiency of logistics processes but also lay the foundation for a long-term balance between economic activity and nature protection. This practice aligns with SDG 12, SDG 13, and SDG 15 through energy-efficient transport, waste reduction, and sustainable resource use, thereby minimizing ecological footprints and preserving biodiversity.

Sustainable use of resources (P_7) implies efficient and responsible access to resources along the entire supply chain, from production to distribution [69]. The implementation of the sustainable use of resources includes various aspects. One of them is the optimization of the production process to minimize waste and reduce the consumption of raw materials. Through the use of efficient technologies and innovations, companies can increase resource efficiency, reducing the negative impact on biodiversity. There cycling and reuse of materials are becoming key elements of sustainable resource use. The integration of circular models into supply chains implies the reuse of products, parts, or materials, reducing the need for new resources and minimizing the amount of waste. Monitoring and evaluating the ecological footprint throughout the supply chain enable companies to identify key areas for improvement. The implementation of technologies for measuring resource consumption and emissions contributes to transparency and informed decision-making. The sustainable use of resources also involves working with suppliers and partners to promote sustainable practices in supply chains. Setting standards for the responsible use of resources and promoting those standards within business relationships contribute to creating more sustainable practices in a wider context. Through all these initiatives, the practice of sustainably using resources in supply chains not only supports nature conservation but also creates the foundations for a long-term sustainable business model aligned with environmental challenges and biodiversity needs. This practice aligns with SDG 9, SDG 12, and SDG 15 through waste minimization, circular economy practices, and collaboration with supply chain partners to reduce ecological footprints and support biodiversity conservation.

Supply chain policies (P_8) for biodiversity protection encompass certifications, standards, codes of conduct, and market exclusion mechanisms to ensure adherence to sustainable practices and biodiversity conservation principles [70]. Certifications and standards, such as the FSC (Forest Stewardship Council) or Fair Trade, validate businesses' commitment to environmental and social responsibility, promoting transparency and trust among consumers. Companies adopting these certifications undergo rigorous evaluation to meet sustainability criteria, fostering responsible practices across the supply chain. Codes of conduct serve as guidelines for suppliers, outlining expectations regarding biodiversity conservation practices. They encompass requirements for sustainable sourcing, responsible land use, and adherence to relevant regulations, embedding biodiversity considerations into sourcing decisions and operational practices. Market exclusion mechanisms enforce compliance with codes of conduct by penalizing non-compliant suppliers, such as through contract termination or fines, incentivizing adherence to biodiversity conservation standards, and driving positive change throughout the supply chain. Together, these policies form a comprehensive framework for biodiversity protection within supply chains [71]. By integrating certifications, standards, codes of conduct, and market exclusion mechanisms, companies promote sustainable practices, enhance brand reputation, and contribute to the conservation of natural habitats, species diversity, and ecosystem health. This approach not only aligns business operations with the highest environmental standards but also fosters long-term resilience and sustainability in supply chains. This practice aligns with SDG 12, SDG 15, and SDG 17 through the integration of certifications, standards, codes of conduct, and market exclusion mechanisms that embed sustainability and biodiversity conservation into supply chain operations.

Compliance with legislation (P_9) in supply chains ensures that businesses comply with legal regulations that support biodiversity conservation [27]. This practice involves careful monitoring and analysis of relevant laws at the local, national, and international levels to ensure full regulatory compliance. Businesses that practice legislative adaptation actively monitor changes in laws related to natural resource management, habitat protection, and reducing impacts on biodiversity. This includes monitoring and adapting practices related to resource exploitation, emissions reduction, and the protection of endangered species. In addition to compliance with existing laws, this practice also includes anticipation and adaptation to future legal changes that may relate to biodiversity conservation. Businesses recognize the importance of a proactive approach to avoid the potential negative consequences of legal changes and, at the same time, contribute to long-term sustainability. Collaboration with legal experts and consultation with relevant regulatory bodies become an important part of this practice. The exchange of information and dialogue with competent authorities enable companies to adequately adapt their operations to reflect the latest legal requirements. Compliance with legislation not only ensures compliance with regulations but also sends a strong message of commitment to biodiversity conservation and responsible business. This practice lays the foundation for business integrity within regulatory frameworks, contributing at the same time to nature protection and sustainable development. This practice aligns with SDG 12, SDG 15, and SDG 16 through proactive adherence to biodiversity-related regulations, fostering accountability, legal integrity, and long-term sustainability in business practices.

3.2. Criteria for the Evaluation of Biodiversity Protection Practices

The degree of direct impact on the preservation of ecosystems and biodiversity (C_1) measures the concrete contribution of the practice to environmental protection. A high score is awarded if the practice directly supports ecosystem and biodiversity conservation, while a low score indicates a lack of direct contribution.

The efficiency and applicability of a practice (C_2) evaluate how effective the practice is in achieving the set goals for biodiversity conservation while emphasizing easy integration into existing business processes. A high score reflects not only efficiency but also easy integration into already established business flows, reducing application complexity and facilitating successful implementation.

The ability to measure and monitor the effects of a practice, transparency, and reporting (C_3) assesses the degree to which it is possible to quantify and monitor the results of applied practices in biodiversity conservation. A high score indicates clear transparency in data collection, facilitating reporting on achieved effects and contributing to the overall improvement process.

The costs and benefits of implementing a practice (C_4) consider the economic aspects of each practice, taking into account initial investments, operating costs, and long-term benefits. The focus is on the financial aspect, evaluating the costs of implementation, maintenance, and long-term investments according to the expected benefits. This analysis enables the ranking of practices according to economic viability and contribution to the ecosystem and community, favoring those practices that provide significant benefits at reasonable costs.

Flexibility (C_5) assesses the adaptability of a practice to different conditions, situations, and changes in the environment. Practices that demonstrate a high level of flexibility easily adapt to the dynamic demands of the business environment, can be quickly integrated into existing business processes, and effectively respond to new challenges. This criterion prioritizes practices that provide sustainable results in different scenarios and easily adapt to changes in business and the environment.

The degree of stakeholder involvement (C_6) assesses the extent of an organization's engagement and interaction with relevant stakeholders. A higher degree of stakeholder involvement indicates open dialogue, cooperation, and consideration of diverse interests. It assesses how the practice actively integrates stakeholder feedback, needs, and perspectives, contributing to the sustainable management of biodiversity and ecosystems. Practices that achieve a high degree of stakeholder involvement receive better ratings because of their comprehensive approach and support from the wider community.

Compatibility and the possibility of combining a practice with other practices (C_7) assess the degree of compatibility and the possibility of integrating a given practice with other defined practices. A higher degree of compatibility indicates the ability of a practice to harmoniously fit with and complement others, thus creating a synergistic effect. Practices that demonstrate high compatibility and complementarity represent a more sustainable and integrative approach to biodiversity and ecosystem management.

4. Methodology

To solve the problem defined in this study, a new hybrid MCDM model was developed. It includes a combination of the BWM and ADAM method in a grey environment. The steps of the proposed model are described below and presented in Figure 1.

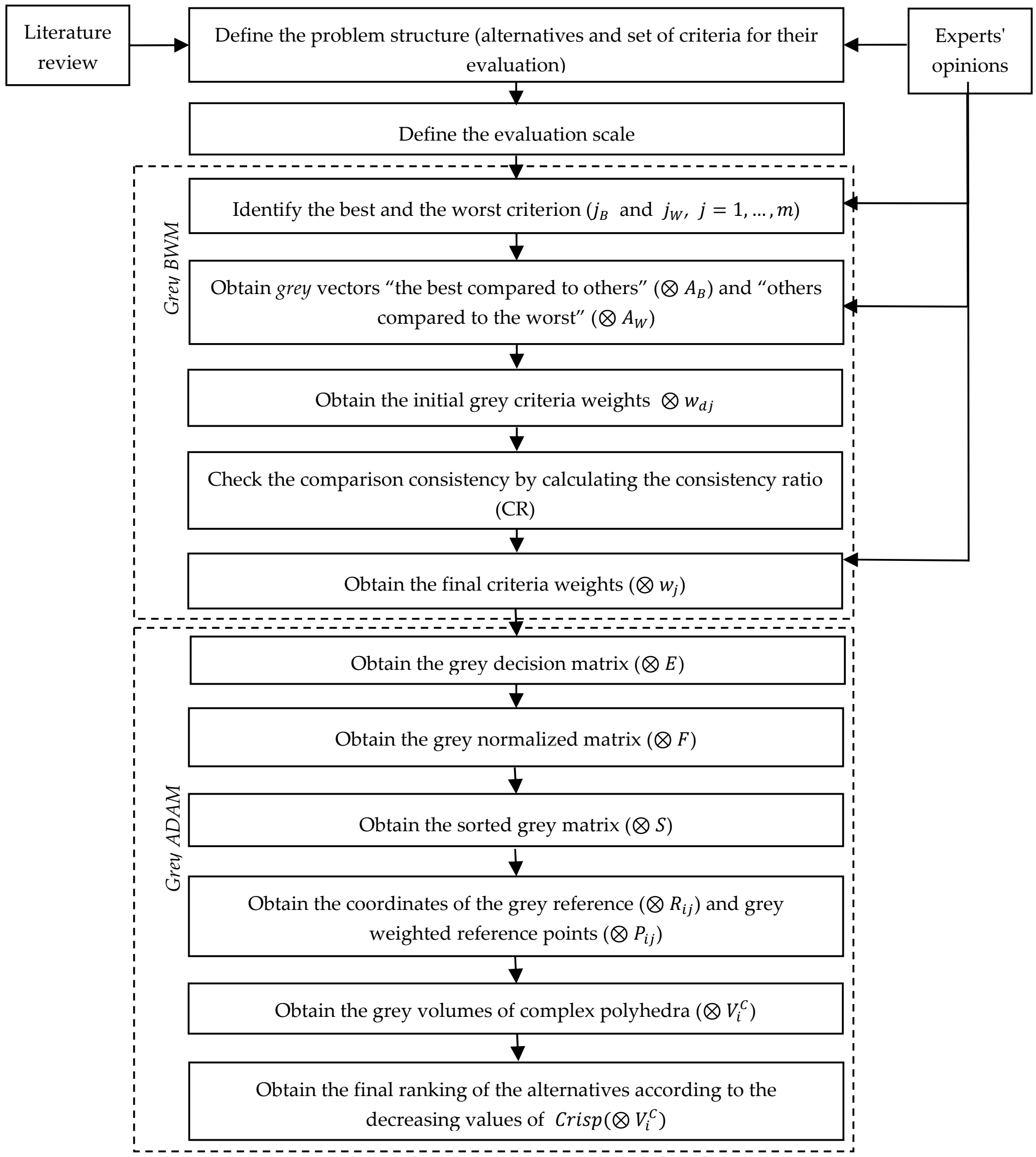

Figure 1. Structure of the proposed MCDM model.

Step 1: Define the problem structure—form the sets of alternatives and criteria for their evaluation.

Step 2: Define the greyscale for the evaluations required by the grey BWM and grey ADAM method (Table 1).

Table 1. Grey evaluation scale.

Linguistic Term	Abbreviation	Grey Scale
"None"	"N"	[0, 2]
"Very Low"	"VL"	[1, 3]
"Low"	"L"	[2, 4]
"Fairly Low"	"FL"	[3, 5]
"Moderate"	"M"	[4, 6]
"Fairly High"	"FH"	[5, 7]
"High"	"H"	[6, 8]
"Very High"	"VH"	[7, 9]
"Extremely High"	"EH"	[8, 10]

Step 3: Obtain the criteria weights by using the grey BWM method [37].

Step 3.1: Decision-makers (DMs) d $(d = 1, \ldots, f)$, where f represents the DMs, select the best and the worst criteria (j_B and j_W, $j = 1, \ldots, m$), where m is the number of criteria. DMs evaluate other criteria in comparison with j_B and j_W, by using the scale from Table 1, thus obtaining grey vectors: "the best compared to others"—$\otimes A_B = (\otimes a_{B1}, \otimes a_{B2}, \ldots, \otimes a_{Bm})$, and "others compared to the worst"—$\otimes A_W = (\otimes a_{1W}, \otimes a_{2W}, \ldots, \otimes a_{mW})$.

Step 3.2: Obtain the optimal grey criteria weights, $\otimes w_{d1}, \otimes w_{d2}, \ldots, \otimes w_{dm}$, $\forall d = 1, \ldots, f$, by solving the optimization problem:

$$\min \otimes\xi \quad s.t. \begin{cases} \left| \frac{\otimes w_B}{\otimes w_{dj}} - \otimes a_{Bj} \right| \leq \otimes\xi \\ \left| \frac{\otimes w_{dj}}{\otimes w_W} - \otimes a_{jW} \right| \leq \otimes\xi \\ \sum_{j=1}^{m} W\left(\otimes w_{dj}\right) = 1 \\ \underline{w}_{dj} \leq \overline{w}_{dj} \\ \underline{w}_{dj} \geq 0 \\ j = 1, \ldots, m \end{cases}, \tag{1}$$

where $\otimes\xi = \left[\underline{\xi}, \overline{\xi}\right]$, $\otimes w_B = [\underline{w}_B, \overline{w}_B]$ is the grey weight of the "best" criterion, $\otimes w_w = [\underline{w}_W, \overline{w}_W]$ is the grey weight of the "worst" element criterion, $\otimes w_{dj} = \left[\underline{w}_{dj}, \overline{w}_{dj}\right]$ is the grey weight of criterion j, $j = 1, \ldots, m$, $j \neq j_B, j_W$, $\otimes a_{Bj} = \left[\underline{a}_{Bj}, \overline{a}_{Bj}\right]$ is the grey preference of the "best" criterion over criterion j, and $\otimes a_{jW} = \left[\underline{a}_{jW}, \overline{a}_{jW}\right]$ is the preference of criterion j over the "worst" criterion. $W\left(\otimes w_j\right)$ is the white value of the grey number $\otimes w_j$:

$$W\left(\otimes w_{dj}\right) = \left(\underline{w}_{dj} + \overline{w}_{dj}\right)/2, \tag{2}$$

Step 3.3: Check the comparison consistency by calculating the consistency ratio (CR) with

$$CR = R(\otimes\xi)/CI, \tag{3}$$

where $R(\otimes\xi)$ is the white value of the grey number $\otimes\xi$, obtained from (2), and CI is the consistency index:

$$CI^2 - (1 + 2\overline{a}_{BW})CI + \left(\overline{a}_{BW}^2 - \overline{a}_{BW}\right) = 0, \tag{4}$$

where

$$\otimes a_{BW} = \max_j \left\{\otimes a_{Bj}, \otimes a_{jW}\right\}. \tag{5}$$

The comparison is considered consistent if the CR value is close to 0.

Step 3.4: Obtain the final criteria weights:

$$\otimes w_j = \left[\underline{w}_j, \overline{w}_j\right], \forall j = 1, \ldots, m, \tag{6}$$

$$\underline{w}_j = \left(\prod_{d=1}^{l} \underline{w}_{dj}\right)^{1/d}, \tag{7}$$

$$\overline{w}_j = \left(\prod_{d=1}^{l} \overline{w}_{dj}\right)^{1/d}, \tag{8}$$

Step 4: Rank the alternatives using the extension of the ADAM-MCDM method in the grey environment.

Step 4.1: Obtain the grey decision matrix:

$$\otimes E = [\otimes e_{ij}]_{m\times n}, \tag{9}$$

where $\otimes e_{ij} = \left[\underline{e}_{ij}, \overline{e}_{ij}\right],\ i = 1,\ldots,m,\ j = 1,\ldots,n$ is the grey evaluation of alternative i regarding criterion j.

Step 4.2: Obtain the grey normalized matrix:

$$\otimes F = [\otimes f_{ij}]_{m\times n}, \tag{10}$$

where $\otimes f_{ij} = \left[\underline{f}_{ij}, \overline{f}_{ij}\right], i = 1,\ldots,m, j = 1,\ldots,n$ is the normalized grey evaluation, obtained as follows:

$$\otimes f_{ij} = \frac{\otimes e_{ij}}{\max\limits_{i} e_{ij}},\ \forall i = 1,\ldots,m,\ \forall j = 1,\ldots,n, \tag{11}$$

Step 4.3: Obtain the sorted grey matrix:

$$\otimes S = [\otimes s_{ij}]_{m\times n}, \tag{12}$$

where $\otimes s_{ij}$ represents the sorted $\otimes f_{ij}$ according to the descending values of corresponding criteria weights.

Step 4.4: Obtain the coordinates of the grey reference $\otimes R_{ij}$ and grey weighted reference points $\otimes P_{ij}$:

$$\otimes x_{ij} = \left[\underline{x}_{ij}, \overline{x}_{ij}\right] = \otimes s_{ij} \times \sin\alpha,\ \forall i = 1,\ldots,m,\ \forall j = 1,\ldots,n, \tag{13}$$

$$\otimes y_{ij} = \left[\underline{y}_{ij}, \overline{y}_{ij}\right] = \otimes s_{ij} \times \cos\alpha,\ \forall i = 1,\ldots,m,\ \forall j = 1,\ldots,n \tag{14}$$

$$\otimes z_{ij} = \left[\underline{z}_{ij}, \overline{z}_{ij}\right] = \begin{cases} [0,0], & for\ \otimes R_{ij} \\ \left[\underline{w}_{ij}, \overline{w}_{ij}\right], & for\ \otimes P_{ij} \end{cases},\ \forall i = 1,\ldots,m,\ \forall j = 1,\ldots,n \tag{15}$$

where

$$\alpha = (j-1)\frac{90^\circ}{n-1},\ \forall j = 1,\ldots,n. \tag{16}$$

Step 4.5: Obtain the grey volumes of complex polyhedra:

$$\otimes V_i^C = \sum\nolimits_{k=1}^{n-1} \otimes V_k,\ \forall i = 1,\ldots,m, \tag{17}$$

where V_k are the pyramids of which the polyhedra are composed:

$$\otimes V_k = \frac{\otimes B_k \times \otimes h_k}{3},\ \forall k = 1,\ldots,n-1, \tag{18}$$

where $\otimes B_k$ and $\otimes h_k$ are the grey base and height of the pyramid, respectively:

$$\otimes B_k = \otimes c_k \times \otimes a_k + \frac{\otimes a_k \times (\otimes b_k - \otimes c_k)}{2}, \tag{19}$$

$$\otimes h_k = \frac{2\sqrt{\otimes s_k \times (\otimes s_k - \otimes a_k) \times (\otimes s_k - \otimes d_k) \times (\otimes s_k - \otimes e_k)}}{\otimes a_k}, \tag{20}$$

The values used in Equations (11) and (12) are obtained as follows:

$$\otimes a_k = \sqrt{(\otimes x_{j+1} - \otimes x_j)^2 + \left(\otimes y_{j+1} - \otimes y_j\right)^2}, \tag{21}$$

$$\otimes b_k = \otimes z_j, \tag{22}$$

$$\otimes c_k = \otimes z_{j+1}, \tag{23}$$

$$\otimes s_k = \frac{\otimes a_k + \otimes d_k + \otimes e_k}{2}, \tag{24}$$

in which

$$\otimes d_k = \sqrt{\otimes x_j^2 + \otimes y_j^2}. \tag{25}$$

Step 4.6: Obtain the final ranking of the alternatives by arranging the corresponding volumes $Crisp\left(\otimes V_i^C\right)$, obtained from Equation (2), in descending order.

5. Results

The defined problem of ranking practices was solved by applying the MCDM model described in Section 4, and the stability of the obtained results was verified by conducting a sensitivity analysis.

5.1. Ranking of Practices

A group of experts with different experiences and backgrounds evaluated the importance of the defined criteria. The expert group consisted of researchers and practitioners from various backgrounds, such as transport and traffic engineers and logisticians (8), economists (6), agricultural engineers (5), industrial engineers (3), biologists (2), law counsels (2), and chemists (1), with multiple years of research and/or working experience in the fields of economy, logistics and supply chains, agriculture, and environmental protection. The structure of the group of experts depending on their experience is shown in Table 2. The process of consulting (interviewing) experts was conducted in online and live sessions (from February to April 2024).

Table 2. Focus group structure.

Sector	Number of Experts	Experience (Years)
Economics	2	<5
	4	5–15
	3	>15
Logistics and supply chain	4	<5
	3	5–15
	3	>15
Agriculture and environmental protection	2	<5
	2	5–15
	4	>15

The experts chose the best and worst criteria and then evaluated the other criteria according to them with linguistic grades corresponding to the grey values (Table 1). An example of the evaluation of the criteria by one expert is given in Table 3. By solving optimization problems (1)and (2) for the grey values of the comparison of the criteria, the optimal grey weights of the criteria were obtained, which are also shown in Table 3. The consistency of the evaluations was checked using Equations (3)–(5). For the sample evaluations from Table 3, $CR = 0.01$ was obtained, which means that the evaluation was consistent.

Table 3. Example of criteria evaluation by one expert.

	C1	C2	C3	C4	C5	C6	C7
Best compared to others	best	"VL"	"FH"	"L"	"FL"	"M"	"H"
others compared to worst	"H"	"FH"	"L"	"M"	"FL"	"VL"	worst
$\otimes A_B$	/	[1, 3]	[5, 7]	[2, 4]	[3, 5]	[4, 6]	[6, 8]
$\otimes A_W$	[6, 8]	[5, 7]	[2, 4]	[4, 6]	[3, 5]	[1, 3]	/
$\otimes w_{dj}$	[0.289, 0.407]	[0.169, 0.259]	[0.064, 0.073]	[0.127, 0.160]	[0.102, 0.107]	[0.076, 0.085]	[0.038, 0.046]

The previously described procedure was repeated for each expert who performed the evaluation. By applying Equations (6)–(8), the final weights of the criteria were obtained: $C_1 = [0.238; 0.334]$; $C_2 = [0.167; 0.247]$; $C_3 = [0.085; 0.098]$; $C_4 = [0.151; 0.188]$; $C_5 = [0.092; 0.097]$; $C_6 = [0.066; 0.075]$; and $C_7 = [0.038; 0.046]$.

In the next step, the experts evaluated the practices according to the defined criteria by applying the relations given in Table 1. An example of the evaluation of the practices by one expert is given in Table 4.

Table 4. Example of practice evaluation in relation to criteria.

	C1	C2	C3	C4	C5	C6	C7
Biodiversity Impact Assessment	"M"	"H"	"VH"	"H"	"H"	"M"	"FH"
Biodiversity goal setting, monitoring, reporting, and transparency	"FH"	"H"	"VH"	"H"	"H"	"M"	"H"
Education and awareness raising	"VL"	"FH"	"H"	"EH"	"EH"	"H"	"VH"
Stakeholder collaboration	"VL"	"FH"	"FL"	"FL"	"M"	"EH"	"EH"
Application of smart technologies	"FL"	"L"	"VL"	"VL"	"L"	"VL"	"N"
Application of green technologies	"EH"	"FL"	"L"	"L"	"FL"	"L"	"VL"
Sustainable use of resources	"VH"	"L"	"N"	"N"	"VL"	"N"	"L"
Supply chain policies	"H"	"EH"	"FH"	"H"	"FH"	"VH"	"M"
Compliance with legislation	"N"	"N"	"M"	"M"	"N"	"FL"	"FL"

The evaluations of all experts were converted into grey values and then statistically processed, and the answers with the highest frequency were chosen as representative. In this way, the grey decision matrix (9) was obtained, which was normalized using Equations (10) and (11) and then sorted using Equation (12). The grey coordinates of points $\otimes R_{ij}$ and $\otimes P_{ij}$ were then obtained by applying Equations (13)–(16). The final ranking of the alternatives was obtained based on the decreasing values of the volumes of complex polyhedra obtained by applying Equations (17)–(25). The final values and ranking of practices are shown in Table 5. The results indicate that the best-ranked practice is P_8, followed by practices P_2, P_3, P_1, P_4, P_6, P_5, P_7, and P_9, respectively.

Table 5. Volumes of complex polyhedra and final ranking of practices.

Practice	$\otimes \mathbf{V}_i^C$	Crisp ($\otimes \mathbf{V}_i^C$)	Rank
Biodiversity Impact Assessment	[0.014, 0.059]	0.037	4
Biodiversity goal setting, monitoring, reporting, and transparency	[0.015, 0.064]	0.039	2
Education and awareness raising	[0.017, 0.057]	0.037	3
Stakeholder collaboration	[0.008, 0.034]	0.021	5
Application of smart technologies	[0.001, 0.016]	0.009	7
Application of green technologies	[0.005, 0.029]	0.017	6
Sustainable use of resources	[0.002, 0.014]	0.008	8
Supply chain policies	[0.019, 0.068]	0.044	1
Compliance with legislation	[0.001, 0.011]	0.006	9

5.2. Sensitivity Analysis

As the results were obtained based on experts' evaluations, it is very important to examine their stability. This implies carrying out a sensitivity analysis, that is, an analysis of changes in the final ranking of alternatives due to changes in the input parameters of the model. In this study, for the sensitivity analysis, seventeen scenarios (Sc. 1–17) were created, in the first fifteen of which the weight was gradually reduced (by 20%, 40%, 60%, 80%, and 100%) for the three most significant criteria (criteria with the highest weights). In the penultimate scenario, all three of the most important criteria were eliminated, and in the last one, the weights of all criteria were equalized. The results of the performed sensitivity analysis are shown in Table 6 and Figure 2. It can be seen that in the mentioned scenarios, there are slight changes in the ranking of alternatives. In seven scenarios, the ranking is identical to the base zero scenario (Sc.0). In six scenarios, minor perturbations occur between alternatives P_1, P_2, and P_3, which are ranked between second and fourth place. In the remaining four scenarios, there are somewhat larger changes in the ranking of alternatives, but even in those scenarios, the three best-ranked alternatives from the basic scenario dominate; that is, they occupy one of the top three places. Following the analysis, it can be concluded that the results obtained in the initial ranking are stable enough and can thus be adopted as the final results. The most favorable practice is P_8 (supply chain policies), followed by practices P_2 (biodiversity goal setting, monitoring, reporting, and transparency) and P_3 (education and awareness raising).

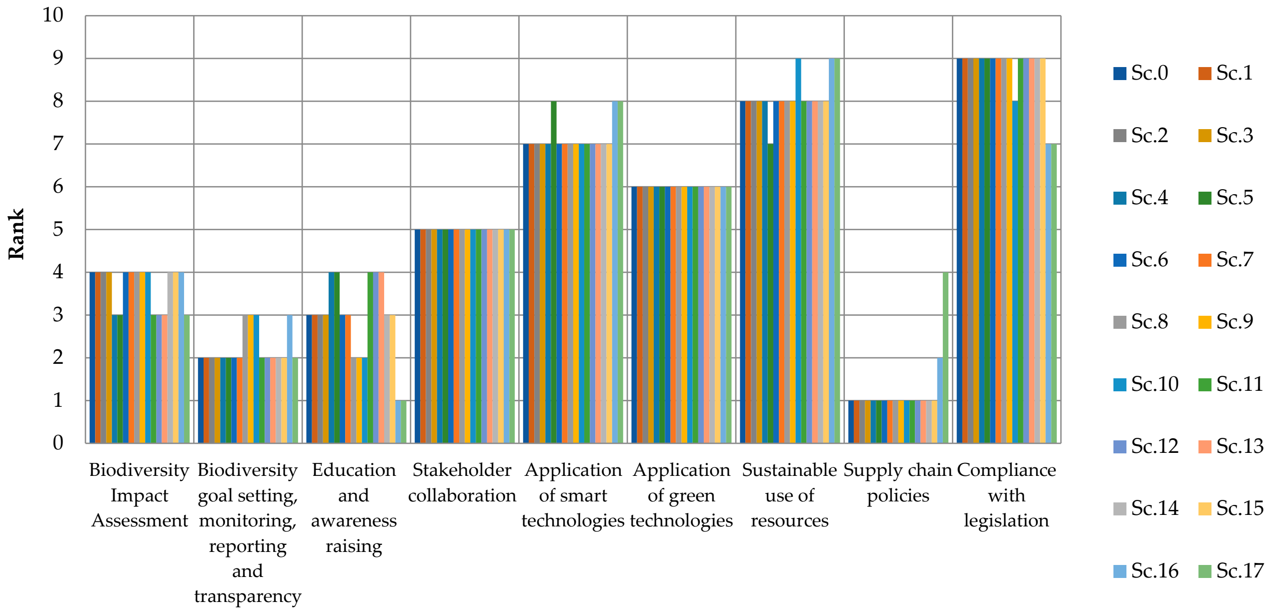

Figure 2. Sensitivity analysis.

Table 6. Sensitivity analysis results.

	Biodiversity Impact Assessment	Biodiversity Goal Setting, Monitoring, Reporting, and Transparency	Education and Awareness Raising	Stakeholder Collaboration	Application of Smart Technologies	Application of Green Technologies	Sustainable Use of Resources	Supply Chain Policies	Compliance with Legislation
Sc. 0	4	2	3	5	7	6	8	1	9
Sc. 1	4	2	3	5	7	6	8	1	9
Sc. 2	4	2	3	5	7	6	8	1	9
Sc. 3	4	2	3	5	7	6	8	1	9
Sc. 4	3	2	4	5	7	6	8	1	9
Sc. 5	3	2	4	5	8	6	7	1	9
Sc. 6	4	2	3	5	7	6	8	1	9

Table 6. *Cont.*

	Biodiversity Impact Assessment	Biodiversity Goal Setting, Monitoring, Reporting, and Transparency	Education and Awareness Raising	Stakeholder Collaboration	Application of Smart Technologies	Application of Green Technologies	Sustainable Use of Resources	Supply Chain Policies	Compliance with Legislation
Sc. 7	4	2	3	5	7	6	8	1	9
Sc. 8	4	3	2	5	7	6	8	1	9
Sc. 9	4	3	2	5	7	6	8	1	9
Sc. 10	4	3	2	5	7	6	9	1	8
Sc. 11	3	2	4	5	7	6	8	1	9
Sc. 12	3	2	4	5	7	6	8	1	9
Sc. 13	3	2	4	5	7	6	8	1	9
Sc. 14	4	2	3	5	7	6	8	1	9
Sc. 15	4	2	3	5	7	6	8	1	9
Sc. 16	4	3	1	5	8	6	9	2	7
Sc. 17	3	2	1	5	8	6	9	4	7

6. Discussion

The obtained ranking of the practices provides information on the order in which the practices should be applied, that is, which practices are the easiest to apply or would provide the most favorable effects in the shortest time with a reasonable expenditure of resources. However, this does not mean that only one practice, i.e., the best-ranked, should be applied. The best effects would be achieved through a combination of various practices. Looking at the top three best-ranked practices, P_8 focuses solely on the supply chain, implementing concrete biodiversity protection tools such as certificates and codes of conduct, P_2 implies a structured approach with clear goals and measurable results, enabling the company to make areal contribution to the preservation of biodiversity, defining what needs to be done, and P_3, through the education of employees, suppliers, and users, creates conditions for long-term success and behavior change, enabling previous practices to be successfully implemented.

By implementing these practices, companies can reduce their negative impact on biodiversity, i.e., their ecological footprint. In addition, they can improve the brand reputation. Consumers increasingly value companies that care about the environment, which can lead to higher sales and loyalty. In general, these practices can lead to a reduction in supply chain risk because sustainable supply chains are less exposed to disruptions due to resource shortages or regulatory changes. Ultimately, these practices encourage innovation as they encourage companies to find new ways to reduce their environmental impact and improve sustainability. Of course, the application of practices has some disadvantages. Establishing a biodiversity protection program may require initial financial investments. Companies may also find it difficult to find suppliers who share their sustainability goals. In addition, monitoring biodiversity impact data and transparent reporting can be challenging, and changing the culture and behavior of employees and suppliers can take time and continuous education.

Previous research has identified some supply chain management practices that can positively impact biodiversity conservation (e.g., [58,60,62]). However, these studies mostly analyze individual practices (e.g., [64,66,70]), while this study offers a more comprehensive approach that considers several practices at the same time and mutually compares, evaluates, and ranks them, which has not been achieved so far. One of the few studies that also looked at a larger number of practices was performed by Salmi et al. [8], but even they did not compare and rank each practice. This study began by conducting a thorough literature review and carrying out expert consultations to identify a comprehensive set of supply chain management practices that contribute to biodiversity conservation. These practices were carefully selected to ensure their realistic applicability in the business world. RQ1 was answered by defining a robust framework and set of criteria for evaluating the identified practices. This framework included criteria that enabled an objective assessment of the contribution of each practice to the preservation of biodiversity. Also, the hybrid MCDM model made it possible to identify the practices that bring the greatest benefits to biodiversity while realistically considering the possibilities and complexity of their implementation. By developing a robust framework and an innovative hybrid MCDM model, this study confirms the possibility of defining a universally applicable approach, thus answering RQ2. The framework and criteria provide a flexible structure for the objective evaluation of various practices in different industrial contexts. By answering the research questions, this study provides significant contributions to the fields of sustainable supply chain management, biodiversity conservation, and MCDM theory.

By defining a set of effective supply chain management practices that contribute to biodiversity conservation, this study adds to the theoretical knowledge of sustainable business practices. On the other hand, the proposed hybrid model contributes to the theory of MCDM methods, especially in the context of sustainability and biodiversity. This study's practical (managerial) implications are numerous and directly aimed at improving business practices. This study could serve as a practical guide for companies. A defined set of applicable practices provides managers with a practical guide to integrating biodiversity protection into their companies' supply chains. The developed framework and criteria enable managers to objectively assess and rank different supply chain management practices based on their contribution to biodiversity conservation. Finally, the hybrid MCDM model provides managers with a structured and reliable framework to make strategic decisions about the implementation of the most effective biodiversity protection practices in their supply chains. Therefore, the results of this study could be useful for academics and researchers in the fields of logistics, transportation, supply chain management, sustainability, and biodiversity conservation, particularly those with an interest in applying multi-criteria decision-making (MCDM) methods to improve sustainability in logistics and transportation operations. Additionally, this manuscript targets logistics and transportation managers and practitioners who are seeking practical guidance on integrating biodiversity protection into their supply chain and transportation processes. It provides insights into effective supply chain management practices that enhance sustainability and contribute to biodiversity conservation, with a focus on improving the environmental impact of logistics and transportation activities.

While the framework itself is universally applicable across various sectors, it recognizes that different supply chains may have distinct characteristics, such as the type of goods sold, geographic location, or specific logistical requirements. As a result, the practices identified for promoting biodiversity conservation may be evaluated and ranked differently depending on the unique circumstances of each supply chain. However, the underlying methodology is flexible and adaptable, providing a robust structure that can be applied across diverse logistics environments—whether in food and beverages, reverse logistics, custom-configured supply chains, or other areas. The key strength of this framework lies in its ability to integrate biodiversity protection into any supply chain, regardless of sector or geographic location, while allowing for context-specific evaluations of the most effective practices. Thus, it offers a reliable tool for making strategic decisions aimed at enhancing sustainability and biodiversity conservation in logistics and transportation operations worldwide.

The limitations of this study concern the problem structure, the set of respondents who performed the evaluation, and the application of the proposed model. The problem included nine practices and seven evaluation criteria. However, it can be argued that some additional practices could have been defined or that existing and new ones could have been evaluated according to a wider set of criteria. Additionally, although this study covered key stakeholders, some other stakeholders may also have an interest in solving this problem. Also, as the results are based on the subjective evaluations of the decision-makers, a larger number of respondents would certainly have contributed to greater reliability for the obtained results. Overall, the developed MCDM model is effective for solving the defined problem. However, although the logic behind the methods used is simple, the calculations can be demanding and difficult to understand for insufficiently experienced researchers, especially practitioners, who would potentially want to apply it. However, all the identified limitations can be addressed in future research and studies.

7. Conclusions

This section synthesizes the key findings, implications, and contributions. It also highlights the study's limitations and offers directions for future research, providing comprehensive reflection on the results and their broader significance.

7.1. Summary of Results and Key Findings

This study addresses the critical need for biodiversity conservation within the context of supply chain management. By evaluating and ranking supply chain practices through a robust hybrid MCDM model, this study identifies the most effective approaches for minimizing environmental impacts and preserving biodiversity. The results highlight that the most effective supply chain management practices for biodiversity conservation were supply chain policies(0.044), biodiversity goal setting, monitoring, reporting, and transparency (0.039), and education and awareness raising (0.037) due to their clear frameworks, measurable goals, and cultural adaptability, while the lowest-ranked practice, compliance with legislation (0.006), reflects a baseline, reactive approach rather than a proactive strategy.

7.2. Practical Implementation and Policy Implications

The results have significant practical applications for companies striving to adopt sustainable business models. This study provides a practical decision-making framework that enables companies to evaluate and prioritize biodiversity-oriented practices based on their effectiveness, feasibility, and alignment with sustainability goals. The framework also offers insights for aligning corporate strategies with international biodiversity conservation initiatives, such as the UN Sustainable Development Goals.

In addition to logistics and supply chain management companies, the wider adoption of best-ranked practices may also have implications for policymakers. To support the economic sector, they could create political frameworks that would help or facilitate the implementation of these practices, which encourage the integration of biodiversity conservation into environmental regulations and industry standards. Thus, the identified practices could support businesses in achieving compliance with existing environmental regulations and preparing for future biodiversity-focused policies.

7.3. Contributions to Theory and Practice

This study makes significant contributions to both academic research and practical applications. Theoretically, it advances our understanding of biodiversity-oriented supply chain practices by defining a comprehensive set of practices and developing a novel hybrid MCDM model that integrates the grey BWM and grey ADAM method. The study also contributes to the broader field of sustainable supply chain management by providing a framework for evaluating and ranking practices across diverse industrial contexts.

Practically, this study offers a valuable decision-making tool for managers seeking to integrate biodiversity conservation into their operations. The hybrid model also serves as a replicable methodology that businesses and policymakers can adapt to similar decision-making problems in other sectors.

7.4. Limitations and Future Research Directions

This study acknowledges certain limitations. The analysis focuses on nine specific practices and seven evaluation criteria, which, while comprehensive, may not encompass all possible approaches or perspectives. Additionally, the results are based on expert evaluations, and a larger and more diverse sample of respondents could enhance the robustness of the findings. The model's reliance on manual calculations may also pose challenges for its wider adoption by practitioners who lack experience with MCDM methodologies.

Accordingly, future research should expand the scope of biodiversity-oriented practices and evaluation criteria to include other aspects of business operations. Incorporating a broader range of stakeholders and larger respondent pools could improve the reliability and generalizability of the results. Automating the proposed methodology through user-friendly software or applications could enhance its accessibility for business managers.

Another promising direction for future research is the application of the hybrid MCDM model to address other problems from this and other areas. Additionally, developing new hybrid models that build on the proposed approach could further advance the field of MCDM and its applications in sustainability.

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