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Research paper

Blockchain-Enabled ESG for Secure and Transparent Sustainability Accounting

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Abstract

Environmental, Social, and Governance (ESG) reporting has developed as an essential structure for assessing corporate sustainability performance and long-term value creation. However, conventional ESG declaration is undermined by data discrepancies, non-auditable indicators, and susceptibility to greenwashing. This article explores the integration of blockchain technology into ESG data reporting frameworks to develop an immutable, auditable, and reliable sustainability accounting system. Blockchain, with its characteristic aspects of decentralized governance, immutable record keeping, and automated agreement mechanisms, offers a novel approach to existing shortcomings in ESG reporting. Through a structured review of recent literature, we inspect how blockchain can improve data trustworthiness, allow real-time reporting, and smart contract-enabled compliance mechanisms. The research outlines novel practices, business applications, and research gaps in ESG-blockchain integration. A five-layer framework is proposed to assess existing blockchain-based ESG models. The framework incorporates parameters such as record traceability, independent verifiability, and compliance with applicable regulations. By integrating insights from accounting, economics, and technological innovation, this article expands scholarly discussion on digital sustainable governance. The findings are particularly important for regulatory authorities, sustainability practitioners, and technological innovators aiming to integrate ESG objectives with robust, auditable, and interoperable reporting infrastructures.

Keywords: *Blockchain, ESG Reporting, Sustainability Accounting, Greenwashing, Smart Contracts, Disclosure, Digital Assurance, SDGs, Data Integrity, Decentralized Systems.*

1. Introduction

In recent years, the corporate sector has seen a major shift in emphasis from concentrating just on financial success to adopting longer-term sustainability and wider aspects of responsibility [1]. ESG disclosure is a public report that provides extensive information about an organization's performance in fields like protecting the environment, social accountability, and the impacts of its activities. ESG disclosures help to understand regulators and investors understand the impact of a company's activities on the environment and society. ESG disclosure enables businesses to express their commitment to green practices and socially responsible policies to stakeholders, including shareholders, clients, and regulators, fostering trust and credibility [2], [3]. Despite progress in ESG reporting practices, ESG disclosures still suffer from insufficient methodological transparency, isolated and inconsistent data, and false claims, which make them susceptible to greenwashing and reduce the trust and confidence needed for stakeholder involvement [4].
To overcome these limitations, scientists and industry professionals are increasingly investing in the role of blockchain technology, a transparent, cryptographically secure record-keeping system, as a mechanism for improving the integrity of ESG disclosures. Blockchain's characteristic attributes, including tamper-resistant recordkeeping, audit transparency, and smart contract–enabled verification, make it suitable for sustainability guarantee applications [5]. For example, EY and Guardtime have collaboratively designed a blockchain-enabled system that enables ESG performance monitoring in the oil and gas sector. Similarly, Banca Mediolanum in Italy has accepted a blockchain-enabled mechanism to validate sustainability reports with verifiable time markers, ensuring transparent communica-

tion to stakeholders [6], [7]. Such real-world examples demonstrate the effectiveness of blockchain to ensure trust and traceability in ESG data capture, verification, and reporting procedures.

This merging of blockchain technology into ESG reporting is strongly aligned with the United Nations Sustainable Development Goals (SDGs). UN-SDG 9 (Industry, Innovation and Infrastructure) supports the implementation of long-lasting and sustainable technological innovations. UN-SDG 12 (Responsible Consumption and Production) advocates transparent management of resources, whereas UN-SDG 13 (Climate Action) encourages for an effective mechanism to monitor emissions. Additionally, UNSDG 16 (Peace, Justice, and Strong Institutions) focuses on anti-corruption and accountable governance targets that blockchain can advance by preventing manipulation of corporate ESG records [8]. Blockchains' feature to create immutable records allows cross-sectoral partnerships (UN-SDG 17) by permitting different stakeholders to share an unchallengeable ESG ledger.

Despite its several advantages, the use of blockchain in ESG reporting remains in its early stages and faces several implementation challenges. This includes the lack of uniform frameworks, regulatory uncertainty, high deployment costs, and energy consumption associated with certain blockchain platforms [9]. Most sustainability performance reports are still generated manually or rely on traditional systems, which restrict their compatibility with blockchain-enabled frameworks [9]. Without compatible data structures and consensus-driven verification mechanisms, there is a risk that blockchain-based ESG platforms could replicate the fragmentation of existing reporting frameworks.

This study seeks to address these challenges by examining how blockchain can transform ESG reporting from a passive, faith-oriented method into an adaptive, information-driven, and fraud-proof accounting model. This article also presents a detailed literature review of blockchain applications in sustainability accounting, followed by a comparative study of existing frameworks, case studies, and pilot projects. A conceptual framework is introduced to demonstrate how ESG data can be secured, digitized, and verified using blockchain infrastructure. This work adds value to ongoing academic and professional conversations by presenting a verifiable, technology-driven approach to sustainability reporting compatible with both accounting standards and global development priorities.

2. Related Work

The use of blockchain infrastructure in Environmental, Social, and Governance (ESG) reporting has gained significant attention, but the field remains at a conceptual level and lacks a standard framework. The focus of early study remained on how blockchain improves trustworthiness and data traceability, especially in supply chain management. For example, Tian first introduced a blockchain and Internet of Things-based system to track food products [10]. Saberi et al. found that blockchain facilitates a better data-sharing platform among stakeholders, decreasing the risk of false reporting in global ESG practices [11].

Pizzi et al. introduced a blockchain-enabled structure for ESG reporting, where self-enforcing smart contracts enable in validation of information and automate sustainability report generation. This framework improves transparency and ensures stakeholder expectations are aligned with reported sustainability metrics [8]. In related work, AlShamsi et al. proved how blockchain, especially permissioned blockchains like Hyperledger Fabric, support live tracking of carbon emissions and compliance to environmental regulations in sectors like mining and shipping [12].

Silkoset, R. et. al investigated the role of blockchain in addressing greenwashing, advocating that smart contracts can tie ESG targets to financial incentives. Benchmarks are achieved only when verified ESG performance is demonstrated, thus improving stakeholder trust [13]. Rejeb et al. highlighted that blockchain ensures data integrity once recorded [14]. But it cannot promise the correctness of the source information. So off-chain verification through community involvement becomes essential. They also stressed the high power consumption related to some consensus protocols, such as proof-of-work.

Tapscott and Tapscott recommended decentralized autonomous organizations (DAOs) to manage ESG initiatives transparently. This approach has several advantages but faces obstacles such as regulatory uncertainty and resistance from established organizations [15]. By conducting a systematic literature review, Arshad et al. recognized common themes and gaps across areas like green logistics and ethical sourcing, calling for more experiential and additional investigation to strengthen the field [16]. At the same time, businesses continued to develop blockchain-enabled ESG projects. VeChain has implemented monitoring platforms in fashion and retail, and PwC has introduced blockchain-enabled ESG reporting and monitoring tools [17].

Building on these foundations, recent research shifted the trend towards developing practical frameworks for carbon accountability. Alotaibi et al. (2024) introduced an integrated system for tracking supply chain emissions, incorporating automated data capture and blockchain-based immutable ledgers. Blockchain-enabled smart contract verification improves the accuracy and uniformity of reported emissions data [18]. Their methodology offers a validated method for advancing carbon accounting in accordance with ESG principles.

Another work by Sui et al. (2025) evaluated the relationship between business adoption of blockchain technology and ESG performance employing data from 5,000 firms. Their investigation shows substantial enhancement in environmental and governance metrics, particularly in firms that leveraged digital financial innovations alongside blockchain [19]. These experimental findings support the theoretical benefits proposed in earlier works.

In 2024, Fernandez Carames and Fraga Lamas highlight how blockchain can enhance IoT systems. This work explored various challenges, such as the protection of sensitive data, the energy efficiency of devices, and scalability performance. They also provided guidelines for developing sustainability solutions by integrating sensing devices with distributed ledgers [20]. López et al. (2023) explored energy-sustainable IoT connectivity. This work highlighted the need to reduce the environmental impact of IoT to ensure that data collection practices are in line with ESG goals [21].

A recent systematic review by Vladucu et al. (2024) outlined environmental sustainability use cases of blockchain, including applications like waste reduction processes, emission monitoring, and regenerative economic systems. This article classified the established models, assessed their performance, and highlighted limitations in current studies, including unclear regulatory frameworks and practical scalability difficulties [22]. The comprehensive review in this section provides a foundation for identifying research gaps.

Table 1: Related Work with Opportunities and Challenges

S. No	Authors (Year)	Blockchain Features Used	ESG Contribution / Focus Area	Opportunities	Challenges
1	Tian (2016) [10]	Public ledger, traceability	Supply chain transparency	Improved food safety; product provenance	Initial data authenticity; scalability
2	Saberi et al. (2019) [11]	Distributed ledger, smart contracts	Multi-party ESG data sharing	Reduces risk of misreporting; collaboration	Lack of standards; cost of implementation
3	Pizzi et al. (2020) [8]	Blockchain, Smart contracts	Transparent ESG dis-	Automated regulatory	Difficulty in merging with

			closure	compliance; real-time monitoring	existing traditional systems
4	AlShamsi et al. (2021) [12]	Hyperledger Fabric, private chains	Carbon footprint assessment and emissions monitoring	live monitoring and regulatory synchronization	Designed to work with external systems
5	Silkoset, R. et. al. (2025) [13]	Smart contract–enabled reward structure	ESG claims verification mechanism	Ties ESG performance to outcomes; builds trust	Subjectivity in ESG metrics
6	Rejeb et al. (2022) [14]	Secured information verification	Immutable ESG information.	Tamper-proof record management and verifiability	Vulnerable to poor quality data source; energy-consuming algorithms
7	Tapscott & Tapscott (2020) [15]	Decentralized autonomous organizations, blockchain governance	UN SDG-compliant governance mechanism	Decentralized participation in ESG	Lack of legal frameworks for DAOs
8	Arshad et al. (2023) [16]	Literature synthesis	ESG use cases: logistics, procurement	Broad review of sectors; framework identification	Limited field validation
9	VeChain, PwC (2022–2024) [22]	Private blockchains	Organizational ESG performance evaluations	Business integration; initial commercial trials	Low public transparency in consortium blockchains
10	Alotaibi et al. (2024) [18]	Blockchain + Smart Contracts	Carbon footprint monitoring in supply chains	Regulatory compliance automation, structured information input	High resource utilization
11	Sui et al. (2025) [19]	Adoption benchmarks, blockchain performance index	Company-level ESG reporting analysis	Empirical link to performance; impact quantification	Sample bias; regional differences
12	Fernandez-Carames & Fraga-Lamas (2024) [20]	Blockchain–IoT ecosystems	Environmental monitoring (IoT + blockchain)	Real-time ESG data collection; automation	Energy use in edge devices; data privacy
13	López et al. (2023) [22]	Lightweight blockchain, IoT	Sustainable data transmission (E)	Efficient ESG data flows	Need for eco-friendly protocols
14	Vladucu et al. (2024) [22]	Cross-industry applications	ESG applications: circular economy, waste tracking	Detailed classification system; policy analysis	Legal compliance; data connectivity

3. Research Gaps

Blockchain adoption in Environmental, Social, and Governance (ESG) reporting has received substantial attention in the last decade. Current research still presents several gaps. Many of the studies mainly highlight blockchain's benefit for improving trustworthiness, traceability, and transparency, particularly within environmental areas like emission tracking and sustainable supply chain management [9]. However, a significant gap remains in the development of standardized, end-to-end frameworks that integrate blockchain directly into ESG reporting mechanisms aligned with established models such as GRI, TCFD, or SDG metrics [23]. The absence of interoperability standards and consistent ESG taxonomies frequently results in fragmented implementations and reduced comparability across firms and sectors [24].

Furthermore, while theoretical proposals and use-case reviews are ample, experiential validation of blockchain-enabled ESG frameworks remains limited. Most applications are restricted to experimental projects or case-specific solutions, such as VeChain’s traceability platform or IBM Food Trust, which cater to specific industries [25]. These implementations often rely on private or permissioned blockchains, which, although efficient, compromise the core idea of transparency and decentralization features that are foundational to blockchain’s demand in sustainability accounting. Within the ESG framework, governance is frequently underexplored, with only limited research considering decentralized autonomous organizations (DAOs) as a possible avenue for innovation [26].

Existing research work indicates the lack of real-time ESG data reporting. Traditional ESG reporting methods are based on fixed reporting cycles and past performance, which restricts the capacity of participants, including investors, regulators, and consumers, to make informed decisions depending on current performance. While blockchain's transparency and smart contract capabilities offer the technological backbone for real-time sustainability reporting, few academic works or industry models have demonstrated this functionality in a replicable or scalable form.

The regulatory and audit frameworks have lagged behind the pace of blockchain adoption in ESG contexts. Issues such as jurisdictional conflict, the legal status of smart contracts, and accountability in decentralized networks present substantial obstacles to institutional trust and mass adoption. The current literature often overlooks these critical compliance and governance challenges or treats them as peripheral to the core technological discussion.

4. Blockchain Technology: Capabilities for ESG Accounting

4.1. Overview of blockchain technology

Blockchain is a peer-to-peer network system that allows transparent recording of data across a distributed network [27]. Every participant in the network can view information stored in the ledger. There is no need for a central authority to manage and validate transactions. Blockchain networks have computers connected in a distributed manner, called nodes, to maintain the ledger. Each participant in the blockchain can verify and validate transactions, ensuring security and trust [28]Transactions are accumulated in blocks, and every block is linked to the previous block using a cryptographic hash, forming an immutable chain of blocks [29]. The hash value is generated from a collection of transactions in a block and refers to the hash of the previous block, thereby forming a chain of blocks in sequential order. This kind of structure guarantees the immutable nature of blockchain. Altering the contents of one block requires recalculating the hash of every subsequent block, a practically difficult task. If any transaction in a block is changed, its hash changes, which invalidates the hash of the next block, which in turn makes tampering immediately detectable.

Blockchain is considered secure because of the consensus mechanism. All members in the blockchain need to agree on the state of the ledger [30]. When a member in the blockchain starts a new transaction, it is sent to all the nodes in the network. To approve most participants is essential. Any change to the ledger also needs approval from most participants. This is achieved through consensus algorithms. Common consensus methods include Proof of Work (PoW), which requires nodes to solve a complex mathematical puzzle to confirm transactions. On the other hand, Proof of Stake (PoS) selects a validator to create a new block based on the amount of stake they hold in the network. These consensus mechanisms are employed to achieve agreement between participants, trust, and security across a decentralized computer network. The more cryptocurrency a miner holds, the higher the chance of being selected to validate a transaction.

To ensure the security of information, cryptography plays a significant role in blockchain [31]. The digital signature proves ownership of the transaction and ensures that the transaction was initiated by the sincere owner. The transaction is signed by private keys and broadcast over the network to every node in the blockchain. Asymmetric key cryptography, known as public key cryptography, allows every participant to verify ownership of a transaction. This cryptographic mechanism is important to establish trust between sender and receiver and to ensure the security of data.

Transparency is another important feature of blockchain. Instead of a single centralized entity controlling all the operations, every member has the right to take part in the decision-making process [27], [32]. All transactions and an entire copy of the ledger are visible to every participant in the blockchain. This transparent and open nature of blockchain ensures that no single member can change data without the agreement of most participants. In applications like supply chain, this transparency allows participants to monitor the source of the product and its movement live. As transaction records are permanently recorded, it allows effective auditing and suspicious activity detection in the financial sector.

One of the important features of blockchain is the use of smart contracts, self-executing programs with the terms of the contracts directly written into lines of code [33]. It enforces the terms and conditions recorded in the program. It carries out the terms of the contract when predefined conditions are met. Once a smart contract is deployed over a blockchain network, it becomes an immutable part of the ledger. Every participant can view the code of the smart contracts. Hence, these programs need to be designed carefully. Smart contract auditing can help in identifying vulnerabilities before deployment. Smart contracts can automate business processes, streamline processes, and improve efficiency by ensuring that all operations are performed as planned.

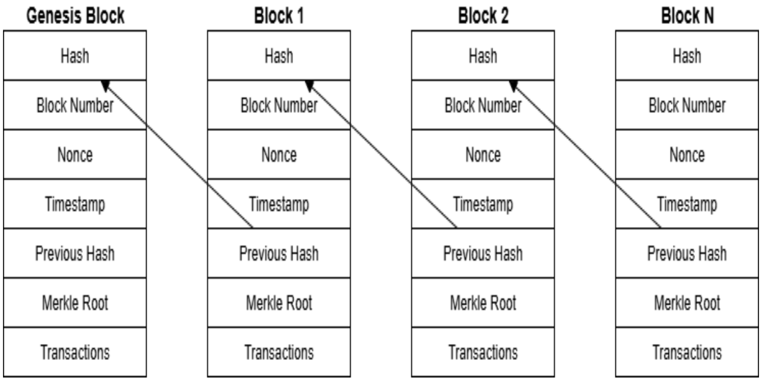

Fig. 1: Blockchain Architecture Showing Hash Linkage.

4.2. Essential characteristics for ESG accounting

Several features of blockchain technology match directly with the necessities of ESG accounting. Its open and unalterable characteristics ensure that once ESG data is recorded, such as carbon emissions cannot be modified. This enables the reliability of the audit trail and ensures trust in ESG reports [9] Transparency and openness allow all stakeholders, including investors, regulators, and civil society, to access and validate sustainability claims in real-time [12].

Smart contracts, defined as self-enforcing programs on the blockchain, allow automation of ESG reporting and monitoring operations. It facilitates the automation of ESG-related workflows, including emissions threshold verification and automatic reporting to regulatory bodies. It may also enable the imposition of penalties for non-compliance [1].

Moreover, participation of all involved parties in decision-making minimizes the possibility of modification by a single party in ESG disclosure, enhancing the credibility of sustainability data [34]. For example, Decentralized Autonomous Organizations (DAOs) can be developed to govern ESG-related decisions transparently through consensus mechanisms, which could replace or help traditional governance models [35], [36].

4.3. Types of blockchains and use-case fit

Blockchain platforms can be mainly classified into public, private, and consortium types. Public blockchains are fully decentralized and transparent, but may raise questions regarding scalability and privacy [27], [33]. Private blockchains deliver superior speed and data protection but may compromise decentralization, making them suitable for internal ESG monitoring and reporting within large corporations [14]. Consortium blockchains, governed by a group of trusted parties, strike a balance between transparency and performance. They are ideal for ESG ecosystems involving multiple parties, such as industry-specific sustainability alliances or regional carbon trading platforms [3].

Each blockchain type provides specific outcomes for the ESG disclosure operation. For example, VeChain, a permissioned blockchain, has been successfully used for emission monitoring and product provenance in the fashion and logistics industries. Similarly, the IBM Blockchain platform has been used in food supply chain tracking tools for validating sustainable sourcing claims [25].

4.4. How blockchain supports ESG and SDG goals

The utilization of blockchain in ESG reporting and monitoring directly supports certain Sustainable Development Goals (SDGs), particularly [5], [37]:

- Sustainable Development Goal 12 (Responsible Consumption and Production): From the source of raw material to manufacturing, supply chain, and consumption, every step of the product can be monitored using blockchain.

- Sustainable Development Goal 13 (Climate Action): Blockchain offers verifiable data for carbon emissions, energy consumption, and energy credits. As the record is publicly verifiable, it is difficult to manipulate it.
- Sustainable Development Goal 16 (Peace, Justice, and Strong Institutions): Blockchain creates records that are difficult to manipulate. As the record is publicly verifiable, it is difficult to manipulate [38].

Everledger uses blockchain technology to record information about where a diamond was mined, polished, and sold. Consumers can verify that it has been ethically mined and that labor methods are in alignment with Sustainable Development Goals 12 and 16. The Energy Web Chain uses blockchain to create digital renewable energy certificates. This certificate ensures that stakeholders are using energy produced from renewable sources like solar. It advances Sustainable Development Goals 7 and 13 through the promotion of renewable energy adoption. These examples demonstrate the effectiveness of blockchain's usefulness in operational and compliance frameworks of multinational enterprises.

4.5 Blockchain adoption in ESG reporting

The use of blockchain technology for ESG reporting is rapidly increasing due to growing demand for transparency. According to a report by Grand View Research (2024), the market size of blockchain technology is valued at USD 31 billion in 2024 and is estimated to grow up to USD 1.43 trillion by 2030 [39]. A large portion of this growth is driven by applications such as finance, supply chain, and sustainability. The growth shows rising business level trust and investment in the field of blockchain technology. The number of applications in tracking emissions, ethical sourcing of raw material, and supply chain traceability has shown a rapid increase over the last few years. The Fig. 2 shows the approximate regional distribution of blockchain initiatives. According to the market research report (2024), North America shows a significant market share, followed by rising adoption by Europe, with Asia-Pacific as a growing market [39].

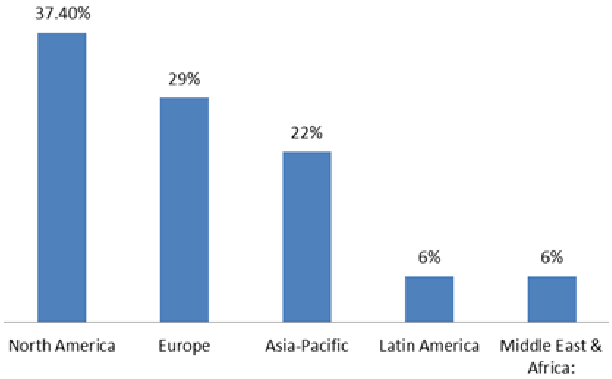

Fig. 2: Regional Distribution of Blockchain Projects in ESG Initiatives (2024).

Blockchain-enabled ESG projects primarily focus on the environmental pillar. The main reason is that environmental data such as quantity of waste generated, carbon emission, energy uses, and use of renewable energy sources are measurable making them well suitable for blockchain. This verifiable data aligns with blockchain features such as trustworthiness, data integrity, and immutability. Findings from reports and research article shows that the majority of projects focus on environmental applications such as pollution monitoring, energy consumption monitoring, and tracking ethical sources of raw data. Projects based on the social and governance pillar share a smaller portion of the ESG tracking ecosystem. The social aspect often involves tracking fair labor practices and workforce diversity, while governance projects may focus on shareholder voting and transparent corporate structures. According to the Deloitte and PaperTale whitepaper [39], [40]Blockchain-enabled ESG projects show a clear prioritization of the Environmental pillar, as shown in Fig. 3.

Beyond environmental use cases, blockchain also offers important contributions to the Social and Governance dimensions of ESG. In the social domain, distributed ledgers can support labor rights monitoring, fair-trade certification, and workforce diversity tracking, ensuring accountability across supply chains. On the governance side, blockchain enables transparent shareholder voting, anti-corruption safeguards, and decentralized autonomous organizations (DAOs) for participatory decision-making. These applications extend the role of blockchain beyond environmental metrics, offering a more balanced ESG approach.

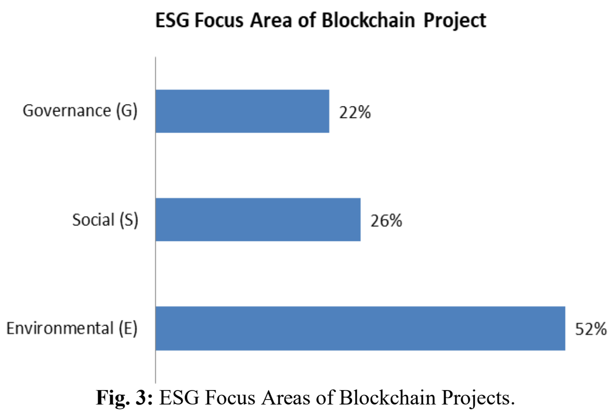

Fig. 3: ESG Focus Areas of Blockchain Projects.

5. Blockchain-Enabled ESG Accounting System (BESGAS)

This section presents the Blockchain-Enabled ESG Accounting System (BESGAS) framework to address limitations of traditional ESG accounting. The BEGAS framework aims to improve the quality of data, standardize the ESG reporting mechanism, and foster stakeholder trust. The outlined framework is divided into five layers interlinked to each other. Each is designed to transform raw ESG-related source information into verifiable, reliable, and immutable ESG reports that support the Sustainable Development Goals (SDGs).

a) Data Acquisition Layer

The bottom layer concentrates on the acquisition of environment and sustainability-related data from different sources. This involves IoT-enabled environmental sensors that acquire emissions, energy consumption, and the quantity of waste generated [9]. Information systems like ERP and MIS can be used to monitor labor practices, employee recruitment processes, and organizational support for employee health and safety. It also includes audit reports by ESG accreditation bodies. To facilitate ESG performance measurement, application programming interface (APIs) may be used to collect data from regulators, suppliers, and sustainability partners. By incorporating sustainable development goals, this layer supports the collection of real-time information from diverse sources

b) Data Verification and Validation Layer

Before adding data to the blockchain, it is essential to check that it is accurate, complete, and authentic. This layer uses asymmetric key cryptographic algorithms, blockchain oracles, and AI-powered anomaly detection algorithms to verify each data input [41]. An example is emission data from a factory that is verified against regional standards and readings from third-party sources before being approved. This step is important to detect fraudulent and manipulated data. The validated trustworthy information provides a basis for credible ESG reports, which in turn builds trust and confidence among stakeholders.

c) Blockchain Integration Layer

This is the technology layer in which all validated environmental and sustainability-related data needed to generate ESG reports is stored immutably on blockchain, such as Hyperledger Fabric or VeChain. Once timestamped ESG data is recorded on the blockchain, it cannot be altered. This layer also incorporates smart contracts to automate ESG-related operations. For example, if carbon emissions exceed a predefined threshold, the smart contract can automatically report non-compliance. Smart contracts help in enhancing operational efficiency [42].

d) Compliance and Analytics Layer

The fourth layer is responsible for analyzing the data recorded on blockchain for regulatory compliance and to measure the organization's performance against environmental, social, and governance indicators. It matches environmental, social, and governance (ESG) indicators with international norms like SASS, GRI, TCFD, and applicable SDGs. This layer is responsible for calculating scores related to ESG, emissions ratios, governance indicators, and social impact parameters. Businesses can see how they're doing in terms of sustainability compared to their competitors and over time, which can help them make better decisions [43].

e) Stakeholder Access and Reporting Layer

This layer provides access to ESG data and analytics dashboards based on user roles. Business associates, including internal teams, investors, auditors, consumers, and policymakers, can view ESG reports that are both detailed and tamper-proof. Public stakeholders may access summarized reports, while regulators and partners can query granular data for audits or verifications. Blockchain's transparency assures users that the data has not been retroactively altered, addressing long-standing concerns about greenwashing [43]. By democratizing access to trustworthy ESG information, this layer strengthens accountability and aligns business practices with SDGs such as SDG 12 (Responsible Consumption) and SDG 16 (Peace, Justice, and Strong Institutions).

The proposed blockchain-integrated ESG accounting framework offers several benefits, including enhanced transparency and automated compliance through smart contracts. Smart contracts automate compliance checks and can trigger penalties for violations; its decentralized authentication builds trust among investors, regulators, NGOs, and consumers while minimizing reliance on third parties. By enabling traceable supply chains, accurate emissions accounting, and anti-corruption safeguards, the framework directly supports key UN Sustainable Development Goals.

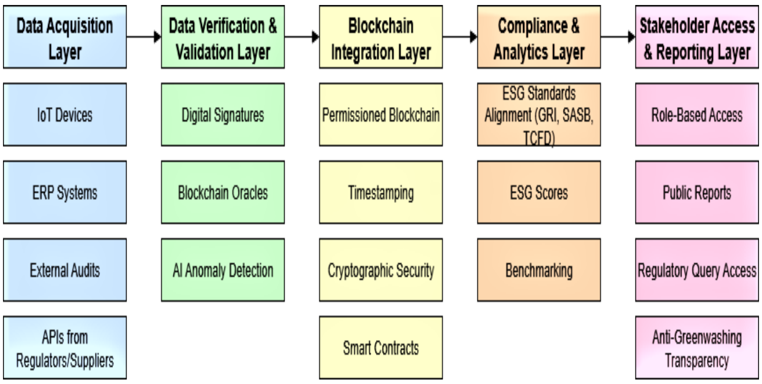

Fig. 4: Blockchain-Enabled ESG Accounting System framework

6. Policy and Practice Implications

The integration of blockchain technology into ESG accounting offers several benefits. However, to realize its benefits, coordinated efforts are needed from different stakeholders and blockchain experts to match governance systems, reporting tools, and standards [38].

6.1. Regulatory modernization

Existing ESG frameworks and reporting mechanisms depend on centralized audit systems, limiting transparency and efficiency. Adopting blockchain into ESG accounting and disclosure requires modifications in regulations to integrate a decentralized and transparent validation framework [44]. Instead of depending on external audits, policymakers can use blockchain-validated ESG data as a component of regulatory structures. Smart contract programs can be used to automatically track predefined environmental, social, and governance benchmarks and impose penalties after violations. Under the EU's Corporate Sustainability Reporting Directive (CSRD), regulators are already moving toward standardized digital sustainability reporting. Integrating blockchain-enabled audit and traceability systems into CSRD frameworks can enhance cross-border comparability, reduce greenwashing, and incentivize adoption in both developed and developing economies.

6.2. Standardization and governance

To ensure consistency and comparability, governments and international bodies (such as the International Financial Reporting Standards (IFRS) Foundation and the International Sustainability Standards Board (ISSB)) must develop blockchain-compatible ESG frameworks [43]. Industry alliances and multi-stakeholder alliances can jointly define protocols for ESG input data and role-based access. They can also provide smart contract design templates and dispute resolution mechanisms.

Such efforts would accelerate cross-border ESG reporting and eliminate greenwashing by reducing the manipulation of information. Moreover, governments could incentivize blockchain adoption through tax credits or subsidies for sustainability technology investment.

6.3. Corporate strategy transformation

In businesses or corporations, the adoption of blockchain in ESG reporting serves not only as a compliance mechanism but also as a strategic asset [32]. It improves brand credibility, increases investor confidence, and fosters stakeholder trust. Publicly accessible ESG data on blockchain platforms could be mandated in public procurement, investor screening, or carbon markets.

Organizations should match their internal ESG metrics and KPIs with on-chain systems, ensuring active engagement from the C-suite to facilitate this transformation. Chief Sustainability Officers and Chief Information Officers must collaborate to formulate sustainable digital governance strategies.

6.4. Empowering stakeholders and investors

Individual investors, clients, evaluation agencies, and other interested parties can obtain certified ESG data in real time via blockchain. Stakeholders can make more informed decisions when ESG data is available in real time on the blockchain. Blockchain dashboards allow investors to instantly verify if a company is meeting ESG requirements, and customers can check if a product is fair trade or carbon neutral before buying. Permanent ESG records could let civil society groups develop decentralized watchdog platforms that identify malfeasance and irregularities.

6.5. Risk and ethical considerations

While blockchain-enabled ESG systems offer several advantages, they also bring several risks, such as data security, monitoring, and algorithmic bias, if not carefully designed [45]. Policymakers must ensure that such systems do not unintentionally marginalize small firms or developing regions due to high technological entry barriers. Efforts should be made to design inclusive and equitable blockchain solutions.

Regulations must also enforce ethical standards in smart contract design, especially when automating sensitive decisions related to social equity, labor rights, or environmental penalties. Continuous stakeholder engagement is essential to keep the technology aligned with public interest.

7. Real-World Case Studies in Blockchain-Enabled ESG Accounting

This section presents case studies of the successful implementation of blockchain-based ESG monitoring and reporting systems in various sectors. These real-world implementations demonstrate how successfully blockchain can improve transparency and reliability in ESG accounting.

7.1. Everledger: ethical sourcing and provenance

Everledger, a blockchain-based provenance platform, uses distributed ledger technology to track the source to sales of diamonds, wine, and other high-value goods [46]. By recording each step of a product's lifecycle, Everledger ensures ethical sourcing, conflict-free mining, and fair labor practices. This aligns directly with SDG 12 (Responsible Consumption and Production) and SDG 16 (Peace, Justice, and Strong Institutions).

It provides transparency to consumers and reduces greenwashing by offering immutable verification of ESG claims. Insurers, retailers, and regulators use the platform to confirm the authenticity and ethical origin of goods.

7.2. IBM food trust: sustainability in agriculture and supply chains

IBM Food Trust, built on Hyperledger Fabric, enables food producers, retailers, and logistics providers to track food products from farm to fork [25]. Blockchain ensures that sustainability metrics such as organic farming practices, water usage, and fair labor are recorded and audited across the supply chain.

Walmart and Nestlé have used the system to trace the origin of products like lettuce and baby food, enhancing consumer trust and compliance with ESG goals. This supports SDG 12 and SDG 3 (Good Health and Well-being) by preventing food fraud and contamination.

7.3. Energy web chain: decentralized renewable energy certification

The Energy Web Chain is a public blockchain tailored to the energy sector, facilitating decentralized and verifiable energy attribute certificates (EACs). It enables individuals, companies, and governments to track renewable energy generation, consumption, and carbon offsetting in real time [47], [48].

This supports SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) by promoting decentralized renewable energy grids and accurate emission reporting. For example, Shell and Singapore Power have used Energy Web Chain to issue digital certificates for green energy, improving transparency in carbon markets.

7.4. VeChain: ESG reporting in fashion and logistics

VeChain, a permissioned blockchain platform, is used by fashion brands and logistics providers to monitor ESG metrics such as carbon emissions, recycled materials use, and labor conditions [49]. For instance, brands like H&M and LVMH have explored VeChain to verify sustainability claims for apparel production.
The platform enables stakeholders to view a product's full lifecycle and verify that production aligns with environmental standards. This enhances accountability and aligns with SDG 9 (Industry, Innovation and Infrastructure) and SDG 13.

7.5. Circularise: transparency in the circular economy

Circularise, a blockchain-based supply chain transparency platform, focuses on circular economy initiatives [50]. It allows companies to trace raw materials, recycling processes, and reuse cycles, making it easier to comply with ESG requirements and circular production standards.
Used in industries such as plastics, chemicals, and electronics, Circularise supports SDG 12 and fosters transparency across multi-tier supply chains without exposing sensitive business data.

Table 2: Real World Case Study Application Areas and Benefits

Case Study / Platform	Application Area	ESG Focus	Relevant SDGs	Key Benefits
Everledger	Fair sourcing and supply chain transparency	Governance, Social	SDG 12, SDG 16	Source tracking, Ethical procurement, anti-corruption safeguards
IBM Food Trust	Food origin verification	Ecological, Social	SDG 12, SDG 3	Food safety, Verified food quality, and consumer trust
Energy Web Chain	Sustainable energy certification	Environmental	SDG 7, SDG 13	Real-time power usage statistics, emission monitoring
VeChain	Fashion supply chain ESG disclosure	Environmental, Governance	SDG 9, SDG 13	Greenhouse gas tracking, lifecycle monitoring, brand accountability
Circularise	Reuse–recycle supply systems	Eco-friendly	SDG 12	Transparent sourcing, recycling verification, and data privacy

8. Conclusion

The integration of blockchain technology into ESG and sustainability accounting represents a significant leap toward tamper-proof, verifiable, and real-time disclosures that can revolutionize how organizations report and act on environmental, social, and governance indicators. By embedding features like immutability, transparency, decentralized consensus, and smart contracts, blockchain addresses longstanding challenges such as greenwashing, delayed reporting, and data manipulation. As demonstrated by both the conceptual framework and real-world implementations like Everledger, IBM Food Trust, and Energy Web Chain, blockchain is not only technically viable but also practically impactful for ESG assurance and SDG alignment. However, this convergence is not without limitations. Issues such as blockchain scalability, energy consumption (especially with proof-of-work chains), data privacy regulations, and the need for multi-stakeholder standardization must be systematically addressed. These limitations are particularly evident in energy-intensive consensus mechanisms such as Proof-of-Work (PoW), which may conflict with ESG environmental objectives. To address this, more sustainable alternatives like Proof-of-Stake (PoS), lightweight consensus algorithms, and renewable-powered blockchain networks are increasingly being adopted. Such solutions can improve scalability and reduce environmental impact while preserving transparency and trust. Furthermore, for blockchain-based ESG systems to gain regulatory acceptance, alignment with global accounting standards and policy frameworks is crucial.
To advance the use of blockchain in ESG reporting, integration of AI with blockchain will be crucial for predictive ESG auditing, allowing companies to detect risks and make real-time operational adjustments. Implementing privacy-preserving mechanisms, such as zero-knowledge proofs, is critical to enable secure, selective disclosure of sensitive ESG data. Developing sector-specific frameworks will make these solutions more relevant for high-impact industries.

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