Measuring the Impact of Ethereum's Transition to Proof-of-Stake Consensus Mechanism

[Author name withheld for anonymity]

***Abstract* - On September 15, 2022, Ethereum underwent a highly anticipated upgrade to abandon energy-consuming cryptocurrency mining that had acted as its consensus mechanism in favor of an energy-efficient proof of stake mechanism. This paper evaluates the actual outcomes of the network upgrade in the 12 months post-upgrade through five factors: energy efficiency, network security, scalability, transaction cost, and deflation. We found that whereas Ethereum did achieve energy efficiency and deflation, it has failed to address its goals of network security, scalability, and transaction costs.**

Index Terms – Ethereum, Proof-of-Stake, Merge, Deflation.

INTRODUCTION

Ethereum is a decentralized, open-source blockchain platform that facilitates the second largest cryptocurrency, the Ether (ETH). As of November 25, 2023, Ethereum has a market capitalization of $245 billion. As a result of Ethereum's more diverse usage, it has the highest daily transaction volume among all blockchain platforms and is notably 80.5% higher than that of Bitcoin.

Cryptocurrencies use a consensus mechanism to validate transactions, such as Proof-of-Work (PoW) or Proof-of-Stake (PoS). In PoW, miners must solve computational puzzles to include a block of transactions in the blockchain. Those with greater computational power stand a better chance of validating blocks and earning a reward, making this mechanism energy-intensive. Conversely, in PoS, validators stake the cryptocurrency's native token. Those with the highest stakes are the most likely to be selected to produce the next block [(1)]. Like Bitcoin, Ethereum was formed as a PoW consensus mechanism.

To make the network more efficient, Ethereum Foundation, the governing body for the Ethereum blockchain, initiated a shift from PoW to PoS consensus mechanism. The role of cryptocurrency miners was replaced with that of node operators who pledge or "stake" 32 ETHs to earn the right to validate transactions and earn block rewards. PoS was marked as the most revolutionary and the most awaited technological advancement in the blockchain world, with the following expected benefits:

- Energy efficiency, by eliminating the energy-intensive crypto mining for transaction validation.
- Network security, by decentralizing validators to protect against 50%+ malicious attacks.
- Scalability, by increasing capacity to process more transactions per second.
- Lower transaction costs, by reducing gas fees.
- Deflation, by burning ETHs and reducing the number of new ETHs minted.

At 2:43 a.m. E.D.T. on September 15, 2022, Ethereum abandoned the energy-intensive mining mechanism to transition to PoS for securing, validating, and adding transactions in an upgrade titled the "the Merge".

This paper evaluates the changes in Ethereum network characteristics in the 12 months following the Merge. Although there have been other studies that evaluated Ethereum's transition to PoS, those studies have generally evaluated only the immediate impact within 60 days or have studied specific topics such as transaction fees and network security, leaving a gap for a thorough, multi-month-long study. Our analysis covers a broad 12-month evaluation period and highlights 5 key characteristics of the blockchain. One of our findings refutes a prior paper's conclusion that gas fees have degraded due to the Merge.

METHODOLOGY

To evaluate how the Merge affected the network, we downloaded daily blockchain statistics directly from the block explorer, Eterhscan.io, and reviewed key blockchain metrics over 12 months post-Merge. To estimate energy efficiency, we calculated electricity in terawatt hours (TWh) used in PoW mining operations. To evaluate network security, we looked at the concentration of voting power held by the largest staking validators. We evaluated scalability by comparing the average number of transactions per second over the 12 months. To study transaction fees, we compared the average monthly gas fees in ETHs for 12 months beginning with the Merge. For studying deflation, we compared the average number of ETHs minted per day for 12 months before and after the Merge. The study excluded metrics such as transaction volume and market prices since those are influenced by factors other than the Merge.

RESULTS

The results of our 12-month study are shown below:

- **Energy efficiency**: PoS has ended mining operations entirely, thus achieving more than 99.9% energy reduction[2]. Before the Merge, annualized PoW energy consumption was 21 TWh, compared to just 0.0026 TWh post-Merge [3]. For reference, the annual amount of energy saved is enough to power half of the country of New Zealand.
- **Network security**: PoS initially delivered decentralization of validators compared to PoS, but over time, staking validators have become concentrated [4]. As a result of high capital requirement and other complexities involved in node setup, staking is dominated by large, sophisticated entities. The top five entities comprise 51.2% of voting power (see Figure 1), such that if they were to collude, they could take over the entire blockchain. Although *Grandjean* had found concentration within 60 days of the Merge, they had anticipated that this problem would be solved over time. However, our study found that even after 12 months, the network remains dependent upon the top five validators.
- **Scalability**: The number of transactions per second (TPS) remains substantially unchanged at 13 TPS (see Table 1), compared to its stated goal of up to 100,000 TPS or compared to Visa's capacity of 65,000 TPS. Ethereum's future upgrade titled Sharding is still in the pipeline and aims to achieve the targeted scalability [5].
- **Transaction cost**: Gas fees used on token transactions went up from 0.0015 ETH in Sep. 2022 to 0.0019 ETH in Sen 2023 (see Figure 2). The increase seen in gas fees is consistent with other studies on the immediate impact of the Merge on gas fees [6], although we found that gas fees have fluctuated over time. Although our data also supports the theory that transaction costs went up post-Merge, we caution that gas fees depend upon many other factors, and notably upon total transaction volume on the blockchain. Therefore, attributing the rise in fees to the Merge alone may be unjustified. Indeed, a comparison of the 30-day daily average of before and after Merge gas fees provides mean values of 0.0015 and 0.0016, respectively, with a t-test of 0.66 and a p-value of 0.25, making the change inconclusive. Still, to the end user for whom transaction fee is the most relevant metric, the upgrade has failed to deliver the promised benefit.
- **Deflation**: PoS has achieved its goal of deflation. Since no block rewards are paid to miners, the network has been burning ETH to achieve a net deflation in ETH supply. During the 12 months before the Merge, daily ETH supply increased by 8,318, but 12 months post-Merge, the average daily ETH supply actually decreased by 807 (see Table 2), resulting in a one-tail t-test of 30 and a p-value of 1.23E-101. PoS stake and burn mechanism has indeed achieved its goal of deflation.

CONCLUSIONS

Our 12-month evaluation post-Merge confirms that Ethereum's PoS upgrade has been a success story, with the primary goals of energy efficiency and deflation having been achieved. Still, the Merge has failed in the equally important and promised goals of increasing network security and scalability and of reducing transaction cost. More technological advancements are needed to fully complete the transition and realize the promised benefits.

FACTS AND FIGURES

Table 1: Ethereum transactions per second

	TPS
Ethereum: pre-Merge	13
Ethereum: post-Merge goal	Up to 100,000
Ethereum: actual 12-months post Merge	13
MEMO: Visa credit card network	65,000

Table 2: Daily change in ETH supply

	12-month Pre-Merge	**12-month Post-Merge**
Mean daily ETH minted	8,318	– 807
Standard deviation	5,548	1,826
Number of observations	365	365
T-stat	30.2	
P value (T<=t)	1.23E-101	

Figure 1: Top ETH staking depositors (as of Nov. 2023)

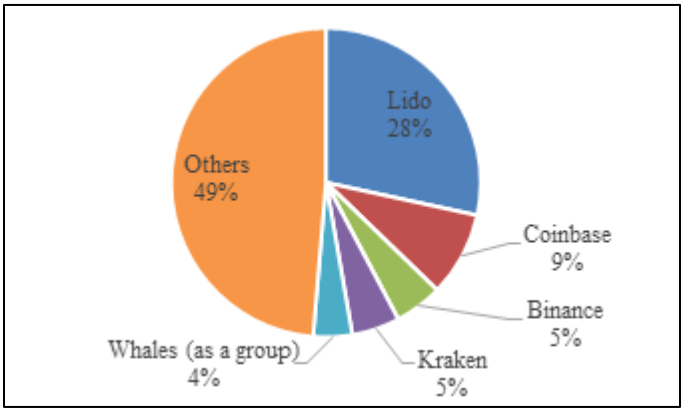
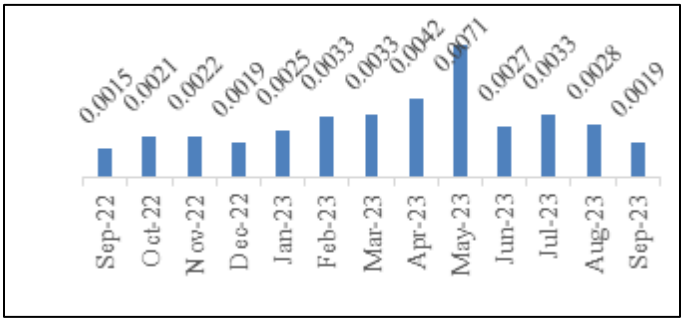


Figure 2: Average gas fees per transaction (ETH)



REFERENCES

[1] Jain, Archana, Jain, Chinmay and Krystyniak, Karolina December 2023. "Blockchain transaction fee and Ethereum Merge" *Finance Research Letters Volume 58, Part C, December 2023, 104507*.

[2] M Cortes-Goicoechea, T Mohandas-Daryanani, JL Muñoz-Tapia, L Bautista-Gomez March 2023. "Autopsy of Ethereum's Post-Merge Reward System" *arXiv preprint arXiv:2303.09850, 2023*

[3] "Ethereum's energy expenditure." 2023. https://ethereum.org/en/energy-consumption/. Web. Accessed: November 23, 2023.

[4] Grandjean, Dominic, Heimbach, Lioba and Wattenhofer, Roger September 2023. "Ethereum Proof-of-Stake Consensus Layer: Participation and Decentralization" *arXiv preprint (2023), 10.48550/arXiv.2306.10777. 2023.*

[5] Hafid, Abdelatif, Hafid, Abdelhakim Senhaji, Prieto, Javier and Durán Barroso, Ramón September 2023. "Sharding-Based Proof-of-Stake Blockchain Protocols: Key Components & Probabilistic Security Analysis" *Sensors (Basel). 2023 Mar; 23(5): 2819. 2023.*

[6] Kapengut, Elie and Mizrach Bruce 2023. "An event study of the Ethereum transition to proof-of-stake" *Commodities, 2 (2023), pp. 96-110, 10.3390/commodities2020006. 2023.*

AUTHOR INFORMATION

[Author name withheld for anonymity]