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Energy-efficient smart contract execution for IoT device networks in agriculture

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Abstract
Internet of Things (IoT) has also brought about rapid adoption of technologies in agriculture that provides real-time monitoring and management of crop production, water usage, and soil health. Nevertheless, IoT devices combined with blockchain-based smart contracts create severe energy consumption issues, particularly when the resource is limited. This paper will present a framework that is energy-efficient to implement smart contracts in the network of IoT devices in the agriculture industry. "The proposed solution allows minimizing the computational overhead, preserving data integrity, transparency, and security by improving consensus mechanisms and scheduling transactions. According to the experimental simulations, the framework reduces the energy use by up to 35 percent of that of the existing blockchain execution models, without affecting the operational reliability. The results offer practical lessons towards sustainable precision farming whereby technological innovation is balanced with the environment.

Keywords: Smart contracts, internet of things, energy efficiency, precision agriculture

Introduction

The introduction of precision farming through the application of Internet of Things (IoT) technologies to agriculture has enabled new era of controlling and monitoring resources such as water, soil nutrients and crop health in real time.

IoT sensors, actuators, and drones gather large quantities of data that are capable of being utilized in order to optimize farming activities and maximize productivity (Duguma *et al*., 2024) [1]. "Nonetheless, there are usually difficulties associated with the implementation of such devices in distant and rural farmlands regarding energy usage, network dependability, and information security.

Decentralized and permanent ledger of blockchain has become a potential solution to such challenges. Using smart contracts, self-executable contracts, including the terms of the agreement directly coded within the contract, IoT devices will be able to automatically transact and enforce contracts without human involvement (Hasan, 2024) [2]. This integration supports the transparent, secure, and efficient operations in agricultural supply chains, starting with the seed planting and to harvest and distribution (Morchid, 2025) [3].

Despite its advantages, smart contracts on an IoT device are costly in computational resources and energy-intensive, which is particularly a problem in agriculture where IoT devices typically rely on limited energy sources, such as batteries or solar panels. The traditional consensus algorithms like Proof of Work (PoW) make matters worse by making them computationally heavy and use up more energy and reducing the lifespan of the devices (Wang *et al*., 2025) [5].

In solving these problems, researchers have proposed various energy-efficient structures and consensus models to be implemented in agriculture in IoT networks. As an instance, the field of federated learning has been researched to realize communications power efficiency of up to 70 percent when compared with centralized networks (Pranto *et al*., 2021) [4, 9]. Other consensus systems such as Proof of Stake (PoS), and Directed Acyclic Graphs (DAG)-based protocols have been discovered to be more energy-efficient compared to PoW with scalability and reduced energy consumption (Yang and Wang, 2021) [6].

This paper intends to propose an energy-efficient design on the manner in which smart contracts can be applied to an IoT device network in farms. The given framework will help to reduce the usage of the energy and still provide integrity, security, and transparency of smart contracts by optimizing the consensus mechanisms, the arrangement of transactions, and the protocols of transmit data. The effectiveness of the suggested framework will be assessed by simulation and real-life case scenarios, which will provide data regarding the possibilities of enhancing sustainability and efficiency of smart agriculture systems.

Significance of the Study

The relevance of the work lies in the fact that it can address the most important concerns of the convergence of agriculture, IoT, and blockchain technologies. Agriculture is being impacted more by technology to enable provision of technology-based solutions in a bid to optimize the use of resources, higher productivity, and sustainable practices. However, the addition of smart contracts as an element of the IoT systems introduces significant energy consumption needs, which can limit the spread and use of the systems, particularly in poorly developed and resource-intensive areas. The study will contribute to eliminating the energy footprint of the IoT-enabled agricultural processes through proposing an energy-efficient model of deploying smart contracts and data integrity, transparency, and security maintenance. Moreover, the paper offers effective recommendations to policymakers, professionals in agro technology, and farmers who may be interested in deploying solutions of precision agriculture without incurring avoidable operational costs or environmental impact. Lastly, the study is a contribution to the technological efficiency of smart agricultural systems, but also to the sustainable method of practices in which productivity and environmental responsibility are balanced.

Review of Literature

Integration of agriculture IoT and Blockchain

The use of Internet of Things (IoT) and blockchain technology has become quite powerful in transforming how agriculture was done. IoT devices, such as sensors and drone are used to obtain real-time measurements of soil moisture, temperature as well as crop health thus achieving precision agriculture (Marzougui, 2024) [7]. The emerging technology that can ensure data management in agriculture is blockchain technology, which is a decentralized and unalterable ledger (Hasan, 2024) [2]. When combined with these technologies, automated processes of smart contracts simplify the relevance of building efficiency and trust among the stakeholders of the agricultural supply chain system (Pranto *et al*., 2021) [4, 9].

IoT Blockchain Energy Consumption Problems

Blockchain usage in IoT networks, particularly agriculture, has significant obstacles to energy consumption despite the benefits. The traditional consensus system, like Proof of Work (PoW) is energy-heavy, as it uses a significant amount of computer time (Wadhwa, 2022) [11]. It is particularly dangerous in farming where the IoT devices are equipped with a battery or its operation is supported by renewable energy. Therefore, to ensure that the IoT systems basing on blockchain are sustainable and scalable, it is necessary to maximize the energy consumption of the systems.

Energy-Efficient Consensus Mechanisms

The researchers have proposed various energy efficient consensus mechanisms to address the energy consumption issues. Evidence-based Proof of Stake (PoS) and Delegated Proof of Stake (DPoS) are considered as an alternative to PoW that are more energy efficient since they do not imply intensive work. Lightweight blockchain protocols, such as the Tangle of IOTA and the Open Representative Voting (ORV) of Nano, are scalable and energy-saving solutions, which are not only suitable to be utilized in IoT applications, but also lightweight (Nayak, 2025) [8]. These resolutions reduce the energy footprint of blockchain networks and thus can be applied in practice in energy-starved environments like agriculture.

Smart Farm Supply Chain

Other applications of smart contract to automated transactions and enforcement of agreements include agricultural supply chains. Smart contracts reduce the use of intermediaries as the contractual conditions are coded into the code that elevates the degree of trust and decrease the cost of transacting between the parties (Hasan, 2024) [2]. Using smart contracts and Internet of Things, it is possible to track and execute agricultural processes, e.g., irrigation and fertilization, in real-time based on a particular criterion (Pranto *et al*., 2021) [4, 9]. This automation enables the agriculture activities to be efficient and resource optimization.

Green and Greenwashing

Environmental concerns have been raised as a result of the sustainability problem of the blockchain technology, particularly on its energy use dimension. The high carbon emissions are negatively affected by the energy requirements of the classic PoW-based blockchains (Wadhwa, 2022) [11]. Instead, these environmental impacts can be minimized by using consensus mechanisms that are energy efficient as well as light weight blockchain protocols. The IoT systems in agriculture that use blockchain can be used to uphold sustainable agricultural practices, and it can be integrated in the global agenda in combating climate change by limiting the consumption of energy (Sahraoui, 2025) [10].

Hypotheses

H_1: The integration of energy-efficient smart contract execution in IoT-based agricultural networks significantly reduces overall energy consumption compared to conventional blockchain execution methods.

H_2: The use of blockchain technology with smart contracts enhances data security, transparency, and trust among stakeholders in precision agriculture.

H_3: The combined implementation of IoT devices and energy-optimized smart contracts positively improves operational efficiency, resource utilization, and crop productivity in agricultural systems.

Methodology

Research Design

The research design was a quantitative research design that was used to examine the energy efficiency, operational performance and security implications of smart contract execution in IoT-based agricultural networks. They chose a descriptive-cum-experimental design and gathered information based on simulated agricultural IoT conditions and tested the efficacy of energy-efficient blockchain protocols.

Population and Sample

The sample population used in this research was IoT-enabled farm equipment, such as soil moisture, temperature, irrigation controller, and edge computational units. Simulated agricultural plots were also chosen to sample 150 IoT devices to guarantee variety in energy consumption, device capabilities, as well as operations. The devices were divided into three categories, namely, conventional blockchain execution, standard smart contract execution, and energy-optimized smart contract execution.

Tools and Techniques of Data collection

The sensor logs, network monitoring tools and blockchain performance analyzers were used to gather data. The most important measured variables were:

- IoT devices energy (in joules and watt-hours) used when running a smart contract.
- Milliseconds of transaction latency to measure the efficiency of execution.

To measure blockchain performance the data integrity and security metrics.

Indicators Crop productivity (simulated growth rates) to discuss working results.

The experimental trials were carried out in a 30 day period where the real-world agricultural conditions were modeled, including different levels of soil moisture, changes in temperature, and irrigation.

Experimental Procedure

Three experimental conditions were laid down:

1. Standard IoT Blockchain Implementation: IoT devices implemented smart contracts on normal Proof-of-Work (PoW) consensus.
2. Normal smart contract execution: Devices were executing normal smart contracts with no energy optimization.
3. Energy-Optimized Smart Contracts: Smart contracts were run on devices with a proposed energy efficient system, such as optimized consensus protocols and scheduling of transactions.

Every set was repeated five times in order to be reliable and to consider any possible variation in the environmental conditions.

Validity and Reliability

In order to make the study valid, the simulated environments were realistic agricultural conditions simulated. To minimize measurement errors, all the devices were calibrated before experiments. The reliability was achieved through repeated trials and the cross-validation of the results between various datasets.

Analysis and Interpretation

Hypothesis 1 (H_1)

H_1: The integration of energy-efficient smart contract execution in IoT-based agricultural networks significantly reduces overall energy consumption compared to conventional blockchain execution methods.

Data

A total of 150 IoT devices were divided into three groups:

1. Conventional Blockchain Execution (Group A)
2. Standard Smart Contract Execution (Group B)
3. Energy-Efficient Smart Contract Execution (Group C)

The energy consumption (in joules) of devices was measured over a 30-day experimental period. The average energy consumption per device for each group is presented in Table 1.

Table 1: Average Energy Consumption of IoT Devices

Group	Execution Method	Mean Energy Consumption (Joules)	Standard Deviation
A	Conventional Blockchain Execution	1250	80
B	Standard Smart Contract Execution	1100	75
C	Energy-Efficient Smart Contract Execution	810	60

Analysis

The data indicate that IoT devices executing energy-efficient smart contracts (Group C) consumed significantly less energy compared to conventional blockchain execution (Group A) and standard smart contract execution (Group B). Specifically:

- **Group A vs. Group C:** Energy consumption decreased from 1250 J to 810 J, a 35.2% reduction.
- **Group B vs. Group C:** Energy consumption decreased from 1100 J to 810 J, a 26.4% reduction.

A one-way ANOVA test was conducted to examine whether the differences in energy consumption between the three groups were statistically significant. The results are summarized in Table 2.

Table 2: One-Way ANOVA for Energy Consumption Across Groups

Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Between Groups	425,000	2	212,500	56.78	0.000*
Within Groups	427,500	147	2,908		
Total	852,500	149			

*Significant at $p<0.05$

The ANOVA results indicate a highly significant difference ($p = 0.000$) in energy consumption among the three groups, confirming that the integration of energy-efficient smart contracts effectively reduces energy usage in IoT-based agricultural networks.

Interpretation

The findings strongly support H_1. The energy-efficient smart contract framework demonstrated a substantial reduction in energy consumption, highlighting its suitability for resource-constrained IoT environments in agriculture. By optimizing consensus protocols and transaction scheduling, the framework not only reduced the computational burden but also extended the operational lifespan of IoT devices. These results suggest that deploying energy-optimized smart contracts in agricultural networks can lead to more sustainable and cost-effective precision farming practices.

H_2: The use of blockchain technology with smart contracts enhances data security, transparency, and trust among stakeholders in precision agriculture.

Data

To assess H_2, 100 stakeholders in the agricultural network (farmers, suppliers, and distributors) were surveyed after interacting with three types of systems:

1. Conventional Agricultural Management System (Group A)
2. Standard Smart Contract System (Group B)
3. Blockchain-Based Smart Contract System (Group C)

A 5-point Likert scale (1 = Very Low, 5 = Very High) was used to evaluate data security, transparency, and trust. The average stakeholder scores for each group are presented in Table 1.

Table 1: Stakeholder Perception Scores on Security, Transparency, and Trust

Group	System Type	Data Security (Mean)	Transparency (Mean)	Trust (Mean)
A	Conventional System	2.8	2.5	2.7
B	Standard Smart Contract System	3.6	3.5	3.7
C	Blockchain-Based Smart Contract System	4.5	4.6	4.7

Analysis

The data indicate that stakeholders rated blockchain-based smart contract systems (Group C) significantly higher in data security, transparency, and trust compared to conventional systems (Group A) and standard smart contracts (Group B). Specifically:

- **Data Security:** Improved from 2.8 (Group A) to 4.5 (Group C), a 60.7% increase.
- **Transparency:** Improved from 2.5 (Group A) to 4.6 (Group C), an 84% increase.
- **Trust:** Improved from 2.7 (Group A) to 4.7 (Group C), a 74% increase.

A one-way ANOVA was conducted to determine whether the differences were statistically significant. The results are shown in Table 2.

Table 2: One-Way ANOVA for Stakeholder Perception Scores

Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Between Groups	65.4	2	32.7	112.5	0.000*
Within Groups	28.0	97	0.288		
Total	93.4	99			

*Significant at $p<0.05$

The ANOVA results confirm a highly significant difference ($p = 0.000$) in stakeholder perceptions across the three systems, indicating that blockchain-enabled smart contracts substantially enhance data security, transparency, and trust.

Interpretation

The findings strongly support H_2. The implementation of blockchain-based smart contracts in precision agriculture significantly improved stakeholder confidence in the system. The immutable ledger and automated enforcement of agreements ensured data integrity, while transparent transaction recording increased accountability. This, in turn, strengthened trust among farmers, suppliers, and other stakeholders, demonstrating that blockchain technology can play a pivotal role in enhancing governance, traceability, and collaboration within agricultural networks.

H_3: The joint use of IoT devices and money-saving smart contracts would have a positive impact on the efficiency of functioning, the use of resources, and the productivity of crops in the agricultural systems.

Data

There were 90 agricultural plots which were splintered into three experimental groups:

1. Traditional (Group A) Practices - Manual monitoring and normal irrigation.
2. IoT-enabled Standard Smart Contracts (Group B) IoT devices with standard smart contracts.
3. IoT using Energy-Optimized Smart Contracts (Group C) - IoT devices with smart contracts that are energy efficient.

Three KPI were quantified: Operational Efficiency (OE), Resource Utilization (RU) and Crop Productivity (CP). The scales of 0 -100 were used to normalize the values to be compared.

The results are shown in Table.

Table 3: Performance Metrics of Agricultural Systems

Group	System Type	Operational Efficiency (Mean)	Resource Utilization (Mean)	Crop Productivity (Mean)
A	Conventional Practices	55	60	58
B	IoT with Standard Smart Contracts	72	75	73
C	IoT with Energy-Optimized Smart Contracts	88	90	91

Specifically

- **Operational Efficiency:** Increased from 55 (Group A) to 88 (Group C), a 60% improvement.
- **Resource Utilization:** Increased from 60 (Group A) to 90 (Group C), a 50% improvement.
- **Crop Productivity:** Increased from 58 (Group A) to 91 (Group C), a 57% improvement.

A one-way ANOVA test was conducted to examine whether the differences among groups were statistically significant. The results are presented in Table below.

Table 4: One-Way ANOVA for Agricultural Performance Metrics

Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Between Groups	15,840	2	7,920	145.7	0.000*
Within Groups	4,740	87	54.48		
Total	20,580	89			

*Significant at $p<0.05$

The ANOVA results indicate a highly significant difference ($p = 0.000$) in operational efficiency, resource utilization, and crop productivity among the three groups.

Interpretation

These findings are a large support to H_3. The joint solution of IoT devices and smart contracts with the use of the energy-efficient one led to the great improvement of the working efficiency, the efficient use of the resources, and the overall crop production. These energy-efficient smart contract systems ensured the reduction of computational complexity to allow IoT devices to implement more effectively and make data-driven decisions in time, optimizing irrigation, fertilization, and pest management. This mix, in its turn, allows sustainable precision agriculture to be a reality since it guarantees larger yields with fewer resources and lower operational expenses.

Conclusion

The paper at hand has reflected on how to integrate IoT devices and energy-efficient smart contracts in agricultural networks regarding energy consumption, data confidentiality, workforce productivity, and crop yields. Three hypotheses were tested with the help of experimental data, and the obtained findings indicate a powerful piece of evidence regarding the benefits of such an integrated approach.

The first hypothesis (H_1) evaluated how energy efficient smart contracts impacted the overall energy consumption. It was found that the energy-optimized smart contracts deployed on the IoT devices utilized consume significantly less energy compared to the conventional blockchain execution plan, and that up to 35 percent of energy savings were achieved. It implies that the introduction of energy-efficient smart contracts can make the operation significantly cheaper and extend the service life of IoT devices in agricultural networks, which would make precision farming more sustainable.

Hypothesis 2 (H_2) was the test of the impact of blockchain technology with smart contracts on the data security, data transparency, and trust among the stakeholders. This information indicated that blockchain-based smart contracts made the stakeholders in the system 60 percent more confident in the system, data security, transparency, and trust, as compared to traditional systems. This underscores the fact that agricultural supply chains may improve governance, traceability and cooperation through the use of blockchain technology.

The interaction of the IoT devices and the energy-efficient smart contracts on the efficiency and resource consumption of the operation and the yield of crops were examined in Hypothesis 3 (H_3). The findings indicated that the three parameters increased with the operational performance, the resource utilization and productivity of the crops increasing by 60, 50 and 57, respectively. This proves the fact that with the help of the IoT, along with the use of energy-saving smart contracts, real-time decision-making, efficient utilization of resources, and crop production can be organized, which will be sustainable.

Overall, this paper concludes that the implementation of energy-efficient smart contracts in IoT-based farming networks will offer a three-fold benefit of saving energy, raising security and transparency, and improving operational efficiency and productivity. The results hold massive importance to the farmers, technologists and policymakers who would want to adopt the sustainable application of precision farming". The real-world implementation of other types of crops can be conducted in the future, and the real-world implementation of the application of machine learning algorithms can maximize resources allocation and the implementation of smart contracts, which will make it the most efficient and sustainable.

References

1. Duguma AL, *et al*. How the internet of things technology improves agricultural efficiency. Artificial Intelligence Review. 2024. Available from: https://link.springer.com/article/10.1007/s10462-024-11046-0
2. Hasan HR. Smart agriculture assurance: IoT and blockchain for trusted food production. Computers and Electronics in Agriculture. 2024. Available from: https://www.sciencedirect.com/science/article/pii/S0168169924005751
3. Morchid A. Blockchain and IoT technologies in smart farming to enhance sustainability. Sustainable Computing: Informatics and Systems. 2025. Available from: https://www.sciencedirect.com/science/article/abs/pii/S2542660525002471
4. Pranto TH, *et al*. Blockchain and smart contract for IoT enabled agriculture. Journal of Cloud Computing: Advances, Systems and Applications. 2021. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC8022535/
5. Wang X, *et al*. Blockchain-empowered H-CPS architecture for smart agriculture. IEEE Access. 2025. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC12279166/
6. Yang Q, Wang H. Privacy-preserving transactive energy management for IoT-aided smart homes via blockchain. arXiv preprint arXiv:2101.03840. 2021. Available from: https://arxiv.org/abs/2101.03840
7. Marzougui F. Blockchain and IoT in smart agriculture. Information and Agricultural Systems. 2024. Available from: https://sciendo.com/pdf/10.2478/ias-2024-0008
8. Nayak S. Energy-efficient blockchain solutions for IoT devices. TechVersions. 2025. Available from:

https://techversions.com/iot/energy-efficient-blockchain-solutions-for-iot-devices/
9. Pranto TH, *et al*. Blockchain and smart contract for IoT enabled smart agriculture. PeerJ Computer Science. 2021;7:e407. Available from: https://peerj.com/articles/cs-407/
10. Sahraoui S. Lightweight consensus mechanisms in the internet of things. Internet of Things. 2025. Available from: https://www.sciencedirect.com/science/article/pii/S2352864824001767
11. Wadhwa S. Energy efficient consensus approach of blockchain for IoT. Sensors. 2022;22(10):3733. Available from: https://www.mdpi.com/1424-8220/22/10/3733