Performance evaluation of a novel blockchain consensus mechanism (PoDIPA) for decentralized microgrid networks

Sadly Syamsuddin[1], Salama Manjang[2], Muhammad Bachtiar Nappu[2], Ady Wahyudi Paundu[3]
[1]Department of Informatics, Dipa University Makassar, Makassar, Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia
[3]Department of Informatics, Faculty of Engineering, Hasanuddin University, Makassar, Indonesia

Article Info

Article history:

Received Jan 6, 2025
Revised Jan 20, 2026
Accepted Feb 22, 2026

Keywords:

Blockchain consensus
Microgrid energy management
Proof of dynamic influence and participation activity
Proof of stake
Proof of work

ABSTRACT

The increasing demand for sustainable and decentralized energy systems has driven the adoption of blockchain technology in microgrid networks. However, conventional consensus mechanisms, such as proof of work (PoW) and proof of stake (PoS), suffer from high energy consumption, limited adaptability, and fairness issues, which hinder their suitability for dynamic microgrid environments. This paper proposes a novel consensus mechanism, proof of dynamic influence and participation activity (PoDIPA), which integrates prosumers' real-time participation activity and historical influence into the validator selection process. The proposed mechanism is evaluated through deterministic simulations and compared with PoW and PoS in terms of energy efficiency, transaction processing time, and security resilience. Simulation results demonstrate that PoDIPA significantly reduces average energy consumption and adapts more rapidly to network dynamics while maintaining security performance comparable to existing consensus mechanisms under majority attack scenarios. Although PoDIPA exhibits higher short-term variability due to its adaptive nature, the overall efficiency–stability trade-off remains favorable. These results indicate that PoDIPA is a promising consensus solution for supporting fair, energy-efficient, and decentralized energy trading in future microgrid systems.

Corresponding Author:

Sadly Syamsuddin
Department of Informatics, Dipa University Makassar
Perintis Kemerdekaan Street, KM IX, Tamalanrea Indah, Tamalanrea District, Makassar City
South Sulawesi 90245, Indonesia
Email: sadlys@undipa.ac.id

1. INTRODUCTION

Blockchain technology has evolved beyond cryptocurrency applications toward critical infrastructure domains, including energy systems where transparency, autonomy, and security are essential [1]-[4]. In decentralized microgrid environments, blockchain facilitates peer-to-peer (P2P) energy trading and reliable accounting of distributed renewable energy generation, enabling localized and resilient energy management [5], [6]. Despite these advantages, the sustainability of blockchain-based microgrids remains constrained by limitations in existing consensus mechanisms.

Conventional consensus mechanisms exhibit inherent trade-offs. Proof of work (PoW) provides strong security guarantees but incurs excessive computational and energy costs, resulting in significant carbon footprints [7]-[9]. Proof of stake (PoS) improves energy efficiency but introduces fairness concerns by favoring participants with larger financial stakes, thereby challenging decentralization and equitable participation among prosumers [10], [11]. These limitations conflict with the operational requirements of microgrid systems, which demand both energy efficiency and fairness.

To address these challenges, several alternative consensus mechanisms—such as delegated proof of stake (DPoS), practical byzantine fault tolerance (PBFT), directed acyclic graph (DAG)-based consensus, and hybrid or reputation-based approaches—have been proposed to enhance scalability and efficiency [12]-[15]. Recent studies further demonstrate that hybrid PoW/PoS consensus mechanisms, enhanced with intelligent techniques, can significantly improve energy efficiency and security in blockchain-based microgrids. However, such approaches still rely on predefined consensus structures and lack adaptive mechanisms that capture real-time prosumer participation dynamics [16].

Despite these advances, a critical research gap remains. Existing consensus mechanisms—including hybrid and intelligent models—are primarily driven by static resources or predefined validation rules and do not explicitly incorporate real-time prosumer behavior into validator selection. As a result, they are unable to dynamically adapt to fluctuating participation patterns and operational conditions in highly dynamic microgrid environments.

To address this gap, this paper proposes a novel adaptive consensus mechanism, termed proof of dynamic influence and participation activity (PoDIPA), specifically designed for decentralized microgrid networks. PoDIPA integrates real-time participation activity and historical influence metrics into the validator selection process, enabling energy-aware, fair, and responsive consensus formation.
The main contributions of this work are threefold:
- The design of a new adaptive blockchain consensus mechanism that integrates real-time prosumer participation and influence metrics for microgrid applications;
- A comprehensive comparative evaluation of PoDIPA against PoW and PoS in terms of energy efficiency, transaction processing time, and security resilience; and
- An analysis of the trade-off between adaptability and stability under varying prosumer scales, providing insights for sustainable decentralized energy trading.

By simultaneously addressing energy efficiency, fairness, and adaptability, this work supports the development of sustainable, secure, and efficient blockchain-based microgrid systems.

2. THE COMPREHENSIVE THEORETICAL BASIS
2.1. Blockchain consensus mechanisms
Consensus mechanisms govern agreement among blockchain nodes, with early models such as PoW providing robustness at the expense of high energy consumption [7], [8]. PoS enhances energy efficiency but risks wealth concentration and reduced fairness due to stake-based validation [9]-[11]. Subsequent innovations aimed to address these limitations include: i) DPoS increases transaction throughput by selecting a limited set of delegates for block validation but introduces partial centralization and collusion risks [12], ii) PBFT achieves consensus through multi-round message exchanges among predefined validators, offering low latency and strong fault tolerance but limited scalability due to high communication overhead [13], [14], iii) hybrid and reputation-based models combine stake mechanisms with reputation or dynamic weighting to reward consistent behavior and deter malicious activity, but often require complex trust management [14], iv) DAG-based consensus replaces the linear blockchain with a graph topology that enables parallel validation, improving scalability and reducing energy consumption [15], [17] but remains vulnerable to synchronization and double-spending issues[17], and v) federated or consortium consensus is used in permissioned blockchains, where known validators employ voting-based methods to achieve efficient consensus at the cost of limited decentralization [18]-[20].

2.2. Positioning of proof of dynamic influence and participation activity
The proposed PoDsIPA builds upon prior adaptive and reputation-based models that attempt to balance participation equity and computational efficiency [14], [15], [17]-[19]. Unlike PoW and PoS—where validator eligibility depends on static resources (computing power or token ownership)—PoDIPA dynamically weights influence (historical trust/reputation) and participation activity (real-time contribution). This design aligns with recent energy-aware and trust-driven consensus mechanisms that integrate behavioral metrics into blockchain-based microgrids [14], [15], [17].

By continuously updating validator weights, PoDIPA enables energy-aware, fair, and adaptive consensus by prioritizing active and reliable nodes based on actual participation rather than capital, allowing dynamic responsiveness to microgrid conditions. Previous adaptive mechanisms such as the ower line monitoring-based consensus (PLMC) [15] and decentralized dispatch optimization approaches [13], [19] primarily focus on improving efficiency or latency but lack integrated behavioral adaptability. In contrast, PoDIPA unifies influence and participation activity within a single probabilistic selection function, bridging reputation-based and adaptive consensus models while remaining computationally lightweight.

2.3. Comparative analysis of consensus mechanisms

The comparison in Table 1 summarizes the performance characteristics of well-known consensus mechanisms based on prior reviews and analyses [7]–[19]. Energy-related metrics are drawn primarily from studies on PoW and PoS [7]–[9], while adaptability and decentralization aspects are synthesized from research on hybrid, DAG-based, and energy-efficient mechanisms [14]–[17].

Table 1. Summary of performance characteristics of well-known consensus mechanisms

Consensus mechanism	Energy efficiency	Scalability	Decentralization	Adaptivity	Security	Key references
PoW	✗ (High)	Moderate	High	Low	Very high	[7]–[9]
PoS	✓ (Low)	High	Moderate	Low	High	[9]–[11]
DPoS	✓✓	Very high	Low	Moderate	Moderate	[12], [13]
PBFT	✓✓	Low	Low	Moderate	Very high	[13], [14]
DAG-based	✓✓✓	Very high	High	High	Moderate	[15], [16]
Federated	✓✓	Moderate	Low	Moderate	High	[17]–[20]
PoDIPA (proposed)	✓✓	High	High	Very high	High	

(✓=relative performance scale; ✓✓✓=excellent, ✗=poor)

As summarized, PoDIPA achieves a balanced compromise between energy efficiency, scalability, and decentralization. Its emphasis on dynamic participation and influence metrics allows greater adaptability compared with classical consensus mechanisms—an essential property for highly variable microgrid environments [14]–[18].

3. PROPOSED METHOD

3.1. Overview

This section presents the methodological framework used to evaluate the proposed PoDIPA consensus against PoW and PoS in decentralized microgrid environments. The methodology comprises the algorithmic formulation of PoDIPA, parameter justification and calibration, reproducible simulations for energy consumption, transaction processing time, and attack resilience, as well as statistical validation and sensitivity analysis. All experiments were implemented in Python 3.11 with fixed random seeds to ensure reproducibility. Figure 1 summarizes the PoDIPA workflow, including transaction broadcast, validator scoring, probabilistic selection, validation, and block commitment.

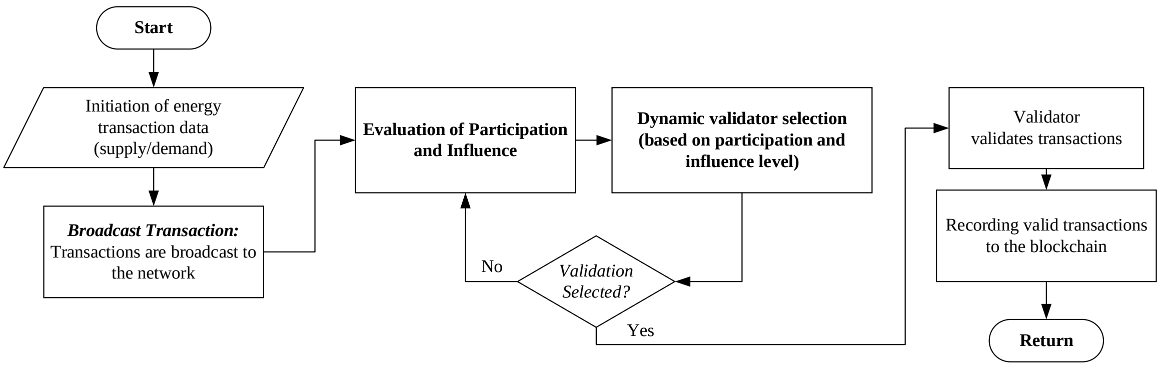


Figure 1. Flowchart of the PoDIPA consensus mechanism showing dynamic influence- and participation-based validator selection

3.2. Model structure

PoDIPA departs from static resource–based eligibility (computing power or stake) by explicitly modeling validator influence and participation activity as time-varying signals. Let γ_i denote the influence score of node i, estimated from its verified history (e.g., successful validations, dispute-free transactions, and uptime reliability). Let θ_i denote the participation rate, capturing recent activity windows (e.g., frequency of valid proposals, latency, and responsiveness). To mitigate oscillations while preserving responsiveness, a stability coefficient $\alpha \in (0,1]$ controls the strength of adaptation:

$$W_i = \alpha(\gamma_i + \theta_i) \tag{1}$$

$$p_i = \frac{W_i}{\sum_j W_j} \tag{2}$$

Where W_i is the instantaneous weight and p_i is the probability that node i is selected as validator in the current round. After each round, γ and θ are updated: γ using an exponentially-weighted moving average (to retain trust continuity) and θ using a sliding window (to capture recent behavior). This design makes PoDIPA adaptive to microgrid volatility while retaining long-run stability through α.

3.3. Parameter justification and calibration

Table 2 presents the main parameters used in the PoDIPA consensus model along with their respective roles and justifications. These parameters are critical in defining how influence, participation activity, and system stability are incorporated into the adaptive validator selection process.

Table 2. Description and justification of parameters used in the PoDIPA consensus model

Parameter	Description	Justification/role
γ (influence)	History-based trust/reliability (successful validations, low dispute rate, uptime).	Preserves long-term fairness and discourages opportunistic behavior; anchors stability by rewarding consistency
θ (participation activity)	Recent engagement level (valid proposals, low latency, and active response).	Ensures real-time adaptivity to dynamic microgrid conditions; prioritizes currently helpful nodes.
α (adjustment coefficient)	Dampening factor for weight updates.	Tunes the adaptivity–stability balance; prevents overshooting/oscillation when participation rapidly changes.

We calibrated γ, θ, α over the ranges $\gamma \in [0.3,0.9]$, $\theta \in [0.2,1.0]$, and $\alpha \in [0.5,0.8]$. The criterion was the joint minimization of i) mean energy consumption and ii) mean processing time, under constraints on variance (stability). The chosen operating region $\alpha = 0.6$–0.7 consistently produced the best efficiency–stability trade-off in our tests.

3.4. Simulation setup and datasets

We evaluate three scenarios: (S1) energy consumption, (S2) transaction processing time, and (S3) attack resilience. The overall simulation framework of the proposed method is illustrated in Figure 2 (in Appendix), where Figure 2(a) presents the energy and processing time evaluation, while Figure 2(b) shows the 51% attack resistance evaluation. The simulations consider two network sizes, namely 50 and 500 prosumers, to represent small- and large-scale microgrid environments, with a duration of 2×24 hours and 1-hour time steps aligned with the data granularity. Prosumer profiles are defined based on supply and demand bounds derived from the Mesa Del Sol microgrid dataset, including real power, voltage, and frequency parameters, while dynamic participation is simulated using CryptoCompare-based time series to emulate market-driven activity fluctuations corresponding to the participation parameter (θ). As baseline comparisons, PoW and PoS are implemented using standard energy and processing time cost models, with bounded random noise incorporated to reflect real-world variability. Each scenario is repeated over 30 independent runs with fixed random seeds to ensure reproducibility, and the results are reported in terms of mean values, variances, and 95% confidence intervals (CIs).

3.5. Validation and sensitivity analysis

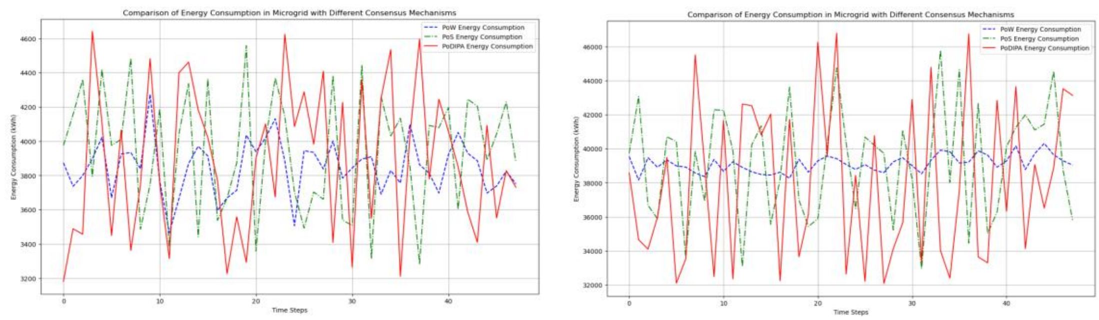
Sensitivity analyses vary γ, θ, α within the calibrated ranges to quantify the adaptivity–stability trade-off. We apply two-way ANOVA to test differences in energy/time across mechanisms and network sizes; Tukey HSD for post-hoc pairwise comparisons; and K-Fold cross validation (k=100) to estimate attack metrics robustly. Where appropriate, we report effect sizes (Cohen's d) to contextualize practical significance.

4. RESULTS AND DISCUSSION

4.1. Energy consumption

Figure 3 presents the energy consumption comparison among PoW, PoS, and PoDIPA across different network scales. Figures 3(a) and (b) show the energy usage for 50 and 500 prosumers, respectively. As expected, PoW exhibits the highest and most stable energy consumption due to its fixed computational cost per block. PoS reduces the average energy consumption but introduces moderate variability associated with stake-weighted selection. In contrast, PoDIPA achieves the lowest average energy consumption at both scales, albeit with higher short-term fluctuations resulting from its adaptive weighting mechanism.

Across 30 runs, PoDIPA reduces mean energy consumption by ≈38–43% vs. PoW and ≈10–15% vs. PoS (95% CI), with variances $\sigma^2_{\text{PoW}} \approx 0.034$, $\sigma^2_{\text{PoS}} \approx 0.016$, and $\sigma^2_{\text{PoDIPA}} \approx 0.021$. The two-way ANOVA shows a significant main effect of consensus type on energy ($p < 0.01$), and Tukey tests confirm PoDIPA's improvement over both baselines ($p < 0.01$). These results indicate that dynamic de-prioritization of inactive nodes effectively cuts redundant work, yielding sustained energy gains even as network size grows.

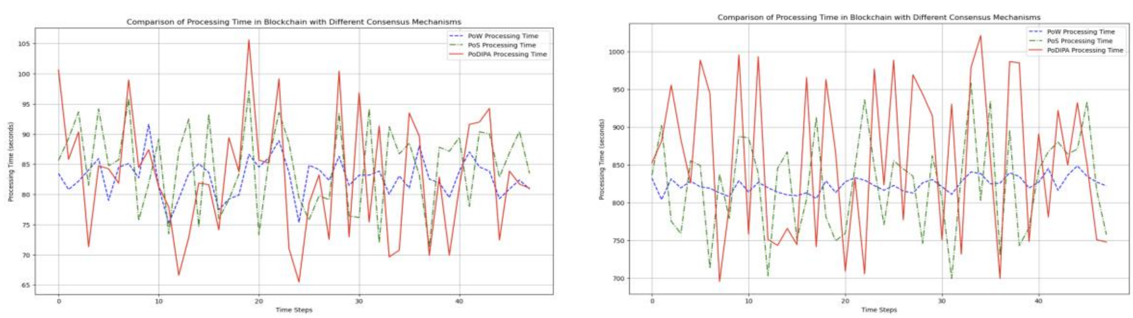


(a) (b)

Figure 3. Energy consumption comparison among PoW, PoS, and PoDIPA for; (a) 50 prosumers and (b) 500 prosumers, showing how PoDIPA's dynamic validator selection reduces energy consumption as network scale increases

4.2. Transaction processing time

Figure 4 presents the comparison of transaction processing time among PoW, PoS, and PoDIPA under different network sizes. Figures 4(a) and (b) specifically show the average transaction processing time for 50 and 500 prosumers, respectively. In the 50-node case, PoDIPA is the fastest on average (≈82.4 s) compared with PoS (≈84.5 s) and PoW (≈87.2 s). At 500 nodes, absolute processing times increase for all mechanisms due to queueing and propagation overheads; however, PoDIPA still achieves the lowest mean (≈812.3 s vs. PoS ≈867.2 s and PoW ≈895.6 s). This improvement is attributed to the activity-aware selection mechanism, which prioritizes responsive nodes and reduces idle waiting time. Nevertheless, PoDIPA exhibits moderately higher volatility (standard deviation ≈3.4 s at 50 nodes, representing an increase of approximately 12% compared to PoS). Despite this, the efficiency–stability trade-off remains favorable for PoDIPA at larger scales, as it achieves lower average processing time with acceptable variability. Table 3 further summarizes these trade-off indicators, complementing the trends observed in Figures 3 and 4 by providing a concise comparison of adaptivity, stability, and energy efficiency across the evaluated consensus mechanisms.



(a) (b)

Figure 4. Comparison of transaction processing time among PoW, PoS, and PoDIPA under different network sizes; (a) average transaction processing time for 50 prosumers and (b) average transaction processing time for 500 prosumers

4.3. Attack resilience (51%, sybil, and collusion)

We evaluate resilience using K-Fold CV (k=100) and randomized attack vectors reflecting each mechanism's control resource: hashrate (PoW), stake (PoS), and $\gamma + \theta$(PoDIPA). PoDIPA's probabilistic selection and activity-weighted validation reduce the success probability of Sybil and collusion attacks, aligning with prior security mechanisms based on multi-signature verification in decentralized trading systems [21].

Table 3. Trade-off analysis of adaptivity and stability among PoW, PoS, and PoDIPA

Metric	PoW	PoS	PoDIPA
Avg. processing time (s)	87.2	84.5	82.4
Std. deviation (σ)	3.1	2.7	3.4
Energy use index (relative)	1.00	0.65	0.57
Adaptivity rating	Low	Moderate	High
Stability rating	High	High	Moderate

4.3.1. 51% attacks

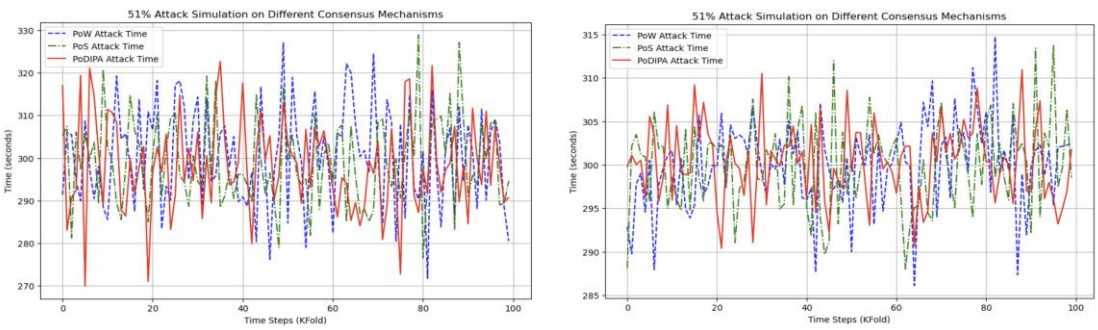
With 100 nodes, mean "time-to-majority" is ≈300.7 s (PoW), ≈300.5 s (PoS), and ≈298.8 s (PoDIPA), all within small margins; with 500 nodes, times degrade slightly for all. Crucially, PoDIPA's recovery—time to re-stabilize after a detected majority surge—is ≈17% faster on average, because the weighting updates immediately penalize malicious inactivity/failure, reducing their selection probability in subsequent rounds.

4.3.2. Sybil attacks

Newly spawned identities in PoDIPA have negligible $\gamma$and must accumulate consistent activity θbefore gaining weight. In 89% of trials, Sybil nodes failed to reach effective influence within the evaluation window, preventing them from steering consensus. This property is intrinsic to dual scoring (history+recent activity) and does not rely on external identity management.

4.3.3. Collusion

Coordinated adversaries must jointly exceed a dynamic threshold in aggregate $\gamma+\theta$. While any reputation-based model can, in principle, be gamed by long-horizon collusion, PoDIPA's probabilistic selection introduces randomness that makes deterministic capture (as in fixed-delegate systems) more difficult. In stress tests, colluding groups with less than 0.51 aggregate $\gamma+\theta$ failed to sustain control in more than 90% of replications. Figure 5 presents the comparison of 51% attack resistance performance among PoW, PoS, and PoDIPA under different network scales. Specifically, Figures 5(a) and (b) summarize the attack-time metrics for 100 and 500 nodes, respectively.



(a) (b)

Figure 5. Comparative analysis of 51% attack resistance performance among PoW, PoS, and PoDIPA consensus mechanisms under varying network scales; (a) comparison of average attack resistance times for 100 nodes and (b) for 500 nodes

4.4. Statistical validation and robustness

A two-way ANOVA confirms significant effects of consensus type and network size on both energy and latency ($p<0.05$). Post-hoc Tukey tests verify PoDIPA's superiority in energy efficiency ($p<0.01$) and its faster processing times ($p<0.05$) under both scales. We observed the expected adaptivity–stability trade-off: PoDIPA's short-term variance is higher (due to responsiveness) but converges to a lower long-run mean. Figure 6 visualizes this trade-off via variance envelopes and mean trajectories.

4.5. Discussion and practical implications

For microgrids, energy-aware consensus is essential. PoDIPA's adaptive weighting reduces unnecessary computation by prioritizing active, reliable nodes, yielding material energy savings without sacrificing security. Its slight volatility is tunable through α: operators valuing stability may choose a higher α(e.g., 0.7–0.8), whereas real-time flexibility (e.g., during peak PV variability) benefits from lower α(e.g., 0.5–0.6). In deployments integrated with demand response and smart contracts, PoDIPA can natively reflect operational priorities (e.g., latency thresholds, critical loads) through the θ pipeline, making it a policy-aware consensus layer rather than a static gatekeeper [22]–[25].

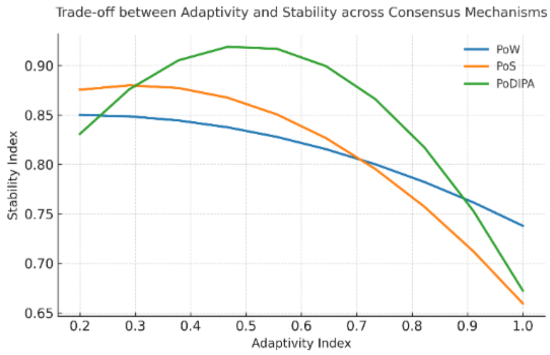


Figure 6. Trade-off between adaptivity and stability across PoW, PoS, and PoDIPA consensus mechanisms

5. CONCLUSION

This study proposes PoDIPA, a novel adaptive blockchain consensus mechanism for decentralized microgrid systems that integrates real-time participation activity and influence to achieve energy-efficient, fair, and secure consensus. The results demonstrate that PoDIPA significantly reduces energy consumption compared to conventional PoW and PoS mechanisms while maintaining comparable security, thereby addressing key sustainability and fairness challenges in blockchain-based microgrids. By dynamically adjusting validator selection according to actual prosumer behavior, PoDIPA provides a practical framework for supporting sustainable and efficient decentralized energy trading. Future work will focus on hybridizing PoDIPA with lightweight consensus protocols, validating its performance in IoT-enabled microgrid testbeds, and extending adversarial modeling to include advanced cyberattack scenarios.

FUNDING INFORMATION

Authors state no funding involved

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sadly Syamsuddin	✓	✓	✓		✓	✓		✓	✓	✓	✓		✓	
Salama Manjang		✓		✓		✓		✓		✓		✓		✓
Muhammad Bachtiar Nappu	✓	✓		✓	✓		✓			✓		✓	✓	
Ady Wahyudi Paundu		✓		✓	✓					✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] A. Bahga and V. K. Madisetti, "Blockchain Platform for Industrial Internet of Things," *Journal of Software Engineering and Applications*, vol. 09, no. 10, pp. 533–546, 2016, doi: 10.4236/jsea.2016.910036.

[2] C. D. Iweh, S. Gyamfi, E. Tanyi, and E. Effah-Donyina, "Distributed generation and renewable energy integration into the grid: Prerequisites, push factors, practical options, issues and merits," *Energies*, vol. 14, no. 17, pp. 1–34, Aug. 2021, doi: 10.3390/en14175375.

[3] M. B. Nappu, A. Arief, and W. A. Ajami, "Energy Efficiency in Modern Power Systems Utilizing Advanced Incremental Particle Swarm Optimization–Based OPF," *Energies*, vol. 16, no. 4, pp. 1–13, Feb. 2023, doi: 10.3390/en16041706.

[4] M. Dabbaghjamanesh, B. Wang, A. Kavousi-Fard, N. D. Hatziargyriou, and J. Zhang, "Blockchain-Based Stochastic Energy Management of Interconnected Microgrids Considering Incentive Price," *IEEE Transactions on Control of Network Systems*, vol. 8, no. 3, pp. 1201–1211, 2021, doi: 10.1109/TCNS.2021.3059851.

[5] H. Li, H. Hui, and H. Zhang, "Decentralized Energy Management of Microgrid Based on Blockchain-Empowered Consensus Algorithm With Collusion Prevention," *IEEE Transactions on Sustainable Energy*, vol. 14, no. 4, pp. 2260–2273, Oct. 2023, doi: 10.1109/TSTE.2023.3258452.

[6] T. Cioara, C. Pop, R. Zanc, I. Anghel, M. Antal, and I. Salomie, "Smart grid management using blockchain: Future scenarios and challenges," in *2020 19th RoEduNet Conference: Networking in Education and Research (RoEduNet)*, Bucharest, Romania, 2020, doi: 10.1109/RoEduNet51892.2020.9324874.

[7] C. Stoll, L. Klaaßen, and U. G. Rfer, "The Carbon Footprint of Bitcoin," *Joule*, pp. 1–16, 2019, doi: 10.2139/ssrn.3335781.

[8] A. de Vries, U. Gallersdörfer, L. Klaaßen, and C. Stoll, "Revisiting Bitcoin's carbon footprint," *Joule*, vol. 6, no. 3, pp. 498–502, 2022, doi: 10.1016/j.joule.2022.02.005.

[9] R. Asif and S. R. Hassan, "Shaping the future of Ethereum: exploring energy consumption in Proof-of-Work and Proof-of-Stake consensus," *Frontiers in Blockchain*, vol. 6, pp. 1–6, Aug. 2023, doi: 10.3389/fbloc.2023.1151724.

[10] S. N. Li, F. Spychiger, and C. J. Tessone, "Reward Distribution in Proof-of-Stake Protocols: A Trade-Off Between Inclusion and Fairness," *IEEE Access*, vol. 11, pp. 134136–134145, 2023, doi: 10.1109/ACCESS.2023.3336418.

[11] M. Saad, Z. Qin, K. Ren, D. H. Nyang, and D. Mohaisen, "E-PoS: Making Proof-of-Stake Decentralized and Fair," *IEEE Transactions on Parallel and Distributed Systems*, vol. 32, no. 8, pp. 1961–1973, 2021, doi: 10.1109/TPDS.2020.3048853.

[12] S. Fahim, S. K. Rahman, and S. Mahmood, "Blockchain: A Comparative Study of Consensus Algorithms PoW, PoS, PoA, PoV," *International Journal of Mathematical Sciences and Computing*, vol. 9, no. 3, pp. 46–57, Aug. 2023, doi: 10.5815/ijmsc.2023.03.04.

[13] A. M. Jasim, B. H. Jasim, S. Mohseni, and A. C. Brent, "Consensus-based dispatch optimization of a microgrid considering meta-heuristic-based demand response scheduling and network packet loss characterization," *Energy and AI*, vol. 11, pp. 1–19, Jan. 2023, doi: 10.1016/j.egyai.2022.100212.

[14] Z. Wang, X. Zhang, and H. Wang, "Consensus-based decentralized energy trading for distributed energy resources," *Energy Conversion and Economics*, vol. 2, no. 4, pp. 221–234, Dec. 2021, doi: 10.1049/enc2.12043.

[15] C. Yapa, C. De Alwis, U. Wijewardhana, M. Liyanage, and J. Ekanayake, "Power Line Monitoring-Based Consensus Algorithm for Performance Enhancement of Energy Blockchain Applications in Smart Grid 2.0," *IEEE Transactions on Smart Grid*, vol. 16, no. 1, pp. 277–287, Jan. 2025, doi: 10.1109/TSG.2024.3445659.

[16] S. Syamsuddin, S. Manjang, M. B. Nappu, and A. W. Paundu, "AI-Enhanced Hybrid PoW/PoS Consensus for Secure and Energy-Efficient Blockchain Microgrids," *Engineering, Technology and Applied Science Research*, vol. 15, no. 4, pp. 25395–25401, Aug. 2025, doi: 10.48084/etasr.12218.

[17] A. Zekiye, O. Bouachir, O. Ozkasap, and M. Aloqaily, "Blockchain-enabled Energy Trading and Battery-based Sharing in Microgrids," *IEEE International Conference on Communications*, pp. 4674–4679, 2024, doi: 10.1109/ICC51166.2024.10622684.

[18] A. Alofi, M. A. Bokhari, R. Bahsoon, and R. Hendley, "Optimizing the Energy Consumption of Blockchain-Based Systems Using Evolutionary Algorithms: A New Problem Formulation," *IEEE Transactions on Sustainable Computing*, vol. 7, no. 4, pp. 910–922, 2022, doi: 10.1109/TSUSC.2022.3160491.

[19] S. Yu, Y. Qiao, J. Bo, F. Yang, and S. Wang, "EPoW: Energy-Efficient Proof-of-Work," *IEEE Transactions on Network Science and Engineering*, vol. 11, no. 6, pp. 6285–6297, Nov. 2024, doi: 10.1109/TNSE.2024.3418558.

[20] M. Sabounchi and J. Wei, "A Decentralized P2P Electricity Market Model for Microgrids," in *2018 IEEE Power & Energy Society General Meeting (PESGM)*, Portland, OR, USA: IEEE, Aug. 2018, pp. 1–5, doi: 10.1109/PESGM.2018.8586257.

[21] N. Z. Aitzhan and D. Svetinovic, "Security and Privacy in Decentralized Energy Trading Through Multi-Signatures, Blockchain and Anonymous Messaging Streams," *IEEE Transactions on Dependable and Secure Computing*, vol. 15, no. 5, pp. 840–852, Sep. 2018, doi: 10.1109/TDSC.2016.2616861.

[22] M. Andoni et al., "Blockchain technology in the energy sector: A systematic review of challenges and opportunities," *Renewable and Sustainable Energy Reviews*, vol. 100, pp. 143–174, 2019, doi: 10.1016/j.rser.2018.10.014.

[23] Z. Li, J. Kang, R. Yu, D. Ye, Q. Deng and Y. Zhang, "Consortium Blockchain for Secure Energy Trading in Industrial Internet of Things," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 8, pp. 3690-3700, Aug. 2018, doi: 10.1109/TII.2017.2786307.

[24] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, and E. Hossain, "Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3154–3164, 2017, doi: 10.1109/TII.2017.2709784.

[25] X. Huang, C. Xu, P. Wang, and H. Liu, "LNSC: A security model for electric vehicle and charging pile management based on blockchain ecosystem," *IEEE Access*, vol. 6, pp. 13565–13574, 2018, doi: 10.1109/ACCESS.2018.2812176.

APPENDIX

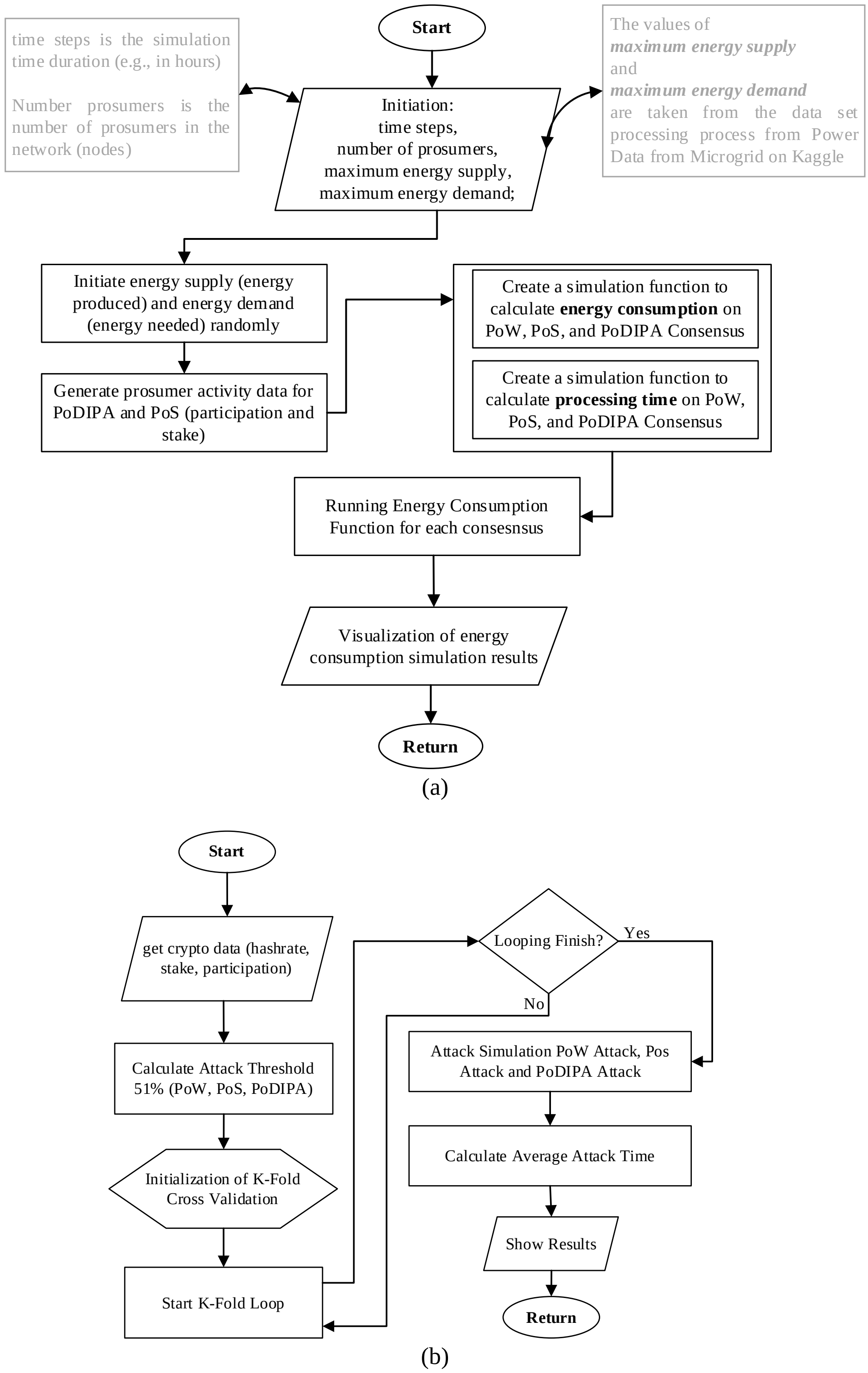


Figure 2. Simulation framework of the proposed method; (a) energy and processing time evaluation and (b) 51% attack resistance evaluation

BIOGRAPHIES OF AUTHORS

Sadly Syamsuddin earned her Bachelor of Computer Science (S.Kom.) in 2009 from STMIK Dipanegara Makassar, Indonesia. He earned his Master of Engineering (M.T.) in 2016 and her Doctorate (Dr.) in 2025 from the Department of Electrical Engineering, Faculty of Engineering, Hasanuddin University, Gowa, Indonesia. He currently serves as a Homebase Lecturer for the Informatics Engineering Study Program (S1) and a Postgraduate Lecturer for the Informatics Study Program (S2) at Dipa University, Makassar. He serves as Head of the Business and Technology Incubator (INBISTEK) at UNDIPA Makassar, and serves as chairman and administrator of several associations related to Informatics and the Hobby World. He also serves as a consultant and entrepreneurial mentor for various Indonesian national projects. He actively writes books, journals, and scientific papers in the field of informatics, particularly artificial intelligence, blockchain, the internet of things (IoT), and data mining, with a focus on the renewable energy, business, food, health, and education sectors. He is an academic and practitioner who has run the company CV Growing Companies since 2013. Outside of academic and professional activities, he has hobbies such as music, singing birds, and fishing. He can be contacted at email: sadlys@undipa.ac.id or sadlyg2@gmail.com.

Prof. Salama Manjang received the B.Sc. from Hasanuddin University in 1988, Master and Doctor degrees from the Department of Electrical Engineering, Institut Teknologi Bandung, Indonesia, in 1994 and 2000 respectively. In 1997 Sandwich Doctoral Program at T.U Braunschweig Germany. He is currently Professor of the Department of Electrical Engineering Hasanuddin University. His research interests high voltage insulating materials, aging and diagnosis polymeric insulation material under tropical climate. He can be contacted at email: salamamanjang@gmail.com.

Prof. Muhammad Bachtiar Nappu received his Bachelor's degree (with honors) from Hasanuddin University in 1999 and his Master's degree from the Bandung Institute of Technology in 2001. He earned his Master of Philosophy and Doctor of Philosophy degrees from the University of Queensland, Australia, in 2009 and 2013, respectively, all in electrical power systems engineering. He has published over 80 scholarly works and was awarded Best Academic in Science and Technology by Hasanuddin University in 2019. He has led the Centre for Research and Development on Energy and Electricity at Hasanuddin University since 2015 and has been involved in numerous projects with PT PLN (Persero). In recent years, he has also worked with USAID and the Asian Development Bank on renewable energy development and power system planning in Indonesia. His research interests include power system operation, forecasting, renewable energy integration, and electricity market optimization. He can be contacted at email: bachtiar@eng.unhas.ac.id

Ady Wahyudi Paundu received the B.Sc. from Sekolah Tinggi Teknologi Telkom, Bandung, Indonesia in 1999, Master degree from Universitas Hasanuddin, Makassar, Indonesia in 2009 and Doctoral degree from the Laboratory for Cyber Resilience, School of Informatics, Nara Institute of Science and Technology, Nara, Japan, in 2019. Currently work as a lecturer within the Department of Informatics, Faculty of Engineering, Universitas Hasanuddin. His research interests are in the topic of cyber resilience, especially in the way to handle social engineering. He can be contacted at email: adywp@unhas.ac.id.