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Green Supply Chain Circular Economy Evaluation System Based on Industrial Internet of Things and Blockchain Technology under ESG Concept

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Abstract: A green supply chain economy considering environmental, social, and governance (*ESG*) factors improves the chances of functional growth through minimal risk factors. The implication of sophisticated technologies such as the Industrial Internet of Things (IIoT) and the blockchain improves the optimization and evaluation of *ESG* performance. An IIoT-Blockchain-based Supply Chain Economy Evaluation (IB-SCEE) model is introduced to identify and reduce functional growth risk factors. The proposed model uses green blockchain technology to identify distinct transactions' economic demands and supply distribution. The flaws and demands in the circular economy process are validated using the IIoT forecast systems relying on *ESG* convenience. The minimal and maximum risks are identified based on economic and distribution outcomes. The present investigation highlights the significance of ongoing *ESG*-conceptualized research into blockchain-based supply chain economics. Companies who recognize the blockchain's potential can improve corporate governance, environmental impact, and social good by increasing transparency, traceability, and accountability. A more sustainable and responsible future for global supply chains can be shaped through further research and development in this field, which will make a substantial contribution to the scientific world. This information is individually held in the green blockchain for individual risk factor analysis. The proposed model improves the recommendation and evaluation rate and reduces the risk factors with controlled evaluation time.

Keywords: green blockchain; economy evaluation; ESG performance; industrial internet of things; supply chain

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1. Introduction

A green supply chain is an operational management method widely used to reduce environmental impact. A green supply chain is also known as a sustainable supply chain. A green supply chain mainly uses renewable materials to create a product that produces eco-friendly products for customers [1]. A green supply chain is a commonly used method to improve the ecosystem and environment that reduces the energy consumption rate worldwide. A green supply chain network is widely used in various fields to improve the economic rate and reduce the costs of the products [2]. Green supply chain economy evaluation is a complicated task to perform in an application. Green supply chain management (GSCM) is most commonly used for evaluation and analysis. GSCM produces feasible and appropriate data related to products [3]. GSCM also provides the necessary set of data for the economy evaluation process. Machine learning (ML) techniques are also used in the

GSC economy evaluation process. The fuzzy logic algorithm is used here to identify the important aspects and effects of a GSC in products and produce an optimal data set for the evaluation process. A ML technique finds the features of products that improve the economy rate and reduce the product rate for the consumers [4,5].

The Industrial Internet of Things (IIoT) is a network that connects objects via software and internet connection. The IIoT improves the performance rate in the communication and interaction process, enhancing the system's feasibility [6]. IIoT-based applications provide necessary services for the users that reduce the complexity rate in providing services. The IIoT is also used in a green supply chain that improves the productivity rate in producing products for customers [7]. The main goal of the IIoT-based green supply chain is to reduce the product's cost and environmental pollution rate. The IIoT provides various services and functions for greens supply chain products [8]. The IoT offers different codes for every product that produce necessary information regarding products. The IIoT uses wireless sensors to track the products and provide users with an optimal set of data [9]. The IIoT mainly connects and collects data from various devices that produce appropriate information to create a product. The IoT improves products' overall efficiency and performance rate, increasing the product demand among users [10].

Blockchain technology is widely used in green supply chain management systems to track products and provide customer data. A green blockchain prevents damages and losing track of certain products. The blockchain improves the accuracy rate in the green supply chain transportation system [11]. The blockchain method is also used in processing data that enhance the efficiency rate of the environment. The blockchain concept is mainly used to remove and reduce the environmental pollution rate. It also provides customers with a feasible set of services, such as transactions, tracking, and product delivery. The green blockchain offers user-friendly products for customers that reduce the environmental pollution rate. The environmental, social, and governance (*ESG*) concept is mainly used for investment [12,13]. The *ESG* concept provides various sets of schemes and policies for the investors that improve the standard and quality of green supply chain products. The *ESG* concept first understands the exact behaviors of investors and provides necessary policies to screen potential investments in particular products [14]. The *ESG* concept mostly uses fossil fuels and greenhouse materials to create products for customers. The *ESG* concept enhances the efficiency and reliability rate of green supply chain products by reducing the environmental pollution rate [15].

The *ESG* concept provides guidelines for developing supply chain management strategies from the bottom up. Assessing a supply chain's environmental, social, and governance (*ESG*) performance will depend on the organization's priorities. *ESG* performance factors are considered when financial institutions make investment choices, resulting in more long-term investments in environmentally, socially, and economically responsible enterprises. However, green financing does not include social and economic aspects. Environmental (green) finance is a subset of climate financing. A wide range of funding operations contribute to sustainable development that comes under the category of sustainable finance. The research presented here suggests a novel paradigm for assessing supply chain economies using blockchain technology from an *ESG* perspective. This strategy incorporates blockchain technology with environmental, social, and governance (*ESG*) principles to boost supply chain visibility, auditability, and responsibility on a global scale.

To accurately monitor and assess sustainability and responsible business practices, it integrates the blockchain's decentralized and unchangeable nature with *ESG* indicators. The approach encourages stakeholders to embrace sustainable behaviors through the use of smart contracts and decentralized applications, thereby fostering an environment that is conducive to collaboration and creativity.

This concept is significant because it has the ability to motivate constructive environmental and social change, inspire ethical corporate conduct, and mold a brighter future for global supply chains. *ESG* goals, supply chain management, and the scientific knowledge of the blockchain's role in sustainable development can all benefit from its application.

The main contribution of this paper is that we design an IIoT blockchain-based supply chain economic evaluation (IB-SCEE) model to identify and mitigate functional growth risk factors. Different transactions' economic demands and supply distributions are identified. The experimental results are implemented, and the suggested model improves the recommendation and evaluation rate and reduces the risk factors with a controlled evaluation time.

2. Related Works

Shojaei et al. [16] proposed blockchain-technology-based circular economy (CE) concepts for the built environment. The blockchain approach is used here to track the materials required to create a product. The proposed method provides reusable options that reduce the pollution rate of the environment. The proposed method improves the sustainability and feasibility of the domain.

Esmaeilian et al. [17] introduced a blockchain-based supply chain management system for 4.0 industries. The Internet of Things (IoT) is used here to provide necessary industry services. The IoT improves efficiency and increases the development rate of sectors. Blockchain technology promotes the green behaviors of customers that reduce the pollution rate in the environment. The blockchain reduces the cost of development and the operation rate, enhancing the system's performance rate.

Nodehi et al. [18] proposed an enterprise blockchain design framework (EBDF) for ecosystem-based applications. The blockchain approach is used here to discover the key configurations presented in architecture. The EBDF provides the necessary set of key values and data for designing enterprises for customers. The proposed method improves the accountability and sustainability rate of the system. The proposed method increases the feasibility and efficiency of the system.

Lui et al. [19] introduced an Internet of Things (IoT)-based green logistics management system. The proposed method is mainly used for e-commerce applications that require a high developmental rate for the products. The IoT reduces the error rate in the logistics management process, enhancing production's feasibility. The proposed method achieves a high efficiency and effectiveness rate in the development process.

Wang et al. [20] proposed an edge computing and Internet of Things (IoT)-based supply chain management system. Edge computing is used here to provide proper data processing and analysis services for the supply chain management system. The IoT is used here to reduce the cost and risk rate in the supply chain management system. Data shared and related data are used here that provide an optimal set of data for further processes. The proposed method is mainly used to enhance the efficiency and reliability of the system.

Lotfi et al. [21] introduced a viable closed-loop supply chain network (VCLSCND) for the CE. Essential parameters are identified here to minimize the complexity rate in the optimization process. The entropic values risk (EVaR) rate is also determined here to provide an optimal data set for the management process. The VCLSCND improves the performance and feasibility rate of the system.

Voldrich et al. [22] designed a new method that combines both operational risk (OR) and processing time and cost (PT&C) for the supply chain environment. The multi-objective methodology is used here for the quantitative analysis process. The multi-objective method provides a feasible data set for different processes in a management system. The proposed method increases the accuracy rate in measuring techniques that improve the system's efficiency.

Kazancoglu et al. [23] introduced an Internet of Things (IoT)-enabled supply chain management system. The main aim of the proposed method is to identify the important set of features and values presented in a management system. The extracted data are used for the detection and identification process. Various analysis and prediction methods are used here that provide an appropriate data set for the management process. The proposed method improves the efficiency and reliability of the management system.

Mirzaei et al. [24] proposed a thematic analysis method for a sustainable supply chain system. The proposed method is mainly used to investigate the viewpoints of products produced by the supply chain. Customers' behaviors, interests, and preferences are also identified here to provide the necessary data for the data management process. The proposed method increases the sustainability and feasibility rate of the system.

Cui et al. [25] introduced a decentralized credit mechanism for the food supply chain. The main aim of the proposed method is to identify the problems presented in the food supply chain system. A decentralized credit mechanism increases the data security rate, reducing the data loss rate in a management system. The proposed method improves the accuracy rate in the classification and identification process, enhancing the system's efficiency.

Li et al. [26] proposed a blockchain-based supply chain finance (SCF) system. Blockchain technology (BT) is used here that recognizes the financial drawback and problems in the management system. The proposed method is mainly used to determine the risks presented in the data management process. The proposed SCF method achieves high efficiency and effectiveness in a management system.

Kabadurmus et al. [27] proposed a new circular food supply chain (SFC) model to reduce food waste in a management system. The SFC produces enormous food waste that increases the pollution rate in the environment. The proposed method is mainly used for the recycling process that reduces the content of food waste in the SFC. The proposed method maximizes the efficiency and reliability rate of the SFC system. The proposed method reduces the overall food waste rate in the SFC.

Akhmatova et al. [28] introduced a combined green supply chain management (GSCM) and total quality management (TQM) method. The proposed method is mainly used to reduce the risk factors presented in the environment. GSCM is used here to analyze the data presented in the management process. TQM reduces the complexity and error rate in the supply chain management process. The proposed GSCM and TQM methods improve the quality and efficiency of supply chain products among the customers.

Mugurusi, G. et al. [29] introduced the cobalt industry to *ESG* (CI-*ESG*) to help them check the components' trips along the chain of custody, which improves their sustainability. One such setting is the cobalt mining sector, which is plagued by violence and gross violations of human rights, especially in the Democratic Republic of the Congo, the world's largest producer of cobalt ore, which is needed to make lithium-ion batteries. To aid businesses in developing interoperable yet comprehensible blockchain architectures, a responsible sourcing framework has been developed to link blockchain source data requirements to *ESG* measures.

3. Proposed IIoT-Blockchain-Based Supply Chain Economy Evaluation Model

The green supply chain economy based on *ESG* concepts in the IIoT-blockchain-assisting evaluation model is becoming unmanageable regarding pressure from stakeholders and green supply chain partners due to the growing economic demands and robustness of *ESG* performance. Amid challenges in the green-blockchain-based economy evaluation system, supply and economic management modifications consider *ESG* performance requirements aimed at satisfying people of various classes. The *ESG* concepts are highly competitive in the green supply chain economy, considering their industrial sector. Green manufacturing is one of the outputs of using the green supply chain economy to augment green performances using green blockchain technology. The issues of climate change, pressure on stakeholders and partners, geopolitics, workers' conditions in emerging economies, etc., require diverse performances. Hence, there are many economic demands: *ESG* performance and supply chains based on the green supply chain users, as well as reliability in the risk assessment and evaluation of *ESG*, are major considerations. Sustainability performance in the supply chain is evaluated using the environmental, social, and governance (*ESG*) paradigm, which is incorporated into the Green Supply Chain Circular Economy Evaluation System [30]. Aligning with established standards and frameworks, such as the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB), the system ensures a thorough assessment by taking into account pertinent environmental, social, and governance variables.

All throughout the supply chain, the system examines and measures a wide range of environmental parameters. Monitoring pollution, trash, greenhouse gas emissions, water consumption, and energy use is all part of this process. The system gathers data in real time from IIoT devices, allowing for precise monitoring of EPIs. It uses GRI- and SASB-recommended criteria and procedures to standardize environmental sustainability measurement and facilitate cross-comparison.

A vital part of any sustainable supply chain is the treatment of social variables, which is why this evaluation framework includes them. Workplace conditions, worker protections, human rights, equality of opportunity, and participation in the local community are all evaluated. The system gives insights into the social impact of supply chain activities by utilizing IIoT data and combining important social performance metrics. To make sure that its metrics for measuring and evaluating social sustainability are consistent with industry standards, it takes into account frameworks such as the Global Reporting Initiative's Social Sustainability Standards.

The governance factors of sustainability play a crucial role in the evaluation process. To ensure accountability, transparency, and ethical behaviors, the system analyzes the supply chain's governing structures, policies, and procedures. Transparency in the supply chain, business ethics, anti-corruption measures, and stakeholder participation are just a few of the criteria considered by the system. The system provides a thorough assessment of the governance practices that underlie sustainability in the supply chain by taking into account KPIs linked to governance.

Consistency, comparability, and credibility of sustainability measures are guaranteed by the evaluation system's conformance to applicable standards and frameworks. It establishes standard reporting criteria and measuring procedures by incorporating guidelines from authoritative bodies such as the GRI and SASB. These guidelines offer a full suite of indicators and performance metrics for assessing *ESG* considerations. To facilitate meaningful comparisons across supply chains and industries, the system ensures that sustainability performance is monitored and reported consistently by adhering to the recognized frameworks.

The Green Supply Chain Circular Economy Evaluation System allows for a thorough evaluation of sustainability performance by combining the *ESG* concept with established standards and frameworks. It assesses the sustainability impact of supply chain activities by measuring and evaluating environmental, social, and governance issues across the entire supply chain. This in-depth analysis helps in making decisions, encourages openness, and pushes progress toward a more ethical and environmentally friendly supply chain.

To further promote sustainability assessment and circular economy practices along the supply chain, we present a complete framework that uses the Industrial Internet of Things (IIoT) and blockchain technology: the Green Supply Chain Circular Economy Evaluation System. Responsible business practices are taken into account during the review process by including the environmental, social, and governance (*ESG*) concept into the design of this system.

There are three primary elements that make up the system's architecture: the IIoT devices, the blockchain network, and the Evaluation Engine.

The system makes use of a collection of Industrial Internet of Things (IIoT) gadgets spread out in key locations all throughout the supply chain. The environmental and social characteristics that can be monitored in real time include energy use, waste disposal, carbon emissions, workplace safety, and product lifetime details.

A decentralized blockchain network links the IIoT gadgets together. By providing an unchangeable and unalterable record of transactions, this network guarantees the honesty, safety, and openness of its users' data. Distributed ledger technology (blockchain) retains the gathered data, reducing the requirement for a trusted third party and fostering greater confidence in the system overall.

The Evaluation Engine is the central brain of the operation. Sustainability and circular economy performance metrics are generated by analyzing data obtained from IIoT devices and applying established evaluation criteria. The carbon footprint, energy efficiency, waste minimization, recyclable materials, fair trade policies, and supply chain traceability are all examples of possible indicators.

The proposed IB-SCEE model is presented in Figure 1.

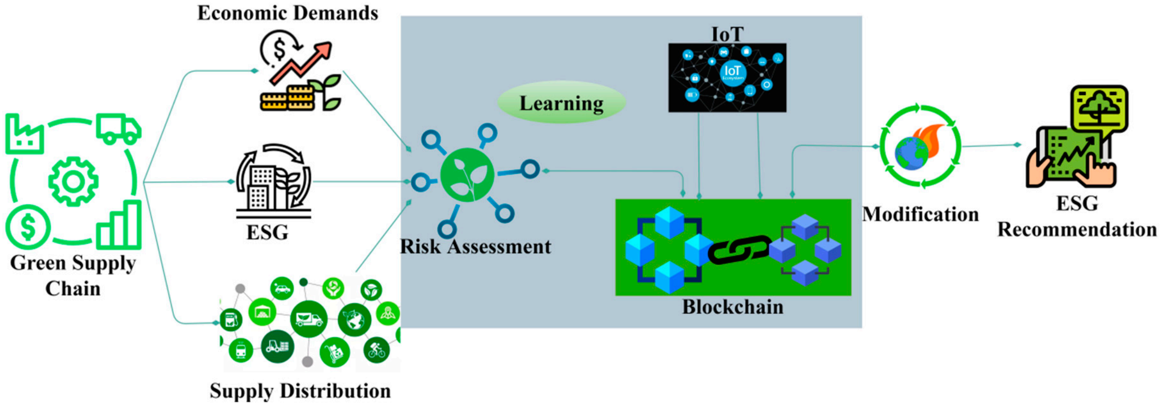

Figure 1. Proposed IB-SCEE.

The proposed IB-SCEE model mainly focuses on this consideration by providing *ESG* performance forecasting or recommendation for the overall development of the green supply chain economy through frequent modifications. In this proposal, the green supply chain economy with an evaluation rate is administrable for people and their *ESG* concepts with the available stakeholders and partners. In a green supply chain scenario, the environmental modifications such as climatic conditions, pollution, use of non-renewable resources, etc., are analyzed for any changes with the previous conditions, and then the information is distributed for *ESG* concept recommendation. The green blockchain combines risk assessment and modifications to identify risk factors based on an improved supply chain process for individual risk factor analysis for *ESG* performance convenience. The green blockchain is classified as risk assessment and modifications based on a green supply chain.

The risk factor assessment based on economic demands and supply distribution is processed through green blockchain technology, where supply distribution and economic management considerations are made. The processing of green supply chain users is based on serving inputs from the environment (GSC_u). Therefore, the optimization and evaluation of *ESG* concepts are modelled into three segments: economic demands, *ESG* performance, and supply distribution. The green supply chain economy with an evaluation system differs based on economic demands to handle many users in that environment. The introducing functions of the economy evaluation system are keen on the green supply chain regarding this objective, as shown in Equation (1).

$$\left.\begin{array}{c} \underset{n\in i}{\text{maximize}} GSC_u \; \forall \; E_d = ESG = S_d \\ \text{and} \\ \underset{j\in ESG}{\text{minimize}} R_f \; \forall \; (E_d + S_d) \end{array}\right\} \quad (1)$$

where

$$\left.\begin{array}{c} R_f = ESG\left[T_{E_d} - T_{S_d}\right] \\ \text{and} \\ \underset{n\in i}{\text{minimize}} ESG_i \; \forall \; n \in E_{di} \end{array}\right\} \quad (2)$$

From Equations (1) and (2), the variables GSC_u, E_d, ESG, S_d are used to represent the green supply chain processing of n^{th} services s, economic demands, and supply distribution, respectively. In the following supply chain representation, the variables R_f, T_{E_d}, and T_{S_d} denote risk factors, economic demands observing time, and supply distribution time, respectively. The third objective of minimizing the risk factor is illustrated using the condition $ESG_i \; \forall \; n \in r_{qE_d}$. If $u = \{1, 2, \ldots, \; u\}$ represents the set of users in a green supply chain environment, then the number of supply distribution and economy demands in the ESG concept processing time is $E_d \times T$, whereas the economic demand is $u \times E_d$. The overall green supply chain economy with demand analysis based on $u \times E_d$ and $E_d \times T$ is the available economic demands for distribution. The risk factor assessment and modifications are precise, using optimization and evaluation of ESG performance based on the upcoming economic needs. In this analysis, the classification of forecasting or recommendation is essential to identify modifications in the green blockchain. The country's economic demand requirements are based on a sustainability (s_n) analysis of the n stakeholders and partners; the remaining time is needed for modifying the supply and economic management for improving ESG performance requirements. The classification of the further modifications in the available n supply chain is performed using the machine learning paradigm. Later, depending upon the classification process, the risk assessment analysis is the augmenting factor. From this classification, recommendation or forecasting of the ESG concept is the prevailing sequence for defining an individual risk factor analysis. The modifications of ESG performance requirements and the available green blockchain for considering the requirements are essential in the following section. The risk factor identification process is portrayed in Figure 2.

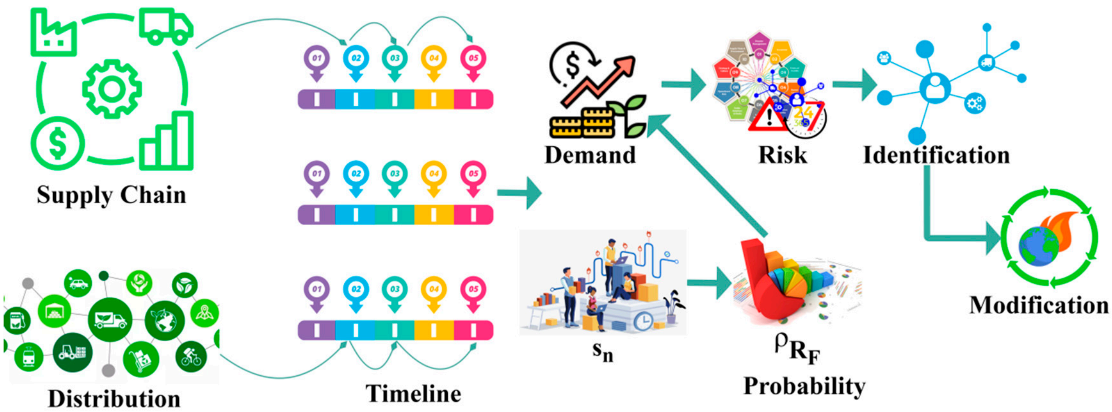

Figure 2. Risk factor identification.

The supply chain and $S_d \; \forall$ with the varying E_d are performed using different timelines for its s_n. Based on the s_n, the risk and its probability, i.e., ρ_{R_f}, are estimated. The probability is different from the actual risk factor that is identified. This identification is used for providing the modification of $\forall S_d$ and supply chain assignments (refer to Figure 2). In this sequential identification of economic demands and supply distribution for distinct transactions based on the green blockchain technology, $(E_d \times T)$ is performed for evaluating the ESG concept for all n basis of s_n in the consideration process. The probability of risk factor assessment $\left(\rho_{R_f}\right)$ in the economic evaluation system is given as

$$\rho_{R_f} = (\, 1 - \rho_{ESG})^{T-1} \; i \; \in T \tag{3a}$$

where

$$\rho_{ESG} = \left(1 - \frac{E_d \in n}{E_d \in T}\right) \times ESG \tag{3b}$$

In Equations (3a) and (3b), the sequential supply distribution in the green supply chain is based on the idle probability of n. Therefore, no pending economic demands, and hence the evaluation of ESG performance, are substituted in Equation (1). Therefore, the risk factor assessment in ρ_{ESG} is as follows:

$$Risk\ factor(n) = \frac{1}{|S_d + E_d - 1|} \times (\rho_{ESG})_T,\ i \in T \quad (4)$$

However, the supply distribution for n as in Equation (4) is valid in both $u \times E_d$ and $E_d \times T$, ensuring reliable distribution outcomes. The economy evaluation process in a supply chain using green blockchain technology assigning different T intervals is used to reduce the impact of the flaws and demands in the circular economy process based on $(u \times E_d) > (E_d \times T)$. The risk factor assessment is descriptive, using the green blockchain and ESG performance convenience. Therefore, the identifiable economic evaluation system follows that $u > T$ and ρ_{ESG} are minimal to satisfy Equation (1). The different outcomes based on the prolonging ρ_{ESG} and hence the evaluation time deviate the risk factors for frequent modifications.

In an IIoT forecast system, the flaws and demands are validated based on that the condition $u \times E_d$ is the maximum, so the supply distribution and ESG performance evaluation time are invariant. The minimum and maximum risks in the green supply chain are identified along with the idle economy evaluation time of n; the risk assessment and modifications are the considering factors here. The probability of individual risk $\left(\rho_{IN_R}\right)$ identification is given as

$$\rho_{IN_R} = \frac{\rho_{R_f} \times Risk\ factor(n) \times \left[(S_d - E_d) \times \rho_{ESG} - \left(\frac{S_d - E_d}{n}\right)\right] F(B_{ch})}{F(B_{ch}) \times n} \quad (5)$$

where

$$F(B_{ch}) = \sum\nolimits_{n=1} \frac{(S_d - E_d) \times \rho_{ESG} \times \rho_{R_f}}{Risk\ factor(n)} \quad (6)$$

From Equations (5) and (6), the variable $F(B_{ch})$ is used to denote the function of the green blockchain at different T intervals. For all the risk assessment processes, the sustainability of the green supply chain is analyzed for n services requiring flaws and demands. As in the above condition, the risk analysis requires more economy evaluation time and increases the needs and flaws. The green blockchain process for risk assessment is illustrated in Figure 3.

S_d and E_d $\forall$ T are used by the blockchain for providing different functions. The functions include risk prediction, assessment, classification, and modification. In this process, $F(B_{ch})$ classifies the different functions based on $\rho_{ESG}\left(\frac{T}{\rho_{R_f}}\right)$ such that s_n is retained. This depends on the identified ρ_{INR}. The risk factor (n) in T is modified through S_d or E_d satisfaction. It is updated in the blockchain for further process amendments (refer to Figure 3). From this sequential analysis of the economy evaluation system, the economic and distribution outcomes are based on identifying the minimum and maximum risks in the supply chain of $u > T$, and n risk factors and evaluation time are the considering factors. These factors are addressable using a classification process to mitigate the impacts through a random forest classifier. The following section represents the classification for the modification process to reduce the flaws and demands in the green supply chain. When it comes to managing a sustainable supply chain, the Industrial Internet of Things (IIoT) plays a crucial role in facilitating real-time monitoring, data collecting, and the analysis of environmental and social issues. The Internet of Things (IoT) allows for the collection and dissemination of data useful to sustainability efforts at every stage of the supply chain through the use of networked sensors, devices, and systems.

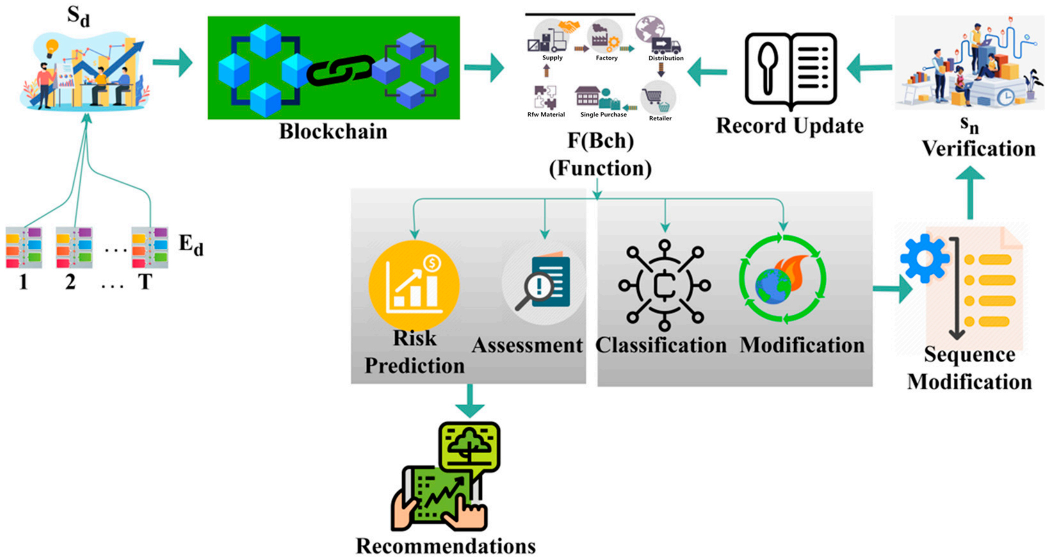

Figure 3. Blockchain for risk assessment.

Real-time monitoring: The IIoT offers real-time monitoring of critical environmental metrics, such as energy use, water consumption, emissions, and trash production. Resource consumption and environmental impacts may be monitored in real-time recognition by sensors implanted in machinery, tools, and infrastructure. By keeping tabs on everything in real time, managers may make educated guesses and swift adjustments to maximize productivity while minimizing negative effects on the environment.

Data Collection and Analysis: Insights into Sustainability through Data Mining: The IIoT makes it possible to collect massive amounts of data from diverse supply chain nodes. Social indicators such as worker safety and working conditions and information on energy consumption, production efficiency, and transportation routes are all included. IIoT data may be analyzed with machine learning and advanced analytics to reveal patterns, pinpoint inefficiencies, and highlight ways to boost sustainability results.

Enhanced Transparency and Traceability: The end-to-end visibility of supply chain activities is made possible by the IIoT, which improves both transparency and traceability. Thanks to IIoT technology, supply chain stakeholders and customers have access to comprehensive data on product origin, production processes, and environmental impact at every stage of the supply chain's operations. This openness encourages responsibility and encourages responsible sourcing, which are beneficial to both the environment and business ethics.

Operational Efficiency: The optimization of resource usage and the reduction in waste are two areas where operational efficiency can be increased thanks to IIoT implementations in the supply chain. Insights gained from real-time data collected by IIoT devices aid in the elimination of bottlenecks, the standardization of procedures, and the improvement of supply chain efficiency as a whole. Predictive maintenance that makes use of data collected by the IIoT can, for instance, keep machines running smoothly and efficiently, minimizing breakdowns and saving money on utilities.

The applications of the IIoT in environmentally responsible supply chain management are extensive. Monitoring, collecting data, and analyzing environmental and social elements in real time are just the beginning of how the IIoT improves operational transparency, traceability, and efficiency. It encourages responsible sourcing, fosters a circular economy, and gives power to decision-makers to create positive changes in sustainability all along the supply chain. A more sustainable and resilient supply chain is possible with the help of IIoT technology.

Modification process in the blockchain using Classification: This process is used for the controlled economy evaluation time for sequential and individual factors—the risk feature analysis for further modifications with the economic demand and supply distribution instances using machine learning. The classification process relies on *ESG* performance requirements to identify flaws and demand probabilities during the risk factor assessment. The random forest classifier is used for estimating the economy evaluation time for the n available features and the risk analysis for estimating the evaluation rate. The first classification relies on maximum *ESG* concept recommendation (ESG_r), and $F(B_{ch})$ is computed as

$$F(B_{ch}, ESG_r) = \left[E_d - \left(\frac{\rho_{ESG}}{\rho_{R_f}}\right) \times \frac{1}{n}\right] - Risk\ factor(n) + 1 \tag{7}$$

In Equation (7), the *ESG* concept recommendation depends on the risk factor analysis in the supply chain for distribution and economic management as in ρ_{ESG} and $Risk\ factor(n)$. Here, the chances of functional growth through fewer risk factors achieving sequential supply distribution are computed in Equation (8):

$$\rho_{ESG}\left(T/\rho_{R_f}\right) = \frac{1}{\sqrt{2n}} experssion\left[\frac{S_d - \rho_{ESG} \times E_d}{n}\right] \tag{8}$$

In the above probability of *ESG* performance requirement computation, the objective is to balance u and T to minimize the evaluation time, and hence, the actual supply distribution in that environment is estimated in Equation (9):

$$S_d = \max\left[\frac{\rho_{ESG} \times E_d}{Risk\ factor(n) - \rho_{R_f}}\right] \tag{9}$$

Therefore, the distribution of supply is computed as $\left[1 - \left[\frac{\rho_{ESG} \times E_d}{Risk\ factor(n) - \rho_{R_f}}\right]\right]$, and this outcome is the economy evaluation time instance of S_d. The exceeding E_d condition based on $[E_d * F(B_{ch}, ESG_r)]$ is the required process, and hence the economy evaluation time demands an increase. The further modification process classifies $(E_d,\ S_d)$ and depends on $\left(r_{E_{dT-1}},\ r_{S_{dT-1}}\right)$ for the supply distribution recommendation at different T instances based on the economic demands. The probability of ρ_{ESG}, ρ_{R_f}, and ρ_{IN_R} is the considering factor for both types of modifications. The modification takes place in the condition of $(E_d,\ S_d)$ and $\left(r_{E_{dT-1}},\ r_{S_{dT-1}}\right)$ and differentiating based on ESG_r for $F(B_{ch})$, given as

$$Risk\ factor(n) = \begin{cases} \frac{n-(\rho_{ESG} \times E_d)}{n+\left(\rho_{R_f}\right)}\ \forall\ S_d = E_d \\ \frac{n-(\rho_{ESG} \times E_d)}{n+\left(\rho_{R_f}+\rho_{IN_R}-\rho_{ESG}\right)}\ \forall\ S_d < E_d \end{cases} \tag{10}$$

In Equation (10), the modification process of $\left(\rho_{R_f} + \rho_{IN_R} - \rho_{ESG}\right)$ is the exceeding idle probability for supply distribution and economic management, which is identifiable in a green supply chain using the blockchain through a $Risk\ factor(n)$ analysis. Hence, the actual n supply chain performs the rest of the economic demands for *ESG* performance forecasting or recommendation, i.e., the remaining economic demands identified until the following frequent modification process. The classification learning is portrayed in Figure 4.

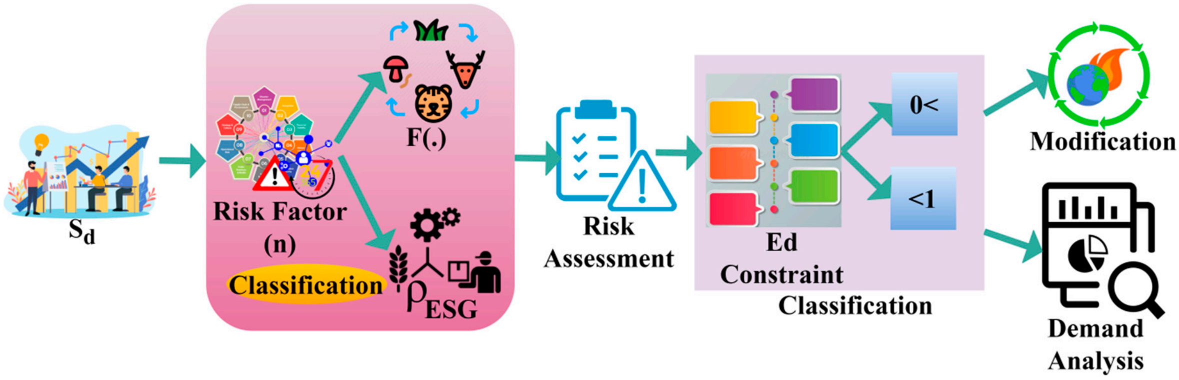

Figure 4. Classification learning for modifications.

The S_d input is classified in two different instances such that $F(.)$ and ρ_{ESG} are used for risk factor (n) estimation (as in Equation (4)). The further classification considers S_d and $E_d \; \forall \; 0 < \rho_{ESG} < 1$ conditions $\forall \; (n - E_d)$. This is required to prevent further modifications in the joint condition. However, the demand analysis is segregated for the varying $T \in S_d$ such that two classifications (as in Figure 4) are required. The remaining economic demands are based on $(n - E_d)$, which is the risk feature analysis concurrently, wherein the sequential risk factor assessment of $T \in E_d$ is performed and supply distribution from different stakeholders and partners takes place based on the sustainability of the green supply chain. Therefore, the risk analysis relies on multiple n and individuals to meet the controlled economy evaluation time. Rather than continuous processing, which improves the optimization and evaluation of ESG performance at different T intervals, one must wait for frequent modifications for the available n supply chain to be processed, confining the additional economy evaluation time for flaws in T. This supply distribution using IIoT forecasting systems depends on the ESG concept convenience, as mentioned in the available n, without requiring additional flaws and demands. The evaluation time is classified under $0 < \rho_{ESG} < 1$ with the previous supply chain analysis. The risk assessment is based on a circular economy process. Here, the evaluation time of economy demands is the sum of ESG performance and supply distribution in two or more n instances that do not augment $n \in \rho_{ESG}$. Therefore, the ESG concept recommendation is shared based on the condition $0 < \rho_{ESG} < 1$ for an individual risk factor analysis without increasing economic demands and reducing flaws. The remaining economic demand $(n - E_d)$ is served in this sequential manner, reducing the flaws and risk factors in the green supply chain. Case studies can be conducted in the manufacturing sector to examine how the Green Supply Chain Circular Economy Evaluation System is being used in practice. Research like this can evaluate the system's effectiveness in fostering the adoption of circular economy practices such as recycling and remanufacturing while simultaneously decreasing energy consumption and trash production. Improvements in energy efficiency, rates of waste reduction, and the utilization of recycled materials in production can all serve as key performance indicators.

The Green Supply Chain Circular Economy Evaluation System can also be used to evaluate the food and agriculture industries to see how they can be more sustainable. This could be the subject of another case study. This assessment has the potential to examine the system's efficiency in lowering water consumption, cutting down on carbon emissions from transportation, and encouraging sustainable farming methods. There are a number of ways to measure the positive environmental impact, including water footprint, carbon footprint, and the usage of organic farming practices.

Case studies are not the only method for gauging the system's effectiveness: simulations can be run too. Supply chain simulations are useful for evaluating a system's potential for maximizing useful output while minimizing unnecessary expenditures. The potential outcomes and benefits of applying the system in different supply chain contexts can be gained by running the simulation with different sets of parameters.

It is possible to quantify the system's beneficial effect on the environment by tracking changes in energy use, greenhouse gas emissions, water consumption, waste production, and pollution levels.

The system's impact on social sustainability and responsible business practices can be measured by indicators including worker safety records, labor practices, community engagement, and supplier diversity.

Energy efficiency, material usage efficiency, and water usage efficiency are all examples of metrics that can be used to assess a system's potential to maximize utility and minimize waste.

The system's contribution to circular economy concepts can be evaluated using metrics that track the percentage of recycled materials, the implementation of remanufacturing processes, and the reduction in single-use packaging.

Evaluation of the system's scalability and flexibility should take into account a wide range of sectors and supply chain settings. Manufacturing, retail, logistics, and healthcare are just some of the industries that could benefit from case studies and simulations. Evaluating the system's efficacy in a variety of settings helps establish its scalability and applicability across sectors. Various supply chain environments have unique difficulties and possibilities, and this analysis will assist in highlighting both.

The evaluation of the Green Supply Chain Circular Economy Evaluation System's efficacy can be improved by the use of case studies or simulations, as well as appropriate evaluation measures. As a result, one may learn how it can improve resource efficiency, cut down on waste, and advocate for circular economy concepts in a wide variety of business sectors and supply chain settings.

Experts in supply chain management, blockchain technology, and ecological sustainability all contributed to this project. In order to obtain real-world supply chain data and insights, collaborations were formed with industry partners.

The present research employs an approach that combines the IIoT with blockchain technologies to assess the supply chain's economic impact. The IIoT refers to the ecosystem of supply chains that includes linked devices, sensors, and data networks. The distributed and unalterable ledger provided by blockchain technology makes it possible to record and verify transactions with absolute certainty.

The goal of this approach is to fix problems with data integrity, transparency, and trust that have plagued previous supply chain evaluation models. The researchers hope to better align supply chain operations with *ESG* principles by using the IIoT and blockchain to increase transparency, traceability, and accountability.

This study utilizes a blockchain-based IIoT methodology to provide a holistic technique for assessing supply chain economics in relation to the *ESG* framework. The strategy improves openness, traceability, and accountability by using the blockchain's distributed ledger to combine data from networked devices. It allows for the collection of performance indicators, the examination of supply chain processes, and the provision of insights and suggestions on environmentally friendly procedures. Those in industry and in government who are interested in fostering sustainable development and enhancing supply chain management will find this methodology to be an invaluable resource.

4. Performance Assessment

The analysis for the proposed model is presented using the data from [31]. The investigation relied on data from a supply chain data set maintained by DataCo Global. This supply chain data set is compatible with machine learning algorithms and the R programming language. Provisioning, production, sales, and commercial distribution are all key areas that need to be registered. This model also enables the integration of unstructured data with structured data for knowledge discovery. The products include clothing, sports, and electronic devices. The result implementation of the proposed IB-SCEE model is performed based on the R programming language. In this analysis, the sports-related data are used to analyze the economic demands E_d and supply distributions $S_d \; \forall \; T$. First, the data representation with extraction is presented in Figure 5.

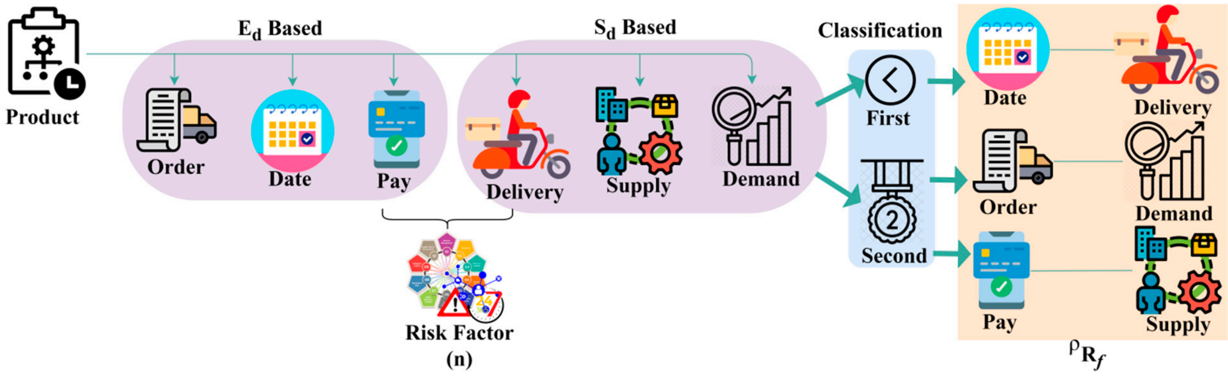

Figure 5. Data representation.

Both sports and electronic device demand types were analyzed for the risk factor assessment ρ_{R_f} estimation, and the example fields are presented in Figure 5. The demand is incurred from the order status showing as "pending" from the delivery date. The flaw is rectified by identifying either of the ρ_{R_f} features for preventing the increase in demands. In Figure 6, the analysis of the risk factor assessment ρ_{R_f} over the varying flaws is present [32]. Many benefits related to immutability, transparency, and decentralized consensus can be gained by integrating blockchain technology into the Green Supply Chain Circular Economy Evaluation System. By providing an immutable and auditable ledger of transactions, blockchain technology promotes honesty and transparency in supply chain processes. Product tracking, certification checking, and the safe exchange of sustainability data are only some of the many uses that could result from this combination.

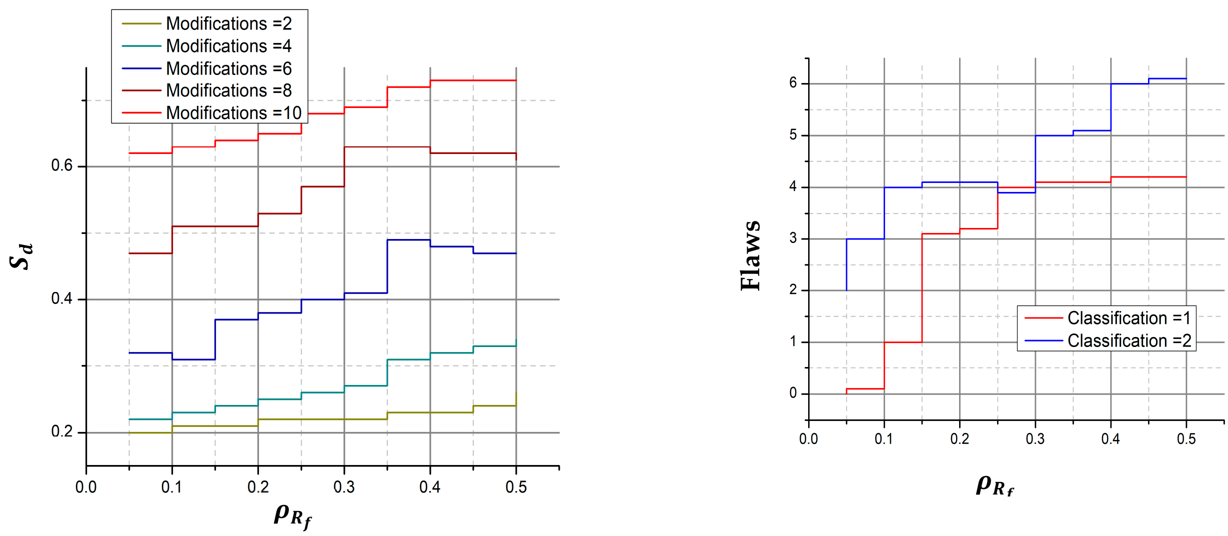

Figure 6. Flaw for ρ_{R_f}.

Blockchain technology guarantees that all data saved on the network cannot be altered in any way. The impossibility of changing or manipulating data after these data have been recorded on the blockchain increases the trustworthiness and integrity of these data in the supply chain. This immutability protects the honesty of performance evaluations and prevents tampering with recorded sustainability measures within the framework of sustainability assessment.

The blockchain makes supply chain processes public and verifiable. There is no longer any need to put faith in authoritative bodies because all transactions and data recorded on the blockchain are accessible to all users. Information on carbon emissions, waste management, and fair-trade practices can all be accessed and verified by interested parties thanks to this openness, leading to more responsibility and facilitating more thoughtful choices along the supply chain.

Decentralized Consensus: The blockchain relies on a system of distributed consensuses to ensure that all transactions are accurate and legitimate. By removing the need for a centralized authority, this consensus technique improves confidence and reliability. In order to ensure credibility and foster collaboration among supply chain operators, the Green Supply Chain Circular Economy Evaluation System makes use of a decentralized consensus to authenticate and verify sustainability KPIs and performance.

Blockchain technology offers full product traceability from the manufacturer to the consumer. A product's provenance, manufacturing process, and distribution channels can all be tracked thanks to the blockchain's immutable record of all transactions and movements. Traceability promotes openness, letting buyers and other stakeholders check for evidence of ethical production, fair trade, and environmentally friendly methods.

Sustainability and circular economy certifications can be verified and streamlined with the help of blockchain technology. The blockchain can be used to store and retrieve credentials such as eco-labels, fair trade certificates, and responsible sourcing certifications. This facilitates reliable certification verification and validation, lessens paperwork, and establishes credibility for sustainability claims.

The blockchain's distributed ledger technology and cryptographic protections make it ideal for exchanging sustainability data across supply chain members. Stakeholders can collaborate safely without worrying about the confidentiality or security of their data thanks to fine-grained permissions. Effective sustainability programs and circular economy practices benefit from increased collaboration and data-driven decision making made possible by this.

Increased confidence, openness, and responsibility in supply chain operations result from the blockchain's incorporation into the Green Supply Chain Circular Economy Evaluation System. This allows for the safekeeping of information, the tracking of products, the validation of certificates, and the safe transfer of sustainability data. The system can encourage eco-friendly, socially conscious business practices all throughout the supply chain by utilizing the benefits of blockchain technology.

The impact of ρ_{R_f} over the distribution is direct before the classification. It relies on the consecutive classification of $F(.)$ and E_d constraints for reducing the impact. Based on the conventional $ESG \in s$, the ρ_{R_f} is reduced by satisfying S_d based on E_d and s_n. As sustainability is achieved, ρ_{ESG} is satisfied, preventing ρ_{INR}. Depending on the risk factor (n), the modifications are performed, and hence S_d is leveraged from the diminishing value. For the dual classifications, the flaws are controlled compared to $F(.)$ or ρ_{ESG}. After the classification process, the proposed model requires $\rho_{ESG}\left(T/\rho_{R_f}\right)$ for analyzing the new risk factors preventing flaws (refer to Figure 6). Based on the possible risks for the combinations in Figure 5, ρ_{IN_R} and $\rho_{R_f} \in S_d$ are analyzed in Table 1.

In the above table, the combinations data delivery; order, demand; and pay, supply are used for analyzing ρ_{IN_R} and $\rho_{R_f} \in S_d$. This is observed for $T = 1$ *to* 5 (for consideration). Under two different classifications, the possible risks for independent and overall features are analyzed. The combinations for high (H) and low (L) availability are used for analyzing the demand, supply, and delivery of the sports goods. Based on the combinations, the risk factors are analyzed; the classification relies on $F(B_{ch})$ for ρ_{ESG}. In this process, the L $\forall$ delivery requires more modification; the consecutive classification rectifies the above flaw [33,34]. Therefore, the following possible combination improves the delivery, preventing the previous varieties. In the alternating process, the variations are suppressed through $\left(\frac{T}{\rho_{R_f}}\right)$ validation (refer to Table 1). The following section presents a comparative analysis by analyzing the above data for the metrics recommendation ratio, evaluation rate, flaws, and evaluation time. The variables considered are risks and modifications. In this comparative analysis, the existing BcSCFP [26], SCFSMS [20], and VCLSCND [21] methods are used. The visual representation of data provided by figures and tables facilitates the understanding of otherwise difficult material. They help scientists communicate findings about patterns and associations clearly and systematically. With the help of visuals, the most important aspects of the research may be conveyed to the audience with ease.

Table 1. ρ_{IN_R} and $\rho_{R_f} \in S_d$.

Classification	ρ_{INR}	ρ_{R_f}	Demand	Supply	Delivery	S_d
1	🟢🟢🟢🟢🟢	🟢🟢🔴🟢🔴	H	H	H	1
	🟢🔴🔴🟢🟢	🟢🔴🔴🟢🔴	H	L	L	0.81
	🔴🔴🔴🟢🟢	🔴🔴🔴🟢🟢	H	L	H	0.92
	🟢🟢🟢🟢🔴	🟢🟢🔴🔴🟢	L	H	H	0.85
	🔴🔴🔴🟢🟢	🟢🔴🔴🟢🔴	L	H	L	0.89
	🟢🟢🔴🟢🟢	🔴🔴🔴🔴🟢	L	L	H	0.84
	🔴🟢🔴🟢🔴	🟢🟢🟢🟢🔴	H	H	L	0.96
	🟢🟢🔴🔴🟢	🔴🔴🔴🔴🟢	L	L	L	0.81
2	🟢🟢🟢🟢🔴	🟢🟢🟢🟢🟢	H	H	H	1
	🔴🔴🔴🟢🟢	🟢🔴🔴🟢🔴	H	L	L	0.85
	🔴🔴🔴🟢🟢	🔴🟢🔴🟢🔴	H	L	H	0.98
	🟢🔴🔴🟢🔴	🟢🟢🔴🟢🟢	L	H	H	0.99
	🔴🔴🟢🟢🟢	🟢🔴🟢🟢🟢	L	H	L	0.87
	🟢🔴🟢🟢🟢	🟢🔴🟢🔴🟢	L	L	H	0.85
	🔴🔴🟢🟢🟢	🔴🟢🔴🔴🟢	H	H	L	0.96
	🟢🔴🟢		L	L	L	0.81

Researchers can display their findings in an open and replicable manner through the use of figures and tables. Researchers make it possible for others to duplicate and evaluate their findings by providing details such as data sources, measurement units, and statistical characteristics. This promotes scientific rigor and accountability by increasing the research's credibility and trustworthiness.

When presented properly in the context of the research, equations provide a succinct and mathematical depiction of the underlying concepts or models. They offer a standardized vocabulary for discussing theoretical frameworks and conceptual associations. When communicating mathematical models, algorithms, or theoretical structures, equations are crucial because they help readers grasp the reasoning behind the research.

4.1. Recommendation Ratio

This proposed model satisfies a high recommendation ratio for identifying flaws and demands using green blockchain technology (refer to Figure 7). The supply and economic management identification is based on sophisticated technologies from the previous green supply chain analysis for identifying the risk factors in both instances [35]. Instead, the flaw and demand identifications are computed to maximize the recommendation and evaluation rate for supply distribution along with the available information. Hence, the *ESG* concept recommendation for a green supply chain is improved. The different time intervals for economy evaluation, the *ESG* concept, are analyzed to prevent flaw detection in the supply chain [36,37]. Therefore, the first input based on economic demands and supply distribution is to be modified based on the $R_f \; \forall \; (E_d + S_d)$ condition [38,39]. The recommendation rate for the economy evaluation system has to satisfy two conditions for retaining the supply distribution. The proposed model analyzes the economic risk assessment to update the new supply chain to maximize the recommendation ratio.

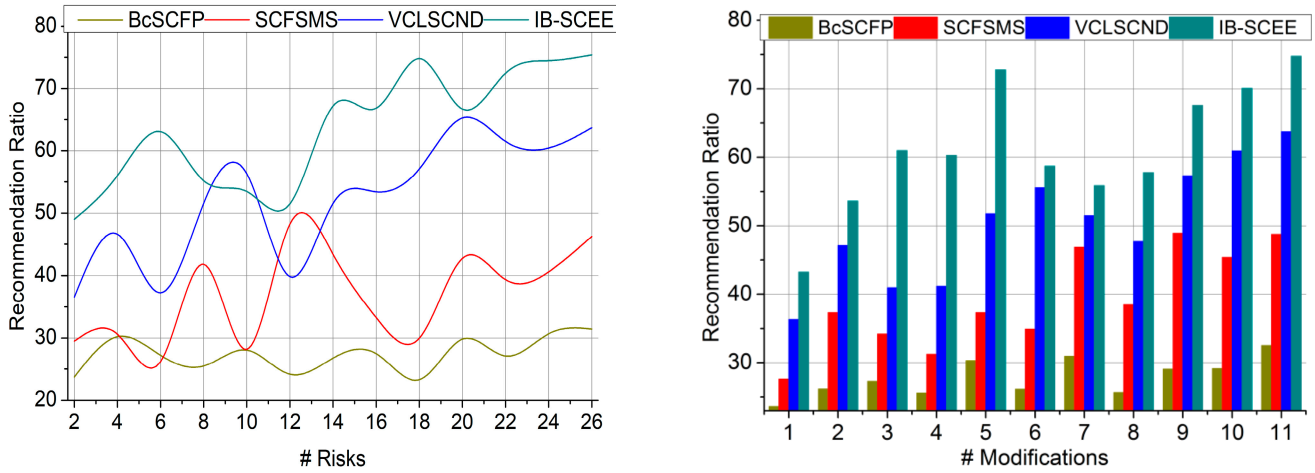

Figure 7. Recommendation ratio comparisons.

4.2. Evaluation Rate

The economy evaluation rate is high in this proposed model. It is used for identifying the particular transactions based on economic demands and the supply distribution analysis compared to the other factors in the green supply chain (refer to Figure 8). In IIoT forecast systems, the minimum and maximum risks are identified for feasible supply chain processing to detect flaws and demands at different time intervals. The above conditions improve *ESG* performance forecasting or recommendation based on supply distribution (as in Equation (7)). The risk factor assessment and modifications are identified for evaluating the economy. Based on this method, risk analysis is defined. The maximum economy evaluation in the environment based on *ESG* performance requirements is considered for economic and distribution outcomes. The identified risk factors require a maximum evaluation rate, preventing the flaw and demand identification sequentially [40,41]. This modification process uses the random forest classifier to update the economic demands such that the IIoT and the green blockchain are validated. This proposed model depends on *ESG* recommendations; therefore, frequent modification is identified for fewer risk factors.

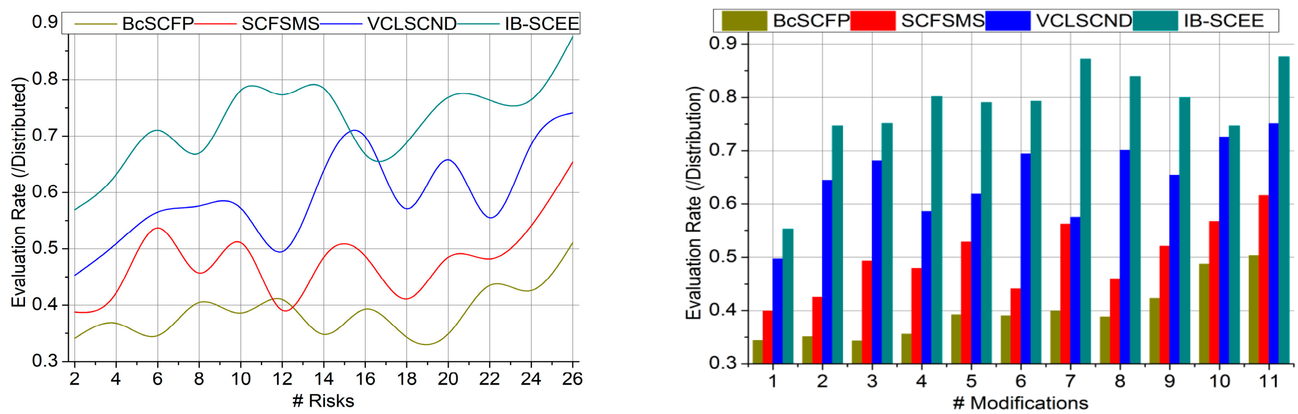

Figure 8. Evaluation rate comparisons.

4.3. Flaws

In Figure 9, the *ESG* performance and supply distribution based on a risk factor analysis through machine learning for optimizing and evaluating *ESG* concepts improves the functional growth in the green supply chain economy. The flaws in the identification-based

ESG concept recommendation for risk assessment provide recommendation and evaluation time through blockchain technology at different time intervals [42]. The economic demands and supply distribution based on the varying environment from the green supply chain information are processed for identifying flaws in both the condition of ρ_{ESG} and $Risk\ factor(n)$, analyzed sequentially. The risk factor verification is based on the risk assessment modifications followed by the distribution outcomes. The available risk features reduce the frequent modifications based on a different supply chain for which the proposed model satisfies fewer flaws. When gathering, storing, and exchanging information on the supply chain and sustainability, privacy and security are of the utmost importance. To preserve confidence and guarantee conformity with privacy requirements, it is critical to safeguard this information against unwanted access or alteration. Several processes and techniques can be employed to protect data privacy and boost security.

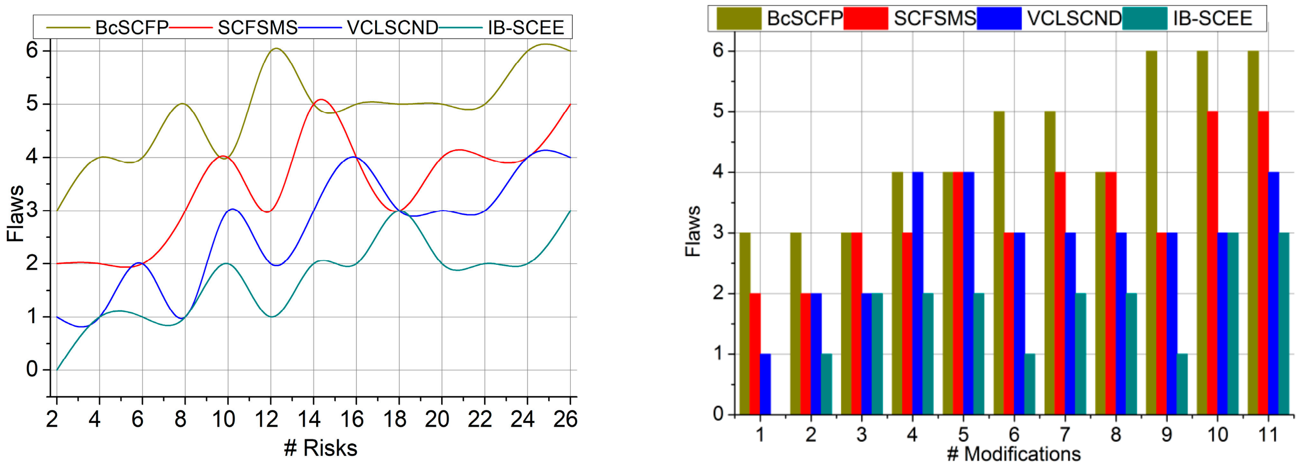

Figure 9. Comparison of flaws.

Encrypting data helps ensure that private information is safe even if it is accessed by the wrong people. When information is encrypted, it is converted into a format that is illegible without the corresponding encryption keys. A further safeguard against intrusion is the use of robust encryption techniques for both stored and in-transit data.

To ensure that only authorized parties have access to sensitive information, it is crucial to set up stringent access controls. RBAC techniques can be used to provide users access to only the resources they need to carry out their assigned tasks. This limits people to seeing only the information they need to complete their specialized jobs, making the system more secure.

Due to the sensitive nature of supply chain and sustainability data, it is essential to seek expressed agreement from all relevant stakeholders prior to collecting or using this information. An individual's consent for data collection, storage, and dissemination can be managed using a consent management method. It allows for openness and gives people agency over their personal information. Consent management frameworks ensure compliance with privacy requirements and foster stakeholder confidence when put into practice.

To further protect privacy, it is recommended to anonymize or pseudonymize sensitive data. Anonymization is the process of making data unidentifiable by removing personally identifiable information (PII). Pseudonymization is a method for protecting individuals' privacy while facilitating data analysis. There is less potential for re-identification and more anonymity is preserved when using these methods.

Audit trails and data integrity checks are essential for keeping supply chain and sustainability data accurate and trustworthy. Digital signatures, hash functions, and checksums are all examples of systems that can be used to identify and prevent data manipulation. Forensic analysis and compliance auditing are both made easier by keeping thorough audit trails of data access, updates, and sharing activities.

Sharing sensitive information with external stakeholders requires the use of encrypted channels and protocols. The safety of information exchange can be improved by using encrypted cloud storage services, virtual private networks, or secure file transfer protocols (SFTP). Establishing data sharing agreements and enforcing rigorous data usage regulations to regulate the treatment and protection of shared data are also crucial.

Conducting security audits and assessments on a consistent basis is essential for spotting vulnerabilities and staying in line with constantly developing security requirements. Potential threats from known vulnerabilities can be reduced by always using the most recent patches and upgrades for one's systems and applications.

It is critical to raise workers' awareness of data privacy and security best practices. Employees should be educated on best practices, hazards, and the significance of data security through regular training programs. Staff members should be instructed in the proper procedures for recognizing and reporting security breaches.

Using these methods, businesses can better protect their customers' personal information and internal sustainability data. An organization's security and compliance with rules and the trustworthiness of stakeholders all are improved by safeguarding personal information.

4.4. Evaluation Time

In Figure 10, the evaluation of the *ESG* concept depends on a risk factor analysis in the green supply chain through the particular transactions analyzed by the blockchain technology based on the flaw identification analyzed using IIoT forecast systems relying on *ESG* performance convenience. This risk factor analysis modifies the economic and distribution observations based on the *ESG* concept for improving the recommendation and evaluation rate of the economy. The economic demands and supply distribution based on risk factor identification from the first input instance are performed [43]. The flaws and demands are verified based on modifications in both conditions in a consecutive manner. These flaws and risk factors are addressed to improve the recommendation and evaluation rate through the learning model; if *ESG* concept information is observed in the green supply chain, a high recommendation and evaluation rate is achieved. Based on the conditions (E_d, S_d) and $\left(r_{E_{dT-1}}, r_{S_{dT-1}}\right)$, all the supply distribution is satisfied, preventing flaw detection. The economic demands are based on different environments and risk factor analyses for which the proposed model satisfies the shorter evaluation time. The comparative results are summarized using Tables 2 and 3 for risks and modifications.

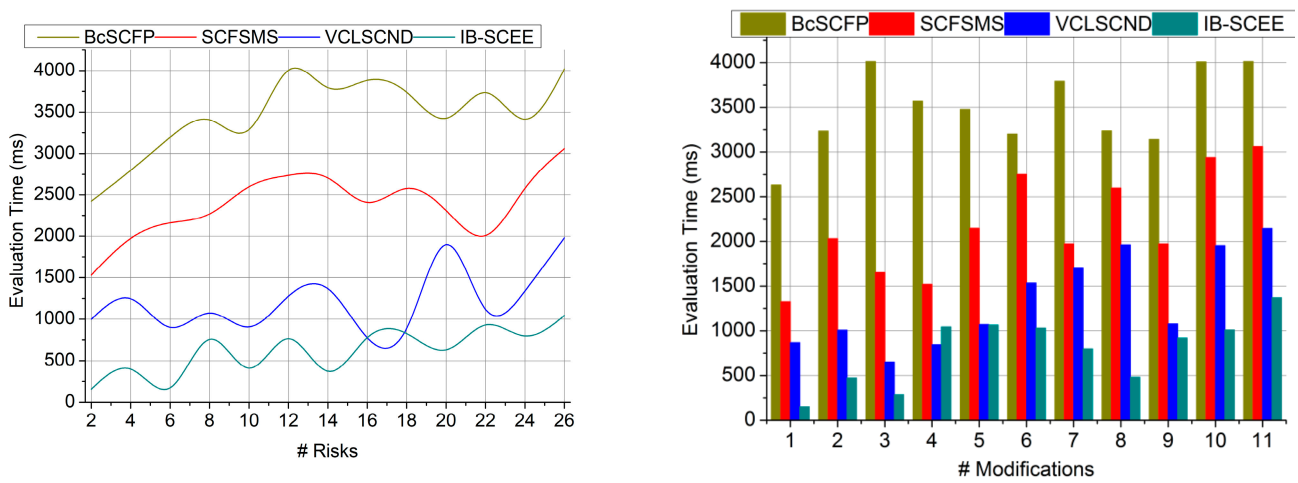

Figure 10. Evaluation time comparisons.

Table 2. Comparative results (#risks).

Metrics	BcSCFP	SCFSMS	VCLSCND	IB-SCEE
Recommendation Ratio	31.44	46.24	63.7	75.401
Evaluation Rate (distribution)	0.511	0.654	0.741	0.8755
Flaws	6	5	4	3
Evaluation Time (ms)	4019.36	3060.65	1979.03	1043.422

BcSCFP: blockchain-driven SCF platform; SCFSMS: system of communicating finite state machines; VCLSCND: viable closed-loop supply chain network; IB-SCEE: An IIoT-Blockchain-based Supply Chain Economy Evaluation.

Table 3. Comparative results (#modifications).

Metrics	BcSCFP	SCFSMS	VCLSCND	IB-SCEE
Recommendation Ratio	32.52	48.75	63.74	74.767
Evaluation Rate (distribution)	0.503	0.616	0.751	0.8761
Flaws	6	5	4	3
Evaluation Time (ms)	4013.17	3062.25	2147.23	1371.251

The proposed model maximizes the recommendation ratio and evaluation rate by 14.14% and 12.01%, respectively. This model reduces the flaws and evaluation time by 13.3% and 10.91%, respectively.

The proposed model maximizes the recommendation ratio and evaluation rate by 13.22% and 12.64%, respectively. This model reduces the flaws and evaluation time by 13.3% and 9.23%, respectively.

An institution's financial stability may be attributed to the existing or potential effects of environmental, social, and governance (*ESG*) factors on its counterparties or invested assets, which are considered *ESG* risks. When discussing sustainable finance, this term is often utilized. Risks associated with the environment, society, governance, human rights, anti-corruption measures, and workplace safety are all examples of *ESG* risks [44].

5. Conclusions

The IIoT-Blockchain-based Supply Chain Economy Evaluation (IB–SCEE) model may identify and reduce supply chain risk factors. Blockchain technology may identify transactions by economic demands and supply distribution. The circular economy faces various implementation obstacles. This study addresses problems and combines blockchain and product service systems with a green supply chain. Blockchain-based advances such as trust, information exchange, and immutability allow new potentials to resolve current problems in the circular economy domain. Product service systems and transactions serve as the application extent due to their already confirmed positive effects on the sustainable supply chain. This article introduced an IIoT-blockchain-based evaluation model to improve the green supply chain delivery efficiency. The proposed model relies on classifier learning for identifying and mitigating risks at different supply chain levels. The risks and flaws are identified for improving the functional growth of the industrial processes and trials. These features are confined to the *ESG* concept recommendations and circular economy guidelines. This model identifies the economic and distribution demands to prevent abrupt modifications in the supply chain. Regarding the green blockchain and IIoT paradigm for record verification and computations, the entire process is aided. The green blockchain distinguishes the risk assessment and modifications over the heterogeneous supply chain sequences. Contrarily, the IIoT paradigm operates on predicting and forecasting risks for improving sustainability. The joint process mitigates the independent risks, and consecutive classifications are enrolled to maximize supply distribution. Green finance in China uses financial services to promote environmental sustainability and social wellbeing goals, including policy recommendation, resource conservation, and energy and sustainability sources. Green finance is essential to the long-term viability of the global economy and a powerful engine of risk management and socioeconomic development. The proposed model maximizes the recommendation ratio and evaluation rate by 14.14%

and 12.01%, respectively. This model reduces the flaws and evaluation time by 13.3% and 10.91%, respectively, for the varying risk factors. Supply chain management that takes *ESG* considerations into account is a major issue on the international stage. The results of this research can be used to shape future policies and programs that support sustainable growth and are in line with global norms.

This report informs policymakers, regulatory agencies, and industry leaders who are working to effect positive environmental and social change by illuminating the potential of blockchain-based supply chain economics to address *ESG* concerns.

This research is significant because it produced useful findings and made wider contributions to the study of blockchain technology, supply chain management, and environmental sustainability. The results show how blockchain has the ability to revolutionize supply chain transparency, while *ESG* integration encourages ethical corporate practices. This study contributes to the scientific knowledge of the role of the blockchain in defining a more sustainable and responsible future for global supply chains by giving actionable insights and opening the path for further research.

The unique contribution of this research is the novel application of IIoT and blockchain technologies to the assessment of supply chain economies within the context of the *ESG* concept. This is significant because it contributes to our understanding of the blockchain's potential to foster responsible and environmentally friendly activities throughout international supply chains, as well as our ability to expand our knowledge in these areas.

6. Future Works

This investigation paves the way for additional research to improve the evaluation of supply chains using the *ESG* concept and blockchain technology. Future research can expand on a number of important points brought up in this study. First, research into the blockchain's scalability and interoperability in multi-party, cross-industry supply chain networks is essential. Decision-makers could benefit greatly from research into the financial repercussions and cost effectiveness of using blockchain systems in supply chains. Additionally, studies might be geared towards standardizing frameworks and criteria for assessing *ESG* performance within blockchain-based supply chain economies. Last but not least, it can help shape regulatory and governance frameworks to investigate the possible social and policy ramifications of the widespread implementation of blockchain technology in supply chains. Research in the future should focus on answering these questions so that we can improve our understanding and use that information to build supply chains that are both sustainable and transparent.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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