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Risk assessment of ESG-based logistics systems using a TOPSIS-based approach

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Abstract: The operation of ESG-based systems is a complex task, as a multitude of environmental, social, and governance factors must be simultaneously addressed within logistics and recycling processes. ESG, as a legal and risk management framework, permeates all economic activities, making it indispensable in logistics, the largest globally interpretable service (supply) activity. The research aims to optimize the application of ESG obligations and opportunities in the field of recycling logistics. The research examined possible solutions through a systematic literature review and the creation of a holistic model. For the model, it was necessary to define the main logistics processes, their components, the scope and types of data required for data-based operation, and the relationships between the elements of the system. Achieving sustainability objectives necessitates the identification, evaluation, and management of risks through approaches capable of integrating diverse considerations. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) provides a suitable tool for ranking decision alternatives by quantifying and comparing various criteria. Integrating the ESG perspective with multi-criteria decision support enables more sustainable and efficient management of logistics operations. An additional advantage of this methodological framework lies in its adaptability to different industry environments and organizational structures. The study's findings lay the groundwork for the development of further model applications and practical implementation strategies.

1 Introduction

Over the past decade, the issue of sustainability has become a defining element of academic and economic discourse, especially in light of global environmental and social challenges such as climate change, the overexploitation of resources, and the necessity to transform supply chains from a sustainability perspective [1].

The emergence of the ESG (Environmental, Social, and Governance) framework offers an integrated approach that enables the coordinated management of environmental, social, and corporate governance dimensions, thereby contributing to companies' long-term sustainability and competitiveness [2].

Recycling logistics plays a pivotal role in today's sustainability efforts. It encompasses not only waste management but also the efficient use of resources, the reduction of environmental burdens, and the construction of a more sustainable future. Recycling logistics includes the collection, transportation, sorting, and processing of waste, as well as the reintegration of recycled materials into production processes [3]. However, it faces numerous complex challenges that must be overcome to achieve a circular economy [3].

The recycling process is inherently complex and costly, encountering several barriers:

- The heterogeneous nature of waste makes the collection and separation of mixed refuse a significant technological and logistical challenge.
- Contaminants reduce the quality and value of recycled materials.
- Deficiencies in logistical infrastructure—such as inadequate collection points or high transportation costs—further hinder efficient recycling.
- Consumer behaviour is also critical: lack of awareness and improper selective waste collection diminish overall system performance.

2 Literature review

The rise of the ESG framework has fundamentally reshaped corporate sustainability and supply chain management. Empirical evidence consistently shows that integrating environmental, social, and governance aspects enhances financial performance and competitiveness [1-2]. Institutional pressures further drive firms to adopt green supply chain practices that indirectly improve efficiency and legitimacy [3]. At the same time, social capital within networks mitigates the negative effects of dependence and supports innovation. On a global scale, multinational corporations use ESG-based, self-regulatory, and information-driven strategies to influence climate policy. Overall, ESG integration has become a strategic foundation for sustainable and responsible corporate governance [4-5]. Logistics plays a key role in this process, as the energy use, emissions footprint, resource consumption, and transparency of supply chains determine the practical achievement of ESG goals [4,6-9].

In the field of sustainable supply chain management, one starting point is the multi-period network redesign model, which aims at developing environmentally friendly systems [10]. The paradigm-shifting importance of the circular economy is confirmed by several authors [11], with special emphasis on logistics solutions that support resource recovery, waste reduction, and decentralized recycling [7,12]. Life Cycle Assessment (LCA) provides a methodological foundation for measuring the environmental impacts of products and processes over their entire life cycle, thereby contributing to sustainable logistics decision-making [12]. Research shows that aligning LCA with reverse logistics carries significant potential for emissions reduction and cost optimization [4,6,13]. In addition, decentralized recycling centers increase network flexibility and reduce transportation burdens [13].

Digitalization and data-driven technologies play an increasingly important role in ESG implementation. Blockchain-based models support transparency, traceability, and data integrity, while also enabling supply chain optimization [6]. The use of IoT and predictive analytics promotes energy efficiency, real-time monitoring, and the search for logistical optima [14]. These technologies also provide risk reduction and cost-efficiency benefits [6,15].

A key element of sustainable logistics is green procurement and supplier collaboration, which help reduce emissions and support ESG auditing processes [9,16]. Corporate reporting and supply chain transparency are evolving in parallel with digital transformation [7], further reinforced by international recommendations and policy frameworks. Sustainability reports also play an important role in the automotive industry and other relevant sectors [6].

Empirical research consistently confirms that ESG performance improves operational efficiency, investor confidence, and financial results [7]. Logistics systems contribute to this not only as an implementation platform but also as a driver of innovation [8,13,14]. Overall, the literature identifies the greatest potential for ESG application in logistics at the intersection of recycling, LCA, digitalization, and network sustainability. Based on the reviewed sources, it can be stated that ESG-based logistics systems simultaneously support environmental sustainability and economic competitiveness.

3 Fundamental tasks of ESG systems

Based on the foregoing, it is apparent that ESG systems hold a pivotal role across various societal sectors. For the optimal operation of any such system, the following fundamental tasks must be addressed:

- Clearly define and delimit the operational domain of the system under investigation.
- Within the delimited system, determine the types and quantities of entities to be examined.
- Identify the characteristic parameters of those entities and their operational strategies within the delimited system.
- Establish the structure of the evaluation framework for the delimited system, specifying which criteria will be used to assess performance and which operational strategies will be compared.
- Uncover the relationships between entity parameters and system performance metrics based on the parameters of the entities comprising the delimited system.
- Employ an appropriate optimization procedure to identify the system optimum under the given conditions.

Based on Figure 1, it is evident that the task at hand involves solving a highly complex problem. The intricacy of the task is further amplified by the following factors:

- A multitude of subsystems can be delineated, yet the ultimate objective remains the optimal operation of the entire ESG system.
- For each entity, the number and types of parameters to be managed must be specified.
- Multiple operational strategies may be assigned to each individual entity, resulting in a wide array of possible system-level behaviours.
- Diverse types of operational characteristics may apply to the various subsystems.
- The relational structure between different entities, their operational strategies and parameters, and the evaluation metrics characterizing the subsystems is inherently complex.
- Multiple optimization procedures and sets of conditions may be employed for system evaluation.

In light of these considerations, it can be concluded that the proper analysis of an ESG system requires a sophisticated data infrastructure, comprehensive operational strategy frameworks, and specialized optimization processes. Such complexity can only be addressed through the implementation of an advanced simulation system.

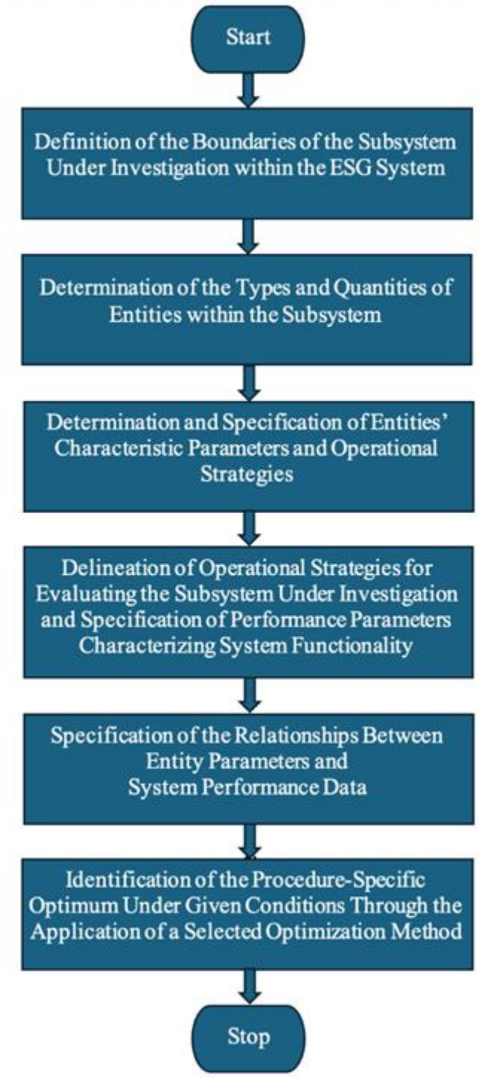

Figure 1 The evaluation process of ESG systems

3.1 The role of risk management in ESG systems

A further analytical perspective on ESG systems involves the systematic identification and management of risk factors and potential threats. Within each operational process—including the logistics processes embedded in ESG systems—various risk elements may arise that jeopardize the continuity and stability of system operations. These risks, stemming from environmental, social, or governance-related uncertainties, necessitate targeted mitigation strategies to preserve the integrity and resilience of the system throughout its lifecycle.

It is a critical consideration that risk factors may disrupt system operations with varying degrees of severity. Therefore, a key task is to rank these risk factors according to the magnitude of the associated risk. This prioritization enables the formulation of appropriate measures to ensure uninterrupted system functionality.

The principal domains of the risk management procedure are illustrated in Figure 2.

The objective of the risk management procedure is to establish and define a comprehensive list of potential risks based on events that may adversely affect the operation of the logistics process within the ESG system.

In the context of logistics processes and systems, a substantial number of risk factors can be identified. These risk factors are associated both with the material flow component and the information flow component of the logistics process. Moreover, they may be linked to the characteristics of material handling equipment as well as to the various operational strategies employed.

The first step in the risk management procedure is the identification of risks. This activity inherently involves subjective elements, which are influenced by the individual conducting the identification. In contemporary practice, artificial intelligence can be utilized effectively in this phase, significantly reducing the degree of subjectivity and enhancing the consistency and reliability of risk detection.

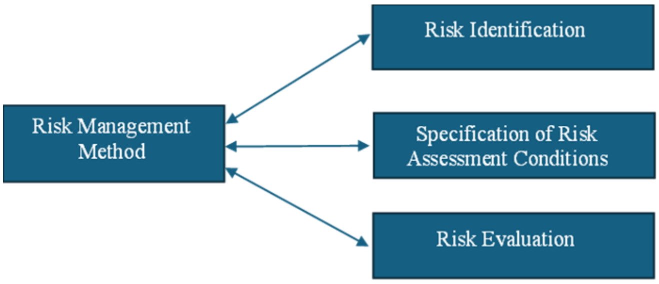

Fig. 2 Risk management method

In order to mitigate the risks inherent in logistics processes, it is essential to identify the full spectrum of risk factors, along with their underlying drivers, associated conditions, and triggering events. This comprehensive exploration serves as the foundation for the development of targeted risk management strategies aimed at ensuring operational continuity and resilience within ESG-oriented logistics systems.

In the context of logistics operations, the following categories of risks are typically considered:

- Material Flow Risk,
- Information Flow Risk,
- Technological Risk,
- Disaster Risk,
- War Risk,
- Globalization Risk,
- Financial Risk,
- Product and Service Risk,
- Social Impact Risk,
- Environmental Impact Risk,
- Product Structure Risk,
- Energy Supply Risk,
- etc.

A wide range of conditions may be specified in the context of risk assessment criteria. In the following, three key factors are highlighted:

- The probability of occurrence of the individual risk
- The potential impacts of the examined type of risk
- The quality of controls implemented to reduce risks across processes, systems, and system components

We evaluate risk factors and conditions using a method that seeks a compromise solution based on the best (positive) and worst (negative) possible values of each parameter. The approach applied for identifying such compromise solutions is the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. In the context of ESG integration among logistics SMEs, this framework enables a systematic comparison of sustainability criteria and reveals key areas where implementation lags behind strategic priorities [17]. The application of TOPSIS thus opens up new possibilities for assessing ESG maturity and guiding more targeted, evidence-based sustainability actions within the sector [18].

3.2 Application of the TOPSIS method in ESG evaluation

In the following section, we outline the application of this method based on the solution-seeking methodology. The application of the TOPSIS method in ESG evaluation enables corporate decision-makers to rank alternatives based on multiple criteria [18,19]. During the integration of environmental, social, and governance dimensions, it is essential that the individual criteria are represented in the assessment with different weights. The advantage of the method is that it compares the performance of the alternatives to the best and worst solutions, thus ensuring an objective comparison. In the process, the evaluation criteria are first defined, followed by the assignment of the corresponding weights and data. This is followed by normalization, which ensures comparability despite different units of measurement. After identifying the positive and negative ideal solutions, the distance of each alternative from both reference points can be calculated.

The final ranking is based on relative closeness, which is well suited for identifying and managing risks in an ESG context. The figure visually presents the steps of the procedure, supporting the understanding and practical application of the process. The first step of the method is the construction of the decision matrix, where the performance of the alternatives is recorded in relation to ESG criteria. This is followed by normalization and weighting, which ensure comparability and the enforcement of priorities. After defining the positive and negative ideal solutions, the distance of the alternatives from each reference value can be calculated. The final evaluation is based on relative closeness, from which a clear ranking of sustainability performance can be established.

The method is particularly useful in cases where several corporate units, suppliers, or investment alternatives need to be evaluated from an ESG perspective. As a result of the decision-support process, not only can the most favorable option be identified, but the areas requiring improvement can also be revealed. This enables the definition of strategic directions and the allocation of resources in line with sustainability objectives.

4 Key components of the general application of the TOPSIS method

Outline of the necessary calculations based on the presented flowchart. Figure 3. illustrates the workflow of the decision-support method developed in this study. The procedure begins with the construction of the task matrix, followed by the normalization and weighting of its elements. Subsequently, the positive and negative ideal solutions are identified, and the deviations of each alternative from these reference points are determined. Finally, the relative closeness of the alternatives to the ideal solution is calculated, enabling their systematic ranking within the evaluation framework. These steps provide a transparent mathematical structure for comparing alternatives, while ensuring consistency in the assessment process. The outlined procedure thus supports robust and reproducible decision-making in ESG-oriented evaluations.

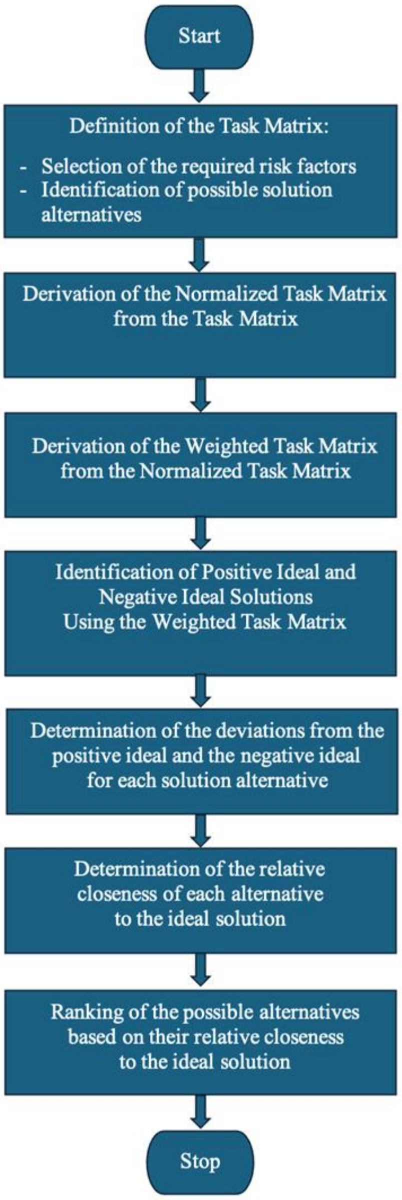

Figure 3 Risk management procedure

4.1 Task matrix (F), normalized task matrix (G) and weighted normalized task matrix (H)

The task matrix F (Figure 4) represents the evaluation framework in which each row corresponds to a possible solution alternative and each column corresponds to a specific risk factor. The element *f(i,j)* denotes the value of the *j-th* risk factor associated with the *i-th* alternative, where i = 1, 2, …, m and j = 1, 2, …, n. Based on this initial matrix, the normalized task matrix G is derived using the subsequent normalization formula. This transformation ensures that the differing scales of the risk factors do not distort the comparative assessment of the alternatives (1):

$$F(i,j) = \begin{array}{c|c} & 1\ 2\ .\ .\ .\ j\ .\ .\ .\ n \\ \begin{array}{c}1\\2\\.\\i\\.\\.\\m\end{array} & \left(\begin{array}{c} \\ \\ \\ f(i,j) \\ \\ \\ \\ \end{array}\right) \end{array}$$

i = 1, 2, … , m	Represents the possible solution alternatives
j = 1, 2, … , n	Represents the values of the risk factors for the given alternative.

Figure 4 Representation of task matrix

$$g(i,j) = \frac{f(i\ ,j)}{\sqrt{\sum_{i=1}^{j} f(i,j)^2}} \tag{1}$$

In determining the weighted normalized task matrix (H), the weighting factors must be taken into account. These weighting factors pertain to the risk factors and are represented by the vector (2) *h(j).*

$$\sum_{j=1}^{n} h(j) = 1, \text{and } 0 < h(j) < 1 \tag{2}$$

Multiplying each column of the normalized task matrix by its corresponding weighting factor yields the weighted normalized task matrix (3).

$$H(i,j) = h_j\ x\ G(i,j), \text{ where } i = 1, 2, ..., m \tag{3}$$

4.2 Identification of positive ideal and negative ideal solutions

The matrix H(i,j) used to identify the positive ideal solutions, which are contained in the vector (4) $M^{+}(j)$, where

$$M^{+}(j) = max\ H(i,j),\ if\ j \in J \tag{4}$$

and contains the negative ideal solutions (5), where

$$M^{-}(j) = min\ H(i,j),\ if\ j \in J' \tag{5}$$

where J and J' denote the sets of benefit and cost attributes, respectively.

4.3 Determination of deviations from the positive and negative ideal solutions for each alternative

In the calculations, we use the weighted normalized task matrix H(i,j), along with the vectors containing the positive ideal solutions (M^{+}), and the negative ideal solutions (M^{-}).

The positive deviations are determined by (7)

$$S(i)^{+} = \sqrt{\sum_{i=1}^{m} [H(i,j) - M^{+}(j)]^2}, \tag{7}$$

Negative deviations are calculated based on (8)

$$S(i)^{-} = \sqrt{\sum_{i=1}^{m}[H(i,j) - M^{-}(j)]^{2}}, \tag{8}$$

4.4 Determination of the relative closeness of each alternative to the ideal solution

C(i) value expresses the relative closeness of the *i-th* alternative to the positive ideal solution. Based on the resulting of C(i) values, the alternatives can be systematically ranked according to their performance. It is calculated by (9), (10):

$$C(i) = \frac{S^{-}(i)}{S^{+}(i) - S^{-}(i)}\,, \tag{9}$$

$$0 \leq c_i \leq 1 \tag{10}$$

During the optimization of ESG risks, the simultaneous consideration of ESG-related parameters affecting logistics processes results in substantial computational complexity. The international ESG standards currently in use define approximately 1,000-1,100 indicators across the environmental, social, and governance dimensions. For the calculation of distances to the positive and negative ideal solutions, and for the methodologically sound application of the TOPSIS method, it would be justified to incorporate at least 5-10% of this indicator set. However, computations of this scale require extensive data preparation, weighting, and normalization procedures, which exceed the length constraints of the present study. Accordingly, the primary objective of this research is the conceptual and methodological establishment of ESG-based logistics risk assessment using the TOPSIS method, while large-scale numerical optimization based on an extensive indicator set is deferred to a subsequent, simulation-based research phase.

5 Discussion

The key contribution of the research lies in the systematic integration of the ESG criteria, recycling logistics, and multi-criteria decision support. Going beyond theoretical approaches, a holistic model has been outlined that reorganizes basic logistics processes along the lines of data-driven operations and environmental and social determinants. Given that recycling is one of the most critical segments of modern supply chains, the research interprets the optimization of this process as a complex risk management task.

The methodological framework is based on an adaptation of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) algorithm, which allows for an objective comparison of different logistics strategies. With the help of the model, the individual alternatives are not only evaluated on a scale, but their proximity to the positive ideal solution and their distance from the worst case can also be determined with mathematical precision. This approach is particularly relevant in an uncertain economic environment where risk assessment is essential.

The modernized risk management protocol developed as part of the research focuses on eliminating subjectivity beyond traditional material and financial processes, integrating responses to global challenges. The developed mathematical framework, including the use of normalized and weighted matrices, is not only a theoretical approach but also provides a direct basis for the development of subsequent digital simulation systems. This integrated approach allows companies to view ESG compliance not as a separate issue, but as an integral part of logistics efficiency and competitiveness. Its practical significance lies in its multidisciplinary nature, technology-focused risk assessment, and the development of a mathematical optimization process that can be translated into practice.

6 Conclusions

The study highlights that the evaluation of logistics systems based on ESG principles can only be effectively conducted through complex, multi-criteria methodologies. ESG frameworks simultaneously encompass environmental, social, and governance factors, which exhibit strong interrelations with the challenges of recycling logistics. Due to the multifaceted nature of risk factors, their structured identification, prioritization, and management are essential. The TOPSIS method serves as a suitable tool for comparing potential solution alternatives, as it quantifies the impact of risk variables and facilitates the selection of the optimal option.

The applied approach enables the mitigation of operational disruptions within logistics systems and supports the achievement of sustainability objectives. Furthermore, the method is adaptable to various organizational and industrial contexts, thereby enhancing its practical relevance. The integration of artificial intelligence into subjective risk identification further strengthens the reliability of the evaluation process.

The findings of the research provide a foundation for the development of simulation models and advanced decision-support systems. Future work should involve testing the methodology on specific industrial cases and comparing it with other multi-criteria techniques. The study contributes to both the theoretical advancement and practical implementation of ESG-oriented logistics systems.

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