Towards a Multi-Dimensional Assessment of Blockchain Decentralization: Empirical Evidence and Future MCDM-Based Integrative Framework

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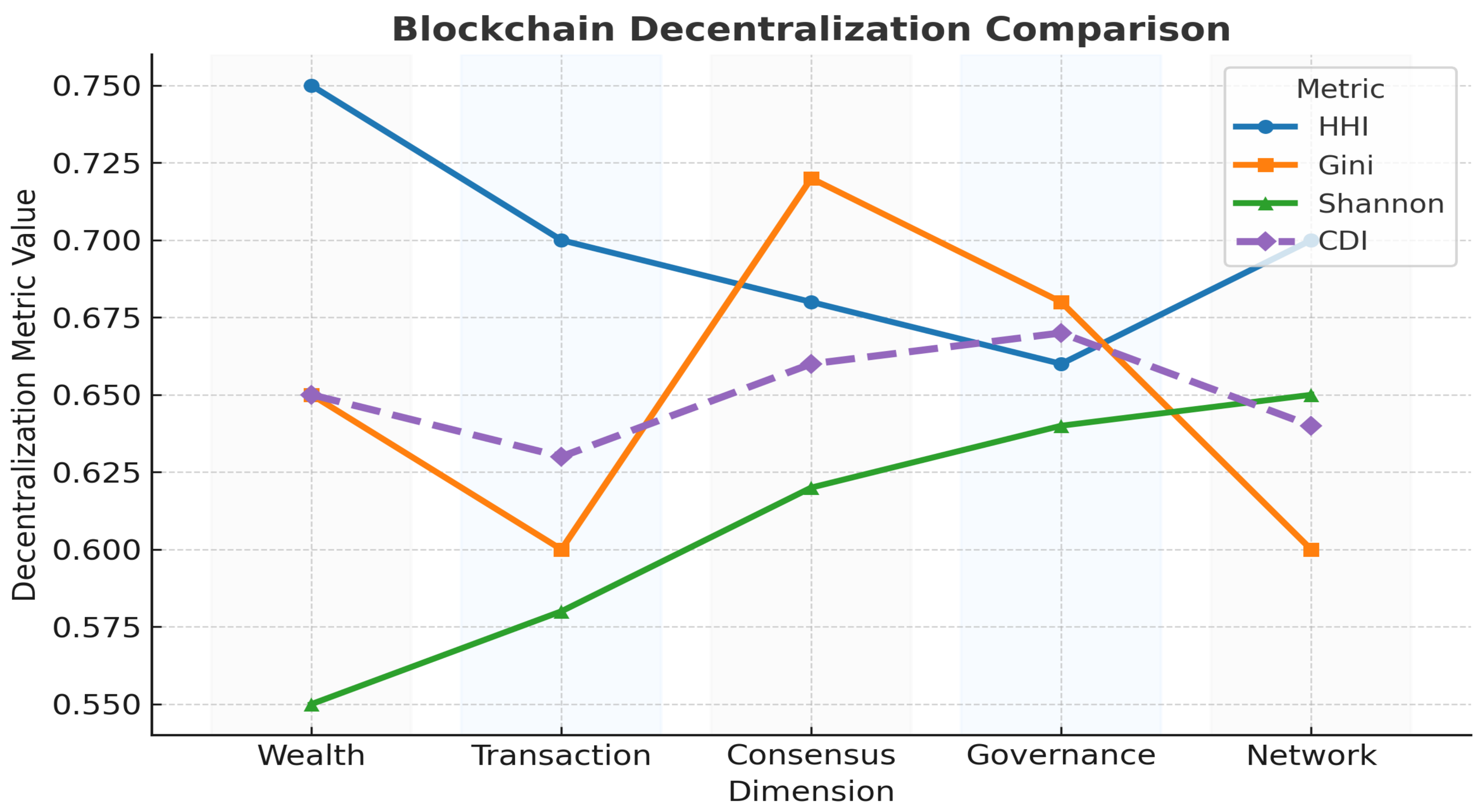
Introduction: Blockchain decentralization is one of the most debated yet least consistently measured properties of distributed systems. While conceptually central to blockchain technology, quantifying decentralization remains challenging due to its multi-faceted nature spanning technical, economic, and governance dimensions.

Our goal: Quantify and compare decentralization across different blockchain dimensions—wealth, transaction, consensus, governance, and network—using empirical data and rigorous analytical methods.



Motivation: Decentralization critically influences blockchain security, fairness, and governance. However, most studies analyze isolated aspects—wealth, consensus, or governance—without accounting for their interdependencies.

Research gap: No unified framework exists for assessing multiple decentralization dimensions simultaneously. Our approach integrates **five layers**—wealth, transaction, consensus, governance, and network—into a holistic empirical model.

Future directions: extend the current framework to all five dimensions and integrate them into a Composite Decentralization Index (CDI) using MCDM techniques:

1. Data Collection: Expand datasets for 10+ blockchain ecosystems.
2. MCDM Application: Apply AHP, TOPSIS, and VIKOR for weighting and ranking.
3. CDI : Develop sensitivity-tested composite index.

Key Results

Wealth Concentration

Persistent high inequality across major networks. Top 1% of addresses control 40-60% of total supply in Bitcoin and Ethereum, challenging claims of economic decentralization.

Transaction Patterns

Bitcoin demonstrates strongest transactional decentralization with lower Gini coefficients. Ethereum shows concentration in smart contract interactions and DeFi protocols.

Layer 2 Tradeoffs

L2 solutions (Optimism, Arbitrum, Polygon) achieve better scalability without complete centralization, but introduce new validator dependencies and security assumptions.

Methodology

We combine empirical blockchain data extraction with statistical analysis and advanced decision-analysis tools to create a robust measurement framework.

Dimension	Metrics	Blockchains
Wealth	Gini, Shanon,	BTC, ETH,
Transaction	Nakamoto,	Layer 2,
Consensus	Herfindahl	Avalanche,
Governance	Hirschman	Algorand,
Network	HHI, CDI	Cosmos, Aaave

The proposed methodology culminates in the **Composite Decentralization Index (CDI)**, enabling transparent and evidence-based evaluation of blockchain systems. It facilitates the identification of systemic vulnerabilities, supports research on protocol and governance structures, and provides a foundation for assessing the long-term sustainability of blockchain ecosystems.

Data used as Input

- **Blockchain ledgers:** Bitcoin, Ethereum, Layer 2 (Optimism, Arbitrum, Polygon),
- Avalanche, Cosmos, Algorand, Cardano, Solana, MakerDAO, Polkadot.
- **Data sources:**
  - Public blockchain APIs (Etherscan, Blockchain.com, Blockchair)
  - Governance and voting platforms (Tally, Snapshot, MakerDAO portal)
  - Network monitoring data (Bitnodes, Ethernodes, validator sets)
- **Data types:**
  - Wealth distribution (address-level balances, token supply)
  - Transactional activity (frequency, concentration, diversity)
  - Consensus and staking data (validator share, block production)
  - Governance participation (voting power, proposal statistics)
  - Network topology (node location, client software diversity)
- **Period covered:** 2021–2025, aggregated and normalized for cross-chain comparison.

Conclusion

By combining multi-dimensional analysis with rigorous MCDM techniques, our approach provides a holistic assessment of blockchain decentralization, moving beyond single-metric evaluations toward integrated, data-driven profiles.

Explanations

- **Wealth:** Measures token ownership concentration via Gini, Shannon entropy, and Herfindahl–Hirschman Index (HHI).
- **Transaction:** Captures activity dispersion through the Nakamoto coefficient and transaction diversity metrics.
- **Consensus:** Evaluates validator and stake concentration, block production diversity, and network participation.
- **Governance:** Assesses decision-making balance via voting power distribution, proposal participation, and decision diversity.
- **Network:** Quantifies node-level decentralization using geographic, client, and connectivity diversity metrics.

References

Juodis, M., Filatovas, E., Paulavičius, R. (2024). Wealth decentralization in blockchain networks. ICT Express.

Juodis, M., Filatovas, E., Goatautas, D., Paulavičius, R. (2024). Examining transactional decentralization on the Ethereum blockchain. IEEE BCCA 2024 Proceedings.

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Juodis, M., Filatovas, E., Goatautas, D., Paulavičius, R. (2025). Transactional decentralization in blockchain networks. Submitted to Blockchain Research and Applications.

Acknowledgment

This research was supported by the **Vilnius University, Institute of Data Science and Digital Technologies (VU DMSTI)**.
We thank **DAMSS 2025 Organizing Committee** for providing a platform to present our work.