E3S Web of Conferences **712**, 07004 (2026) https://doi.org/10.1051/e3sconf/202671207004
*ICFEE 2026*

# A Blockchain Framework for Trustless Next-Generation University Energy Management

*Kitt Tientanopajai*[1], *and Wanida Kanarkard*[1,2*]

[1]Department of Computer Engineering, Khon Kaen University, Thailand.
[2] Smart City Operation Center, Khon Kaen University, Thailand.

**Abstract.** Effective energy management is a critical component for achieving sustainability on university campuses. Conventional energy management systems often encounter challenges such as fragmented data silos, dispersed data ownership, and compromised data integrity due to reliance on manual and infrequent recording processes. These limitations obstruct automated data integration and impede efficient resource planning. This paper proposes a novel framework that leverages blockchain technology and smart contracts to establish a decentralized, transparent, and automated energy ledger. The system is engineered to support large-scale smart meter deployment by tokenizing energy units (kilowatt-hours) on an Ethereum Virtual Machine (EVM)-compatible blockchain. Within this framework, energy providers, including local solar farms and national utilities, can mint tokens corresponding to energy injected into the grid, while campus buildings automatically burn tokens equivalent to their energy consumed. All transactions are autonomously recorded by respective smart meters. A proof-of-concept smart contract was developed and deployed on the Thai Blockchain Services Infrastructure (TBSI). The results indicate that this approach effectively eliminates data silos, guarantees data integrity and availability through blockchain's inherent immutability, and provides a cost effective, trust minimized platform for data integration. The high frequency, granular data captured by the system establishes a robust foundation for future AI driven energy optimization and advanced microgrid management strategies.

## 1 Introduction

Universities globally are under increasing pressure to optimize energy consumption in pursuit of sustainability goals and operational cost reduction. As large-scale energy consumers, the transition to smart metering infrastructure for real-time data collection represents a critical step in this process. However, the underlying data management architecture often remains a significant bottleneck, perpetuating inefficiencies. Conventional systems are frequently characterized by fragmented data silos, where information is sequestered in disparate, centralized databases managed by different administrative units or external providers, complicating automated integration and preventing a holistic view of energy flows.

* Corresponding author: wanida@kku.ac.th

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

Compounding this issue is a pervasive lack of data integrity and granularity, stemming from reliance on manual or semi-automated recording processes that are prone to human error and typically occur on an infrequent basis, such as monthly, which is inadequate for the dynamic demands of a smart energy grid. These challenges are particularly acute in the context of Thai universities, where rapid campus expansion and the pressing need for sustainable development outpace the modernization of energy management systems. Specific institutional hurdles include legacy infrastructure, budgetary constraints for comprehensive system overhauls, and the logistical difficulty of integrating data from diverse sources, such as the national utility grid and emerging on-site renewable generation, into a coherent management framework [1].

Consequently, the planned institution-wide deployment of smart meters mandates a modern and robust data infrastructure to address these foundational challenges. While blockchain technology has been proposed for energy management, existing literature predominantly focuses on peer-to-peer energy trading models, which are not directly applicable to the centralized consumption profile of a university campus. This paper, therefore, proposes a novel blockchain-based framework designed not for trading, but to serve as a decentralized, transparent, and automated foundational data layer for a campus microgrid, directly tackling the specific data integrity and integration challenges prevalent in the smart university environment.

## 2 Related Work

The application of blockchain technology in energy systems has gained significant research interest, primarily focusing on decentralized market mechanisms. Zia et al. (2020) [2] provided a foundational review of microgrid transactive energy systems, proposing a seven-layer functional architecture. Their analysis critically evaluated various distributed ledger technologies, including blockchain, directed acyclic graphs (DAGs), and hashgraph, highlighting the trade-offs in microgrid applications. They concluded that while permissionless systems offer superior transparency and security, they incur performance and computational costs, whereas permissioned systems, like the one proposed in this paper, provide greater efficiency suitable for institutional settings. This work establishes a crucial architectural context for designing scalable campus energy management systems. Vieira and Zhang (2021) [3] explored this by designing Ethereum-based smart contract frameworks that implemented continuous double auction and uniform-price double-sided auction mechanisms. Their validation with real-world data demonstrated the potential of blockchain-agent hybrids to complement centralized grids. Similarly, Umoren et al. (2020) [4] developed a blockchain-based trading scheme between electric vehicles as prosumers and critical loads, leveraging 5G networks to facilitate trusted P2P transactions. While these trading models are insightful for campuses with distributed energy resources (DERs), they address a use case of direct financial exchange between peers, that is often secondary to the primary need for robust, verifiable data infrastructure in a university's operational microgrid.

Beyond trading, researchers have integrated blockchain with other advanced technologies for holistic management. Mithul Raaj et al. (2024) [5] combined 6G IoT, artificial intelligence, and blockchain for intelligent smart grid management, using machine learning for load forecasting and blockchain for transaction verification. This multi-technological approach underscores the potential for synergy in data-rich environments like universities. However, its complexity may exceed the initial requirements for a foundational data layer. Security and privacy in smart grids are also key concerns addressed by blockchain. Badra and Borghol (2025) [6] proposed an efficient privacy preservation scheme that mitigates data forgery and profiling attacks while ensuring authentication, showcasing blockchain's utility for securing advanced metering infrastructure (AMI) with minimal overhead.

Complementing this, Liu and Ai (2024) [7] designed a privacy-focused strategy for shared energy storage microgrids, using smart contracts for dispatch management and Shamir secret sharing to protect sensitive data. These studies are highly relevant for ensuring the security and privacy of campus energy data. Further extending the market concept, Boumaiza et al. (2024) [8] simulated a blockchain-enabled renewable energy trading market, introducing a native cryptocurrency to clear prices based on demand response. This framework illustrates automated trading for campuses with significant renewable generation. Finally, Valdivia and Poblet (2022) [9] shifted focus to the governance dynamics of technology-enabled energy transitions, providing critical insights for university administrators on the regulatory and institutional challenges of deploying blockchain systems. In summary, while existing literature extensively covers P2P trading, multi-technology integration, and security, a gap remains for a dedicated, non-speculative blockchain framework that functions primarily as an immutable data ledger for campus-wide energy accounting.

## 3 Proposed Innovative Blockchain Framework

To address the critical challenges of data fragmentation and integrity, this paper proposes a trustless data layer for the campus energy microgrid based on blockchain technology and smart contracts. The core innovation of this framework is the tokenization of energy, whereby a standard kilowatt-hour (kWh) is represented as a fungible ERC-20 token [10] on an Ethereum Virtual Machine (EVM) compatible blockchain in Fig.1. This approach leverages the inherent properties of distributed ledger technology to create a decentralized, transparent, and automated energy ledger. The operational flow is designed for full automation: energy producers, such as the national utility and campus solar farms, are authorized to mint new kWh tokens corresponding to their verified energy injection into the grid, while smart meters at campus buildings are authorized to burn tokens equivalent to their energy consumption. This mint-and-burn mechanism, executed via smart contracts, provides a near-real-time, immutable record of the net energy balance.

A production-level smart contract was developed in Solidity and deployed on the Thai Blockchain Services Infrastructure (TBSI) [11], a national-level platform utilizing a fee-free, Proof-of-Authority consensus ideal for institutional use. By cryptographically sealing every production and consumption transaction on-chain, the system fundamentally ensures data integrity, eliminates single points of failure, and creates a unified, trust-minimized data source, thereby directly overcoming the limitations of traditional siloed and manual energy management systems.

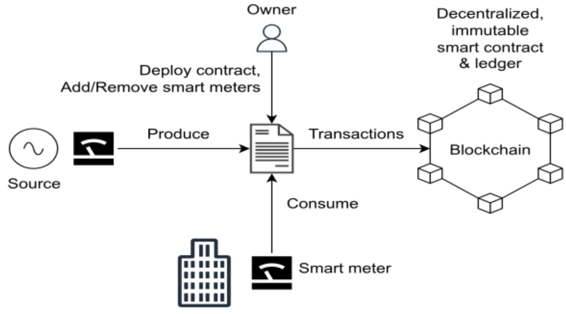


**Fig.1.** Operational workflow of the proposed blockchain energy management system.

Fig.1 illustrates the core mint-and-burn token mechanism. Energy producers e.g., solar farm, national grid inject energy into the campus microgrid, and their smart meters automatically call the produce function to mint an equivalent amount of kWh tokens into the university's central pool. Concurrently, campus buildings consumers draw energy, and their smart meters call the consume function to burn the corresponding tokens from the pool. All transactions are immutably recorded on the blockchain, creating a transparent and synchronized ledger of energy flow.

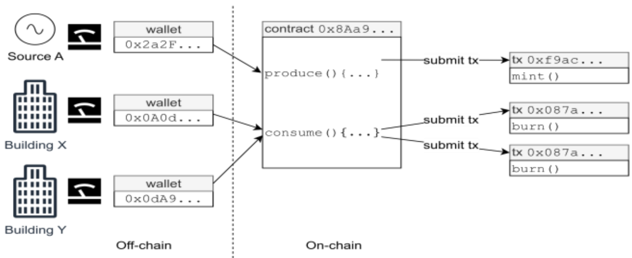


**Fig. 2.** Data transaction flow distinguishing off-chain and on-chain processes.

This blockchain framework in Fig. 2 is engineered to seamlessly integrate with the planned smart meter infrastructure, establishing a secure and automated backend for processing high-volume, real-time data streams. The core innovation of the system lies in the tokenization of energy, wherein a standard unit—the kilowatt-hour (kWh)—is represented by a fungible token on the blockchain. The operational flow is entirely automated through a mint-and-burn mechanism. Smart meters at energy production sources, such as the Provincial Electricity Authority (PEA) and campus solar farms, autonomously invoke a produce energy function on the smart contract to mint new kWh tokens commensurate with the energy fed into the grid, crediting them to a central university pool. Conversely, smart meters at campus buildings invoke a report consumption function, which burns a corresponding number of tokens from this pool based on measured energy usage. This process creates a synchronized and immutable ledger of energy flows. This mint-and-burn mechanism provides a transparent, near real time accounting of the net energy supply on campus. As these transactions can be called automatically by the smart meters every 5 minutes, the system generates a highly granular dataset far superior to traditional monthly records.

## 4 Results and Discussion

The implementation and analysis of the proposed system on the Thai Blockchain Services Infrastructure (TBSI) yielded several significant outcomes that confirm its viability and effectiveness. Fig.3 depicted that every energy produced and consumed is automatically recorded as a digitally signed, immutable, transaction on-chain. This provides data integrity and availability to the energy production and consumption records. The deployment demonstrated robust operational performance, with the smart contract successfully processing over 1,000 simulated mint and burn transactions without failure, confirming the functional reliability of the automated token lifecycle.

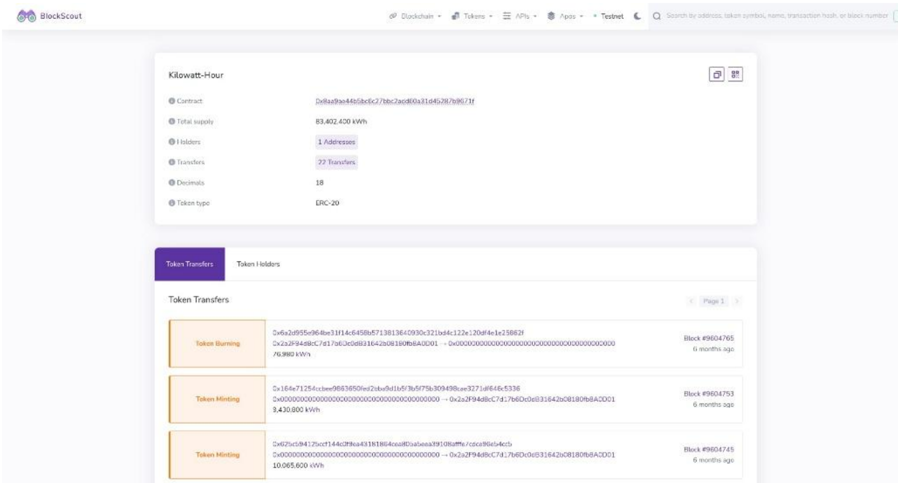


**Fig. 3.** The on-chain contract and transactions of the university' energy consumption.

A key metric of effectiveness was the system's data integrity; the cryptographic immutability inherent to blockchain ensured a 100% consistency in the audit trail, with all energy transactions becoming tamper-evident and permanently accessible, thereby eliminating discrepancies from manual recording see Table 1.

**Table 1.** Comparison of key performance metrics between the traditional system and the proposed blockchain-based framework.

| Traditional System | Proposed Blockchain Framework |
|---|---|
| Traditional systems often rely on monthly manual meter readings | The new system automatically records data every 5 minutes. |
| Number of readings per month: 1 reading | Number of readings per month: 43,200 minutes/5 minutes/reading = 8,640 readings |

Furthermore, the system achieved a substantial improvement in data granularity, capturing energy flows at 5-minute intervals compared to traditional monthly readings, which enhanced temporal resolution by over 8,600%. This high-frequency data capture, a direct result of the blockchain's ability to securely record high-volume, time-stamped transactions was achieved without incurring monetary transaction fees, a critical efficiency afforded by the TBSI platform. This approach proved to be a more cost-effective and scalable solution for data integration compared to the complex task of reconciling legacy data silos, as it establishes a single, shared source of truth from its inception. The successful implementation thus provides an invaluable, rich dataset that lays a foundational infrastructure for future advanced analytics, enabling AI-driven consumption forecasting, dynamic load balancing, and sophisticated energy procurement strategies.

## 5. Conclusion and Future Work

This innovative framework successfully demonstrates that a blockchain framework constitutes a robust and efficient trustless data layer for energy management in a smart university environment. By tokenizing kilowatt-hours and automating the recording of production and consumption via smart contracts, the proposed system delivers significant benefits, including guaranteed data integrity, the elimination of data silos through a single source of truth, and the creation of a cost-effective, trust-minimized platform for data integration. This reliable and granular data infrastructure is not merely a technical improvement; it is a critical enabler for strategic Environmental, Social, and Governance (ESG) initiatives. It provides the verifiable and auditable data necessary to accurately track carbon footprints, report on sustainability metrics, and demonstrate institutional accountability towards environmental stewardship and social responsibility.

Future work will progress along two parallel tracks, implementation and advanced analytics. The immediate next step involves deploying the smart contract on the TBSI and developing a real-time dashboard for operational monitoring. Further research will exploit the rich, high-frequency dataset to integrate future trends in artificial intelligence, developing models for predictive maintenance of energy infrastructure and AI-driven optimization of energy purchasing from multiple providers. This aligns with the emerging trend of AI-blockchain fusion for autonomous system management. Additionally, we will explore the framework's expansion to incorporate carbon credit tokenization, creating a unified system that links energy consumption directly to environmental assets, thereby further strengthening the university's ESG reporting and contribution to a sustainable, decentralized energy future.

## References

1. P. Aregarot, K. Kubaha, S. Chiarkorn, J. Sustainability, 16(7) (2024).
2. M. Zia, M. Benbouzid, E. Elbouchikhi, S. Muyeen, K. Techato, J. Guerrero, J. IEEE Access, 8 (2020).
3. G. Vieira, J. Zhang, J. Renew and Sust. Energy Reviews, 143 (2021).
4. I. Umoren, S. Jaffary, M. Shakir, K. Katzis, H. Ahmadi, J. IEEE Consumer Electronic, 9(6) (2020).
5. A. Mithul Raaj, B. Balaji, P. Sai Arun Pravin, N. Rani Chinnappa, M. Rajesh Kumar, R. Prakash, R. Sujatha, K. Vaegae Naveen, A. Geetika, S. Arooj, J. IoT, 5(3) (2024).
6. M. Badra, R. Borghol, J. Sec. Security, Privacy and Authentication, 6 (2025).
7. W. Liu, Q. Ai, J. Front. Energy Res., 12 (2024).
8. A. Boumaiza, M. Wanik, A. Sanfilippo, in Proceedings of the IEEE International Conference on Compatibility, Power Electronics and Power Engineering (CPE-PowerEng) 29 June 2025, U.K. (2022).
9. L. Valdivia, M. Poblet, SSRN, 3777293 (2022).
10. F. Vogelsteller, V. Buterin, EIP-20: Token Standard, Ethereum Improv. Proposals 20, https://eips.ethereum.org/EIPS/eip-20 (2015).
11. ETDA Thailand, Thai Blockchain Services Infrastructure (TBSI), https://blockchain.or.th (2022).