Blockchain Energy Consumption: Proof of Work vs Proof of Stake

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ABSTRACT

Blockchain technologies, however recent, have become popularized especially due to their use in the finance sector. Despite the benefits blockchain technologies offer, there is a growing concern over their enormous energy consumption and their impact on the climate crisis, with research pointing to blockchain's Proof of Work (PoW) consensus mechanism as the main culprit of this issue. As such, some blockchains have started to move away from PoW into other mechanisms, with Proof of Stake (PoS) being pushed as a suitable alternative to keep the integrity of blockchain's while reducing energy consumption. While research has showed that PoS does indeed consume less energy, the is not a lot of research that focuses on directly comparing the two mechanisms in two different blockchains. As such, this paper intended to address this problem by directly comparing these two mechanisms across different metrics (CPU usage, memory usage, disk usage and network traffic). For this purpose, Bitcoin was selected as a blockchain that used PoW, and Ethereum was chosen as a blockchain that moved away from PoW into a PoS mechanism. Despite the small scale of this paper's experiments and the use of testnets rather than live blockchains, it was still possible to observe that Ethereum's PoS showed significant reductions in CPU usage when compared to BItcoin's PoW, with other metrics not showing significant differences. This serves as evidence that PoS does indeed consume less energy than PoW and could be a more energy-efficient alternative.

1 INTRODUCTION

Blockchain originated in 2008, when Satoshi Nakamoto, whose identity was never verified, published the Bitcoin whitepaper. This was the precursor that led to the creation of Bitcoin the following year. Although blockchain technology is relatively recent, its use has exponentially increased since its inception. It has been popularized for its role in facilitating financial products such as cryptocurrencies and NFTs, but it has also increasingly been used for other purposes such as healthcare, agriculture and energy supply chains.

Despite being an area of research with many applications, its use has become controversial mostly due to high profile financial scams and its staggering energy consumption. This last issue being the focus of this paper.

Research conducted on Bitcoin, the first cryptocurrency and the most widely known blockchain technology, has arrived to the consensus that it indeed spends massive amounts of energy, with higher estimates of a yearly consuption of 87.1 TWh electricity, which is comparable to a country like Belgium (De Vries, 2020). [1]

Research has also been able to identify what aspect of Bitcoin technology is responsible for its energy consumption, and it mostly comes down to its Proof of Work (PoW) consensus mechanism. In blockchain, the consensus mechanism is the rules by which new blocks can be added to the chain. In the case of Bitcoin, it is through solving complex hash problems that are difficult to solve, but easy to check. However, Bitcoin's blockchain only allows for a new block to be added after a 10 minute interval on average. Because of that, the increasing popularity of Bitcoin has brought many new users and miners to the network, so, in order to maintain the 10 minute interval, the difficulty of the hash puzzles needs to increase exponentially. This requires massive computational power, inevitably increasing the energy consumption.

Bitcoin is only one blockchain, and many more blockchains exist that use PoW as its consensus mechanism. This creates a clear problem of over consumption of energy resources, especially in a time where the world is facing a climate crisis. Because of this, newer blockchain technologies, like Ethereum, have started to move away from PoW as its consensus mechanism, and shifting to Proof of Stake (PoS). PoS works differently than PoW, not by demanding that miners prove they have done the computational work to add a block, but by requiring that "miners" (which are called validators in PoS blockchains) prove they have "stake" in the blockchain, specifically, that validators must own a certain amount of coins or tokens in order to be able to add a block, and they must be willing to offer some tokens as collateral, this is called "staking". When a block is added, a random validator is chosen to receive the token rewards of adding the new block, with validators who staked more tokens being more likely to be chosen. This consensus mechanism does not require the same amount of computational power that PoW systems usually need.

Ethereum started by having a PoW mechanism, but it has shifted to PoS with Ethereum 2.0, which has significantly decreased its energy consumption, and has led to the rise of PoS as the mechanism consensus that can address blockchain technologies' energy consumption problem.

This paper aims to compare Bitcoin's PoW and Ethereum's PoS's energy consumption through different metrics, with CPU usage being the main metric used for this purpose.

2 MOTIVATION AND PROBLEM DEFINITION

2.1 Motivation

Climate change is one of the most important issues facing humanity in the 21st century. Left unchecked, Climate researchers have predicted tragic and near apocalyptic events, like increases in natural

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disasters, food supply collapses, displacement of populations leading to unprecedented amounts of refugees, significant economic loss, resource scarcity, etc. Current trends in global carbon emissions put us on track to this reality and, as such, it is imperative that the scientific community works together with policymakers to address this issue.

In 2018 almost every nation on Earth signed the Paris Climate Agreement, and committed to making changes to prevent the global surface temperature from rising to more than 2.0ºC compared to preindustrial averages. This requires major shifts in global emissions. The agreement also declares that 1.5ºC is the preferable limit, which requires rapid and unprecedented changes to the way countries operate.

As previously stated, Bitcoin's yearly consumption is staggering and equivalent to the expenditure of entire countries. Since energy consumption is directly tied to carbon emissions, Bitcoin and other PoW blockchains' energy consumption has been deemed unsustainable and there has been significant push to address this problem.

One solution that has been proposed to this problem is to switch from a PoW consensus mechanism to a PoS mechanism. Since PoS does not require the same level of computational power as PoW, it has been proposed as a solution to reduce the energy consumption of blockchain technologies. In 2022, the most popular blockchain for NFTs and other smart contracts Ethereum shifted mechanism from PoW to PoS, and since then research has focused on evaluating whether this change impacted the energy consumption of the blockchain.

This research is motivated by this need to assess whether PoS is a suitable replacement for PoW in regards to energy consumption, and as a solution to address blockchain technologies' carbon emission problems.

2.2 Problem definition

Since blockchain itself but especially PoS mechanisms are relatively new technologies, the research on its energy consumption is limited. While there is extensive literature on Bitcoin's energy expenditure, this research usually focuses on large scale estimations to estimate absolute values, rather than comparative studies between different blockchains. This is even more so the case with Ethereum PoS, which has only been around for two years. While there is some research that has shown a decrease in energy consumption due to the shift from PoW to PoS in the Ethereum blockchain, the amount of comparative studies between Bitcoin's PoW and Ethereum's new PoS is still small. Because finding a way to reduce the energy consumption of blockchain technologies is paramount to the their future, it is important to understand how these systems fare against one another. This is the gap in knowledge that this paper aims to address.

3 EXPERIMENTS

3.1 Methodology

The primary objective of this paper was to compare the Bitcoin's PoW with Ethereum's PoS consensus mechanisms in a controlled environment. This was achieved by simulating both blockchains, tracking transactions, and analyzing how each blockchain utilized the local machine's resources. The data was then analyzed to check for any significant differences between both of these mechanisms.

To conduct the experiment in a controlled and comparable environment, the simulations were run in the same computer, and had the equal run time of 5000 seconds. CPU usage, memory usage over time, disk read/write over time and network in/out over time were the metrics selected to compare both blockchains. CPU usage was, however, the primary metric, since it correlates directly to energy consumption, the main goal of this paper. Each blockchains' testnets were used instead of the mainnets to minimize the costs of running the simulations on live blockchains. Since there are many available testnets for Ethereum, the Sepolia testnet was chosen since it uses the PoS mechanism, which is not true of all Ethereum testnets.

The experiment had the following steps:

(1) Using a Bitcoin testnet to simulate PoW.
(2) Using Ethereum's Sepolia testnet to simulate PoS.
(3) Generating transactions in the local machine for 5000 seconds for each blockchain.
(4) Tracking the relevant metrics throughout the experiment by registering them to a .txt file.
(5) Using a Python script with pandas and matplotlib libraries to plot graphs of the relevant metrics.
(6) Analyze the results.

3.2 Experimental Setup

To ensure that the results were comparable between experiments, it was essential to control as many variables as possible. Because of that, both simulation were run in the same computer with the following specifications:

- **Operating System:** macOS Sequoia 15.1.1
- **Computer Model:** MacBook Pro, 13-inch, 2019
- **Processor:** 1.4 GHz Quad-Core Intel Core i5
- **RAM:** 8 GB 2133 MHz
- **Disk:** 256 GB SSD

The blockchain used to simulate PoW was the Bitcoin testnet, which mirrors the mainnet but operates with a smaller block size and lower difficulty. To simulate PoS Ethereum's Sepolia testnet was used since it uses the PoS mechanism which is not true of all Ethereum testnets.

The metrics tracked were CPU usage (main metric), memory usage, disk read/write operations and network in/out traffic. These metrics were written into a .txt (one file for Bitcoin, another for Sepolia) every 10 seconds. Each simulation had the total duraction of 5000 seconds.

Lastly, a Python script was employed to extract the data record from the .txt files. The pandas library was used to handle and organize the data, and the matplotlib was used to create graphs that were used to visualize and analyze the data.

3.3 Results

The experiments yielded 8 graphs, one for each metric of each blockchain. Through these graphics it was possible to compare the PoW and PoS consensus mechanisms.

The Bitcoin graph for CPU usage shows that the CPU usage was on average between 10-20%. However, there were frequent spikes

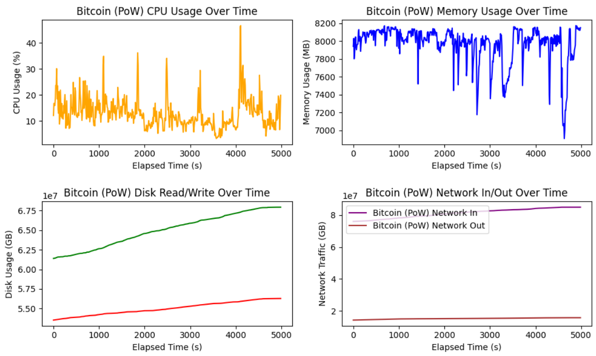

Figure 1: Metrics tracked for the Bitcoin PoW during the simulation. It is important to note that in the read/write graph, the green line represents read and the red line represents write.

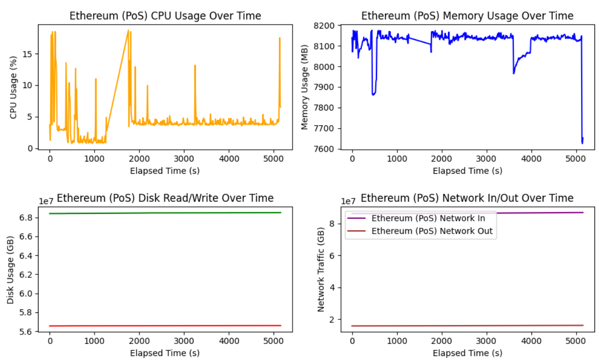

Figure 2: Metrics tracked for the Ethereum PoS during the simulation. It is important to note that in the read/write graph, the green line represents read and the red line represents write

in CPU usage, including some that reached over 30% or 40% usage. The memory usage was around 8000MB throuhout the simulation, even though it dipped several times to as low as 7000MB. The disk usage for read operations started between 6.00 and 6.25GB but increased steadily until it reached over 6.75GB. The disk usage for write operations started significantly lower, below 5.5GB, and increased to just a little over that value by the end of the simulation. The network in/out traffic was relatively unchanged throughout the simulation with around 8GB and less than 2GB respectively.

The Ethereum graph for CPU usage shows that the CPU usage was much lower, averaging between 0-5%. With some spikes that never reached the 20% usage mark. The memory usage was slightly higher than for Bitcoin, at around 8100MB throughout the simulation. It also dipped like BItcoin but less frequently and only to values above 7600MB. The disk usage for read/write operations was almost unchanged over time, staying at a little over 6.8GB and a little over 5.6GB respectively. It is possible to see that in the Bitcoin simulation these metrics started out at lower values, but increased to similar values as Ethereum towards the end. Regarding the network in/out traffic the values were similar to the Bitcon's, staying relatively unchanged throughout the simulation at around 8GB and less than 2GB respectively.

4 DISCUSSION, LIMITATIONS AND FURTHER WORK

4.1 Discussion

The results of the experiment highlight some important aspects of how PoW and PoS are not only different but also similar. The main focus of this paper was energy consumption, so the primary metric to be analyzed is the CPU usage. It is also the metric that showed more significant differences between Bitcoin's PoW and Ethereum's PoS. Bitcoin's CPU usage was around double that of Ethereum's, confirming the hypothesis that PoW does indeed lead to more energy consumption over time. Although it is just an anecdote, it is also relevant to point out how the machine running the simulation's battery was drained relatively fast while running the PoW simulation, and this was not noted during the PoS simulation. However, this was not a metric that was carefully tracked throughout the experiment, and as such, it might not have the same validity as the other metrics. Even so, it is relevant to state. With these comparisons PoS seems to be an appropriate alternative to PoW in terms of reducing the computational power needed to operate a blockchain. However, due to the limitations that will be discussed further in this paper, it is not possible to indisputably claim that PoS can solve blockchain's energy consumption problem.

Additionally, the other metrics tracked in this paper do not show significant differences between Bitcoin's PoW and Ethereum's PoS. While CPU usage is the metric that most directly correlates to energy consumption, the others metrics tracked also involve some energy expenditure. Not only that, but considering that Ethereum's memory usage was slightly higher than Bitcoin's it raises the question of whether PoS can really solve blockchains' energy consumption if it does significantly reduce other metrics.

4.2 Limitations

In this paper, while it was possible to evaluate aspects in which PoW and PoS consensus mechanisms are similar or different, it is important to acknowledge the small scale of this project. Firstly, this experiment only ran for 5000 seconds for each of the blockchains, so it was not possible to observe how these metrics evolve over long periods of time. Especially when considering that one of the main reasons that contributes to Bitcoin's PoW mechanism's massive energy consumption is the exponential increase in the difficult of the hash puzzles that need to be solved to add blocks to the chain, it is important to acknowledge that this paper did not run its experiments long enough to observe this.

Another important aspect to consider is the fact that the experiments were made using testnets and not the actual blockchains as they are used in its real life applications. In the case of the Bitcoin testnet, it follows the same rules as the mainnet, but mining difficulty and blockchain size are significantly scaled-down. In the case of Ethereum's Sepolia testnet it does not fully replicate the complexity of Ethereum's mainnet. However, this paper's main focus was on comparing Bitcoin to Ethereum, so the conclusions drawn from comparison are still valid, but it is not possible to use this paper's absolute data as an exact representation of these blockchains' real-world implementations.

4.3 Further Work

This paper has acknowledged its limitations above, but it is also important to note what further work can be in the path to more sustainable blockchains. An important aspect to deconstruct is how this paper poses Proof of Work (PoW) vs Proof of Stake (PoS) as a dichotomy. While these are the most used consensus mechanisms utilized in blockchains, they are certainly not the only options. Many more consensus mechanisms are being employed, namely Proof of Authority (PoA), Proof of History (PoH), Proof of Burn (PoB), Proof of Importance (PoI), etc. It is important that these other mechanisms are also thoroughly studied in order to solve blockchain's energy consumption problem, and it is important that research considers different mechanisms and that the solution is not seen as a simplistic duel between PoW and PoS.

5 RELATED WORK

In 2023, Mulligan et. al [2] published their literature review on Blockchain for sustainability. The paper was mostly focused on specific blockchain research that is targeted towards sustainable development; however, the authors acknowledge that blockchain itself has an energy consumption problem. Even though this issue was not the primary focus of their paper, it served as the motivation for this research.

While mentioning blockchain's energy consumption, the authors reviewed several papers that tried to assess the energy expenditure of the Bitcoin blockchain as well as Ethereum's. Most of those papers do not directly compare Bitcoin PoW with Ethereum's PoS, as it was attempted in this paper, but they attempt to calculate the energy footprint of different blockchains. Most papers focused on Bitcoin with its PoW mechanism, and while there were papers that focused on Ethereum, they targeted Ethereum's PoW, rather than its newer PoS consensus mechanism. There were only two papers that included both Bitcoin PoW and Ethereum PoS, this highlighted the gap in literature of direct comparisons between these two blockchains and respective consensus mechanisms.

The energy footprints in the paper where expected considering the background knowledge of these blockchains. Papers that focused on Bitcoin showed levels or energy consumption that were orders of magnitude bigger than Ethereum's even when Ethereum was using PoW. The values were as high as 117296.4GHWh or as low as 876.0GWh, with most research pointing to values between 40000GWh and 90000GWh. In order to understand these numbers, the papers that had data on Ethereum only showed values of 974.7GWh and 311.9GWh for PoW and 2.7GWh and 10.0GWh when PoS was used. This clearly shows that PoS as a consensus mechanism significantly decreases energy consumption. Even though the data comes from different papers who might have different methodologies, the papers that calculated Ethereum's energy consumption based on PoW showed significantly higher values than when PoS was employed. This appears to mean that switching from PoW to PoS was an important step in mitigating energy consumption for Ethereum.

It is important to acknowledge, however, that research that estimated Ethereum's energy footprint even when PoW was being used showed significantly lower values than Bitcoin's PoW's energy consumption. As such, it is important to consider whether there are other aspects contributing to Bitcoin's high energy consumption apart from its consensus mechanism.

6 CONCLUSION

This paper's main goal was to compare two distinct blockchains with two distinct consensus mechanisms, in order to assess how they fared in terms of energy consumption. Due to their widespread use, Bitcoin was used as the blockchain that used PoW, and Ethereum was chosen as the blockchain that used PoS. Ethereum was also chosen because of its shift from PoW to PoS, making it an interesting case in how these consensus mechanisms affect energy consumption.

This paper conducted a small experiment to compare these two blockchains and respective mechanisms, placing a strong emphasis in assuring a controlled environment. The findings of this experiment confirmed that Ethereum's PoS mechanism required significancy less CPU usage than Bitcoin's PoW, supporting the argument that PoS is a more energy-efficient consensus mechanism. It was also noted that the other metrics analyzed did not show significant differences between both mechanisms, which raised the question of whether PoS is truly the best alternative to address PoW's energy consumption. Even with this considered, it is undeniable that PoS represents a significant improvement in terms of energy expenditure compared to PoW.

While this paper was able to make a meaningful comparison, it is important to acknowledge that the small scale of the experiment and the use of testnets rather than live blockchains represent a significant limitation. Future research should not involve longer simulations in live blockchains, but it is also important to assess whether other consensus mechanisms could be better alternatives to both PoW and PoS.

In conclusion, while limited in its scope, the paper provides some evidence that Bitcoin's PoW mechanism is an important aspect of its massive energy consumption, and that Ethereum's PoS allows for reductions in the energy required to keep these blockchain's running.

REFERENCES

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A GITHUB REPOSITORY

The GitHub repository of this project can be accessed through this link: https://github.com/23-jose/PoWvsPoS