Green Blockchain – A tamper-proof, energy-efficient tool for decentralised climatic data

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***Abstract*—Blockchain technology has transformed industries with secure, decentralized ledgers, but its adoption raises sustainability concerns due to the high energy demands of Proof-of-Work systems. This paper introduces the Green Blockchain, a tamper-proof and energy-efficient tool for the collection, processing, visualization, and auditing of climatic data. By leveraging second-generation blockchain technology, the Green Blockchain significantly reduces energy consumption while maintaining high throughput and security. The system's architecture integrates mid-cost sensors, a frugal smart contract for secure notarization, and a decentralized application that enables data visualization and auditing of the data notarized so far. The aim of Green Blockchain is twofold: on the one hand, our low-energy solution showcases "greener" applications of the blockchain; and on the other hand, our decentralized notarization service brings trust and transparency on climatic data to the public.**

***Index Terms*—blockchain, low-energy consensus, data collection and processing, climatic data, decentralized notarization**

I. Introduction

Ecological transition and climate neutrality are among the main challenges targeted by the European's "Green Deal" [8]. In this context, accurate and trustful environmental data is critical for informing decision-making both at local and global levels. Traditional methods for data collection and verification are often based on centralized systems, which may suffer from lack of transparency and be susceptible to tampering. Blockchain technology has emerged as a promising solution to address these concerns.

At its core, a blockchain is a distributed ledger that ensures data integrity through cryptographic techniques and consensus algorithms, without the need for intermediaries [5]. This paradigm shift from centralized to decentralized systems has paved the way for numerous applications in sectors such as finance, supply chain management, and energy trading. Among its advantages, blockchain enhances security and resilience against cyberattacks, as participants share an immutable ledger that significantly reduces tampering risks [6].

Blockchain's advantages come with environmental concerns, especially with energy-intensive Proof of Work (PoW) systems in first-generation technology. This has driven the development of more sustainable second-generation blockchains using Proof of Stake (PoS) and Byzantine Fault Tolerance (BFT) mechanisms.

In this context, the Tendermint protocol [9] was chosen for this project because it eliminates the need for energy-intensive mining while enforcing high throughput, low latency, and deterministic finality.

Blockchain technology introduces smart contracts, which are self-executing programs that run on the blockchain and that encode predefined rules and automatically enforceable conditions. Smart contracts enable trustless transactions, as their execution is guaranteed without reliance on third parties. For instance, in supply chain management, smart contracts can automate payments upon delivery confirmation, thereby reducing human intervention and errors [7].

This paper presents the Green Blockchain [10], a tamper-proof and energy-efficient tool for the collection, processing, visualization, and auditing of climatic data. These data come from so-called 'Atmoboxes', which are mid-cost sensors deployed in urban areas and managed by a decentralized network of climate laboratories. Our tool relies on an innovative notarization service implemented by a frugal smart contract that runs on a blockchain with Tendermint consensus. The Green Blockchain demonstrates how blockchain technology can be applied to monitoring of CO_2 concentration using IoT devices such as Atmoboxes. This innovative notarization service secures the collected and processed data by anchoring it on the blockchain. This mechanism enables the cross-verification of notarized data: in a posterior phase of audit, a laboratory can replay the calculation process of the data notarized by another laboratory and check its integrity.

In the following sections, we provide an overview of blockchain technology, discuss the Green Blockchain's architecture, evaluate its energy efficiency, and explore potential future applications and challenges.

II. Architecture of the Green Blockchain

Our solution employs the Evmos blockchain [14], a platform combining Ethereum Virtual Machine (EVM) [15] capabilities with the Tendermint consensus protocol [1]. Evmos supports smart contracts written in the widespread Solidity language [16].

The architecture (Fig.1) is designed to ensure seamless integration with existing data workflows while minimizing disruptions to pre-existing systems. Data collection begins with Atmoboxes, which collect CO_2 concentration data daily. Raw data files are securely transmitted to a laboratory server, where they are processed through a sequence of stages including quality control and calibration. These stages are automated using containerized environments to ensure reproducibility and traceability, and their result is notarized on the blockchain.

A unique aspect of the Green Blockchain architecture is the optimized implementation of the notarization service by a lightweight, low-energy smart contract. This smart contract ensures the integrity of both raw and processed data by anchoring these data on the blockchain, i.e., by storing "crypto" footprints of data and metadata files on the blockchain. The use Merkle trees for efficient aggregation and verification of data states allows us to store only one footprint per data flow and day, which is independent of data size. This mechanism enable the independent verification of the entire life cycle of the data, from collection at Atmoboxes to processing at laboratories, and finally to its visualization at the decentralized application (DApp) that interfaces between the blockchain, the laboratories, and the end users.

The DApp consists of a web-based dashboard for managing transactions, monitoring data dependencies, visualizing corrected data, and performing audits on notarized data. This dashboard is accessible to both technical users (i.e., laboratories' staff) and non-technical end users (i.e., general public).

The Green Blockchain architecture has been designed for its application to the management of climatic data, but otherwise this architecture is agnostic to the domain of application: similar notarization service and DApp could be used to implement data processing collected at IoT devices and managed by a decentralized network of institutions, for other use cases in any domain of application beyond climatic data.

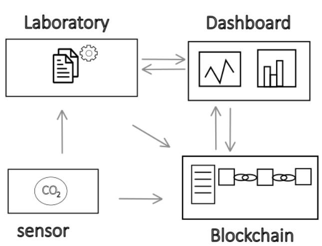

Fig. 1. The architecture of the Green Blockchain Project system

III. Energy Consumption of the Green Blockchain

The Tendermint protocol is recognized for its energy efficiency, primarily due to its consensus mechanism that eschews the computationally intensive processes characteristic of Proof-of-Work (PoW) systems. Unlike PoW, which requires significant computational power to solve complex puzzles for block validation, Tendermint employs a Byzantine Fault Tolerant (BFT) consensus algorithm. This approach enables validators to reach agreement on the blockchain's state through a series of voting rounds, significantly reducing the energy expenditure associated with block production. As a Proof-of-Stake (PoS) protocol combined with Byzantine Fault Tolerance (BFT), Tendermint minimizes computational demands, leading to significant reductions in energy usage. Studies highlight that Tendermint achieves high throughput and finality without the energy-intensive mining associated with PoW systems [2]. Additionally, Tendermint's deterministic finality ensures that blocks are confirmed once consensus is reached, further optimizing resource efficiency [4]. The protocol has demonstrated suitability for energy-constrained environments like microgrids, where it supports decentralized energy trading with minimal overhead [3].

The energy efficiency is enhanced as well by frugal smart contracts that minimize computational overhead of the notarization service. By using Merkle trees—a cryptographic structure that aggregates a collection of data hashes into a single root hash—the system efficiently verifies the integrity of large datasets with minimal computational effort. This approach reduces the number of required transactions and, consequently, the energy consumed per operation.

Additionally, the deployment of lightweight devices—such as Raspberry Pi—for certain nodes ensures that even the hardware footprint aligns with the system's sustainability goals.

We also implemented a interactive simulation tool [13] designed to quantify the energy consumption and carbon footprint of our solution based on the number of sensors and blockchain nodes. Built upon the work in [11] and the proposed BCTMark model, the tool takes as inputs parameters such as node hardware (DELL or Raspberry Pi), the number of nodes N, and the computational complexity of the smart contract, and returns an estimation of the energy consumption incurred by the notarization service.

The tool also calculates the carbon footprint using the carbon intensity of the area associated with the geolocation of blockchain nodes based on the entries coming from [12].

For example, with a configuration 1000 blockchain nodes and 25 Atmoboxes the notarization service consumes $1,62\%$ of the energy consumed by the totality of the Atmoboxes, and $0,62\%$ of the Atmoboxes' carbon footprint.

IV. Conclusion and Future Work

In this paper, we have introduced the Green Blockchain, an energy-efficient and secure framework for decentralized environmental data management. This solution has the potential to enhance trust and reliability in environmental data, which is crucial for decision-making in addressing climate change and other environmental challenges.

Our work demonstrates the feasibility of combining sustainability with blockchain technology, opening the door for a wide range of decentralized applications in various sectors.

Future work will focus on expanding the Green Blockchain's use cases beyond climatic data to include applications in agriculture, supply chain monitoring, and renewable energy. We also plan to explore further optimizations in consensus mechanisms. Addressing these challenges will help make the Green Blockchain a versatile, sustainable, and scalable solution for decentralized data management in a variety of domains.

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References

[1] Y. Amoussou-Guenou, A. Del Pozzo, M. Potop-Butucaru, and S. Tucci-Piergiovanni, "Correctness of Tendermint-Core blockchains," in *22nd International Conference on Principles of Distributed Systems (OPODIS 2018)*, Schloss Dagstuhl–Leibniz-Zentrum fuer Informatik, 2018.

[2] C. T. Nguyen, D. T. Hoang, D. N. Nguyen, D. Niyato, H. T. Nguyen, and E. Dutkiewicz, "Proof-of-stake consensus mechanisms for future blockchain networks: fundamentals, applications and opportunities," *IEEE Access*, vol. 7, pp. 85727–85745, 2019.

[3] M. L. Di Silvestre, P. Gallo, M. G. Ippolito, E. R. Sanseverino, G. Sciumè, and G. Zizzo, "An energy blockchain, a use case on Tendermint," in *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, pp. 1–5, 2018.

[4] Y. Amoussou-Guenou, A. Del Pozzo, and S. Tucci-Piergiovanni, "Tendermint," in *Blockchains: A Handbook on Fundamentals, Platforms and Applications*, Springer, pp. 195–221, 2023.

[5] S. Nakamoto, "A peer-to-peer electronic cash system," *Bitcoin*, vol. 4, no. 2, p. 15, 2008. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[6] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: Current status, classification and open issues," *Telematics and Informatics*, vol. 36, pp. 55–81, 2019.

[7] K. Christidis and M. Devetsikiotis, "Blockchains and smart contracts for the Internet of Things," *IEEE Access*, vol. 4, pp. 2292–2303, 2016.

[8] Council of European Union, "Proposal for a regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC," 2022.

[9] J. Kwon, "Tendermint: Consensus without mining," Draft v. 0.6, vol. 1, no. 11, pp. 1–11, Fall 2014.

[10] CEA, "Blockchain Verte," [Online]. Available : https://blockchain-verte.fr/.

[11] D. Saingre, T. Ledoux, and J.-M. Menaud, "Measuring performances and footprint of blockchains with BCTMark: a case study on Ethereum smart contracts energy consumption," Cluster Computing, vol. 25, no. 4, pp. 2819–2837, 2022.

[12] Electricity Maps, "Live 24/7 CO_2 emissions of electricity consumption," [Online]. Available: https://app.electricitymaps.com/map.

[13] CEA, "Blockchain Verte Energy Consumption Simulation tool," [Online]. Available: https://blockchain-verte.fr/map.

[14] "Evmos Develop Documentation," Evmos.Docs, 2023. [Online]. Available: https://docs.evmos.org/develop/.

[15] "Ethereum development documentation," ethereum.org, 2022. [Online]. Available: https://ethereum.org/en/developers/docs/.

[16] "Solidity Doc," Solidity, 2023. [Online]. Available: https://docs.soliditylang.org/en/latest/.