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Distributed
Computing

Post Merge Cryptocurrencies

Bachelor's Thesis

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Abstract

This study investigates the allocation of computational resources previously dedicated to Ethereum mining following the implementation of The Merge on September 15th, 2022, which marked the transition from proof-of-work to a proof-of-stake consensus mechanism. By reconstructing the network hashrate, we could analyze the redistribution of computing power to other proof-of-work currencies. Our findings reveal that approximately 30% of Ethereum's hashrate was reallocated by the end of September, with Ethereum Classic absorbing the majority. Furthermore, we identified alternative uses for the remaining GPUs, including their sale, utilization as heaters during winter, and repurposing for the emerging AI market. This research highlights the impact of Ethereum's transition on the mining landscape and the subsequent diversification of computational resources.

Contents

Chapter 1

Introduction

A blockchain is a decentralized and distributed ledger that maintains a transparent and immutable record of transactions. It consists of a series of interconnected blocks, where each block contains a collection of transactions. Stored transactions are cryptographically signed via unique, unchangeable hashes, such as those created with the SHA-256 algorithm. The hash from each block is used in the block that follows it when its hash is created. This creates a ledger of chained blocks that cannot be altered because the information from every block is included in the newest block's hash. And since all transactions are cryptographically signed and can't be altered, records are immutable—so any changes to the ledger can be recognized by the network and rejected.

The ledger is stored across multiple computers, known as nodes, in a network. The distributed nature of the ledger is a fundamental security feature of blockchain technology. No single node has the authority to unilaterally modify or manipulate the ledger, as changes require consensus among the participating nodes. Nodes collectively determine which transactions are valid and in what order they should be included in the ledger. Even if a node is compromised or experiences a failure, the remaining nodes in the network can ensure the continued operation of the blockchain, safeguarding the integrity of the data.

However, the distribution of the ledger introduces challenges. With an increasing volume of transactions, different nodes may record them at slightly different times or in varying orders, potentially resulting in ledger discrepancies. Additionally, in the event of an attack on a node, it is crucial to identify and rectify any false copies of the ledger to maintain data accuracy. This raises the question of determining the authoritative copy of the ledger.

To address these challenges, blockchains employ consensus protocols, which establish a set of rules for nodes to agree on the state of the ledger and achieve consensus on valid transactions. Various consensus mechanisms exist, with proof-of-work and proof-of-stake being the most widely known in the context of blockchain. These mechanisms provide a means for nodes to collectively validate transactions and reach an agreement on the authoritative state of the ledger while providing fault tolerance.

1.1 Proof-of-work (PoW)

Proof-of-work is a consensus mechanism involving a competitive process among computers or nodes to solve a computationally intensive mathematical puzzle. This puzzle aims to establish the legitimacy and order of transactions recorded on the blockchain.

When transactions occur, they go through a validity verification before awaiting in the memory pool until they can be included in a block. Before the mining process can start, transactions have to be aggregated into a candidate block with follows the structure shown in Table 1.1. In order for the block to be considered valid, a miner must discover a solution to the proof-of-work algorithm.

The goal is to find a special value called the "nonce" that, when combined with the block header, produces a hash that is smaller than a specific target. Miners start with a nonce of zero and calculate a hash using the block header. If the resulting hash is smaller than the target, the miner has successfully solved the puzzle. However, if the hash is greater than the target, the miner increments the nonce by

Table 1.1: Structure of the block header

Field	**Description**
Version	A version number to track software/protocol upgrades
Previous Block hash	A reference to the hash of the previous (parent) block in the chain
Merkle Root	A hash of the root of the merkle tree of this block's transactions
Timestamp	The approximate creation time of this block (seconds from Unix Epoch)
Difficulty target	The proof-of-work algorithm difficulty target for this block
Nonce	A counter used for the proof-of-work algorithm (initialized to 0)

1 and tries again. This process outlined in Algorithm 1 is repeated by all miners in the network as they attempt to find the correct nonce that leads to a hash below the target.

Algorithm 1 Proof-of-work

```
function PROOF_OF_WORK(header, target)
    max_nonce ← maximum value of nonce
    for nonce ← 0 to max_nonce do
        hash_result ← calculate SHA-256 hash of (header + nonce)
        if interpret_as_integer(hash_result) < target then
            print "Success with nonce", nonce
            print "Hash is", hash_result
            return (hash_result, nonce)
        end if
    end for
    print "Failed after", max_nonce, "tries"
    return max_nonce
end function
```

The outcome of the hash function cannot be predicted in advance, and there is no way to create a specific hash value using a predefined pattern. This means that the only way to obtain a hash result matching a specific target is through trial and error. Miners modify the input randomly, attempting different nonce values until they chance upon a desired hash result[1].

Example of a proof-of-work

Proof of work requires a computer to randomly engage in hashing functions until it arrives at an output with the correct minimum amount of leading zeroes. The more zeroes required, the smaller the acceptable range of valid hashes will be and the more difficult it will be to find a valid hash.

For example, the hash for block 775,771[2], mined on Feb. 9, 2023, is:

$$00000000000000000003aa2696b1b7248db53a5a7f72d1fd98916c761e954354$$

The block reward for that successful hash was 6.25 BTC and 0.1360 BTC in fees. The nonce was 2,881,347,934, there were 1,519 transactions in the block, and the total value of the block was 1,665.9645 BTC. Remembering that a hash is generated and the nonce starts at zero, this block was hashed by a miner 2.8 billion times before reaching a number less than the target[3].

The node that successfully solves the puzzle first is rewarded with cryptocurrency tokens, specific to the blockchain network, as an incentive for their computational work. Moreover, the node's block containing the verified transactions is considered the authoritative block and is added to the blockchain. Other nodes in the network then validate the winning node's work and replicate the block, ensuring consensus across the network.

After validating and replicating the winning node's block, the remaining nodes gradually continue their attempts to solve the subsequent proof-of-work puzzle, thereby commencing the mining of a new block on the blockchain. Consequently, temporary forks (blockchain splits into two separate branches) can arise, since various nodes may simultaneously be engaged in mining different blocks. Hence, the computing power of the system is not exclusively focused on a specific block.

The process outlined above continues as new transactions accumulate, enabling a secure and transparent recording of transactions on the blockchain.

Proof-of-work consensus mechanisms have been widely adopted due to their ability to maintain the integrity and immutability of the blockchain ledger. However, the computational resources required for solving these puzzles have raised concerns about energy consumption and scalability. As a result, alternative consensus mechanisms, such as proof-of-stake, have emerged to address these challenges.

1.2 Proof-of-stake (PoS)

In a proof-of-stake system, node operators, referred to as "validators," participate in block creation and verification based on the amount of cryptocurrency they "stake" or commit.

In the case of Ethereum, validators are required to deposit 32ETH into a dedicated deposit contract. This stake of cryptocurrency is held securely and cannot be accessed by the validator for an extended period of time. By staking their cryptocurrency, validators demonstrate their commitment to the network and have a vested interest in maintaining its security and integrity.

Instead of relying on computationally intensive puzzles, a proof-of-stake system operates through regular time intervals known as "slots" and "epochs." On the Ethereum blockchain, slots occur every 12 seconds, and epochs consist of 32 slots. During each slot, a validator is randomly selected from the pool of participants and is responsible for creating the next block.

To ensure accountability and prevent malicious behavior, a committee of validators is also randomly chosen to verify the work of the block creator for each slot. This verification process adds an additional layer of security and consensus to the network. Validators who actively participate and fulfill their roles in block creation and verification receive rewards in the form of Ether, the native cryptocurrency of the Ethereum network. Validators who engage in misconduct can face consequences in the form of penalties, leading to a deduction of ether from their balance. Alternatively, more severe measures, such as slashing, may be imposed, which involve forcibly removing the validator from the network, burning a portion of their staked ether, and initiating a period where the validator's stake gradually decreases. These measures were designed to incentivize validators to maintain honest behavior[4].

Proof-of-stake systems have gained popularity due to their scalability and the ability to achieve network consensus without relying on resource-intensive computations. However, they also introduce new challenges related to the distribution of stake, prevention of centralization, and mitigating potential new attacks by malicious actors.

1.3 The Merge

Vitalik Buterin, Ethereum's co-creator, always intended for Ethereum to use proof-of-stake. But when Buterin realized that developing a proof-of-stake algorithm to achieve a meaningfully decentralized system was “non-trivial"[5], the Ethereum community decided to have Ethereum use proof-of-work while they chipped away at the problem. After undergoing extensive iterations and testing of the proof-of-stake consensus protocol, the Ethereum Community launched the Beacon Chain on December 1st, 2020, as a live test to evaluate its viability. The success of this proof-of-concept led to the decision of transitioning Ethereum from a proof-of-work system to a proof-of-stake system by merging the existing transaction history with the Beacon Chain. This significant transition, known as the Merge, occurred on September 15th, 2022, effectively merging the Ethereum Mainnet with the Beacon Chain and completing the conversion to a proof-of-stake system. It resulted in the elimination of energy-intensive mining practices, with the Ethereum network now being secured through the use of staked

Ether. As a result, Ethereum's power consumption decreased by over 99%. Considering that Ethereum previously accounted for 0.2% of global energy consumption, this reduction had a significant impact on a global scale. However, it is worth noting that Ethereum was one of the few blockchains based on proof-of-work that could be profitably mined using GPU (Graphics Processing Unit) computers, rather than specialized ASIC (Application-Specific Integrated Circuit) machines required by blockchains like Bitcoin. Consequently, the shift from proof-of-work to proof-of-stake forced many Ethereum miners to swiftly explore alternative ways to generate revenue from their GPU machines[6].

1.4 Research objectives

The aim of this Bachelor's thesis is to investigate the allocation of computing power previously dedicated to Ethereum mining following the implementation of The Merge. In order to achieve this objective, we explore alternative cryptocurrencies that miners may have transitioned to and analyze their respective hashrates, which involves gaining a deeper understanding of what hashrate is and how it is computed. To accomplish this, we extract data from the blockchains of various currencies to perform a comprehensive hashrate analysis.

By converting the obtained hashrates into equivalent Ethereum hashrates, we can quantify the extent to which Ethereum's computational power has been redirected towards other cryptocurrencies.

Additionally, we explore potential alternative applications for the computational power that was previously employed for mining Ethereum. This exploration provides insights into the possibilities of repurposing mining hardware in a post-Merge crypto environment.

In the subsequent chapters of this thesis, we will delve into the methodology employed for data collection, analysis techniques utilized, and present the findings that contribute to the aforementioned research objectives.

Chapter 2

Data Collection

2.1 Selection of Cryptocurrencies

2.1.1 GPU-mineable coins

Definition 2.1 (ASIC)**.** An application-specific integrated circuit (ASIC) is an integrated circuit chip designed for a specific purpose. An ASIC miner is a computerized device that uses ASICs for the sole purpose of "mining" digital currency. Generally, each ASIC miner is constructed to mine a specific digital currency. Developing and manufacturing ASICs as mining devices is costly and complex. However, because ASICs are built especially for mining a specific cryptocurrency, they do the job faster than less powerful computers[7].

To identify the potential cryptocurrencies to which Ethereum GPUs could have shifted to after The Merge, we examine all proof-of-work currencies at the time of The Merge. It is crucial to exclude cryptocurrencies that are primarily mined using ASIC hardware (e.g. Bitcoin) or CPU (e.g. Monero), as mining them with GPUs would not be economically viable and thus, not an option for miners. Table 2.1 shows all the GPU-mineable coins ordered by their average network hashrate on the day of The Merge (15th Sept.).

Definition 2.2 (Network hashrate)**.** The network hashrate is a measure of the total computational power being utilized by a network to validate and process transactions. It is often characterized as the number of hashes per second performed by the network, expressed in units such as gigahashes per second (Gh/s). The network hashrate represents the collective number of calculations carried out by all participating miners in their pursuit of discovering the correct hash for the candidate block. A higher network hashrate signifies a greater allocation of computational resources to mining activities, resulting in enhanced security for the network[8].

To narrow down the list of potential alternative coins, we focus on the currencies that experienced an increase in network hashrate during the week leading up to The Merge (7th to 15th of September). We exclude coins that show a negative growth rate, indicating a decline in hashrate over the specified period. Then, we narrow down our selection by focusing on coins with a significant network hashrate exceeding 1Gh/s, as illustrated in the upper portion of Table 2.1.

Comparing the magnitude of increases across different coins becomes challenging due the different hashing algorithms. It's important to note that the hashrate achieved with one algorithm, such as Autolykos, cannot be directly compared to another algorithm like Ethash. Each algorithm is uniquely designed, leading to variations in computational requirements. Consequently, certain algorithms inherently involve more computations than others, making the hashrates incomparable. To effectively compare the different hashing algorithms and identify the currencies with the most significant increase, we need to convert all collected hash rates to ethash equivalents.

Table 2.1: GPU-mineable cryptocurrencies

Coin	**Algorithm**	**Block Time (s)**	**Network Hashrate (7th Sep)**	**Network Hashrate (15th Sep)**	**% Increase**
Ethereum	EtHash	13	873.930 Th/s	-	-100%
EthereumClassic	EtcHash	13	49.67 Th/s	307.99 Th/s	520.07%
Ergo	Autolykos	120	26.13 Th/s	149.39 Th/s	471.72%
Kaspa	kHeavyhash	1	75.20 Th/s	95.22 Th/s	26.62%
Ravencoin	KawPow	60	3.83 Th/s	18.82 Th/s	391.38%
Alephium	Blake3	4	35.26 Th/s	17.55 Th/s	-50.23%
Neoxa	KawPow	60	1.91 Th/s	3.75 Th/s	96.34%
Conflux	Octopus	1	835.68 Gh/s	2,530.00 Gh/s	202.75%
EtherGem	Ethash	13	2.25 Gh/s	448.78 Gh/s	19845.78%
Firo	FiroPow	160	91.86 Gh/s	435.00 Gh/s	373.55%
Expanse	Ethash	20	25.63 Gh/s	264.73 Gh/s	932.89%
Sero	ProgPow	13	49.82 Gh/s	182.88 Gh/s	267.08%
Callisto	Ethash	13	71.38 Gh/s	102.22 Gh/s	43.21%
Etho	Ethash	13	4.95 Gh/s	84.45 Gh/s	1606.06%
Ubiq	Ubqhash	20	17.45 Gh/s	83.06 Gh/s	375.99%
Quarkchain	Ethash	60	24.71 Gh/s	82.76 Gh/s	234.93%
Zano	ProgPowZ	60	6.89 Gh/s	16.77 Gh/s	143.40%
Nimiq	Argon2d-NIM	60	1.90 Gh/s	3.97 Gh/s	108.95%
Vertcoin	Verthash	160	1.54 Gh/s	3.57 Gh/s	131.82%
Sinovate	X25X	60	202.27 Mh/s	141.40 Mh/s	-30.09%
BitcoinGold	Zhash	600	1.94 Mh/s	7.87 Mh/s	305.67%
Flux	ZelHash	120	3.51 Mh/s	5.98 Mh/s	70.37%
Conceal	CryptoNightGPU	120	1.50 Mh/s	2.52 Mh/s	68.00%
Ryo	CryptoNightGPU	250	722.11 kh/s	1,640.00 kh/s	127.11%
Beam	BeamHashIII	60	364.56 kh/s	1,480.00 kh/s	305.97%
Equilibria	CryptoNightGPU	120	1.37 Mh/s	1.31 Mh/s	-4.38%
Aion	Equihash (210,9)	10	263.54 kh/s	572.47 kh/s	117.22%
BitcoinZ	Zhash	600	46.29 kh/s	220.61 kh/s	376.58%
Aeternity	CuckooCycle	180	29.18 kh/s	88.18 kh/s	202.19%
Bloc.money	CryptoNightHaven	200	69.82 kh/s	58.85 kh/s	-15.71%
Gemlink	Zhash	60	10.26 kh/s	23.54 kh/s	129.43%
Grin	Cuckatoo32	60	9.23 kh/s	9.75 kh/s	5.63%
Swap	Cuckaroo29s	15	300.00 h/s	941.00 h/s	213.67%
BitTubeCash	CuckooCycle	15	208.00 h/s	507.00 h/s	143.75%

2.1.2 Ethash Conversion Factors

The hashrates generated by different GPUs for a specific algorithm may vary due to differences in their design and processing capabilities. To account for this variability, we consider multiple GPUs that were previously recommended for Ethereum mining[9]. For each GPU, we will determine the hashrate per algorithm and calculate its factor in relation to the ethash hashrate. By averaging the factors calculated for each GPU, we can determine the average factor for a given algorithm.

Since different mining sites may also report slightly different hash rates for a given GPU-algorithm combination, we gather multiple values from various sources (2miners, WhatToMine, CryptoCalc and TheMinerBay). We obtain a representative hash rate for each algorithm on a specific GPU by taking the median value, which is displayed in the respective GPU column of Table 2.2.

Using the ethash hashrate as a baseline, we compute the corresponding conversion factor for each algorithm by dividing its hash rate by the ethash hashrate.

$$ethashfactor = \frac{algorithm\ hashrate}{ethash\ hashrate}$$

This factor represents how the algorithm's hash rate compares to ethash and can be found under the "Ethash factor" column in Table 2.2. Dividing the algorithm's hash rate by this conversion factor allows us to express it as an ethash equivalent, enabling straightforward comparison between algorithms.

We obtain an average conversion factor for each algorithm by repeating this procedure for different GPUs and putting together their values. We can see how much the factors can differ depending on the GPU (see Figures 2.1 and 2.2).

In Table 2.3, we took all these factor values and calculated both the median and maximum conversion factors to provide a representative value as well as a lower bound.

Table 2.2: Computation of ethash factor based on GPU hashrates (MH/s)

Algorithm	Nvidia GTX 1080	Ethash factor	Nvidia RTX 3090	Ethash factor	Nvidia RTX 2080	Ethash factor	Nvidia RTX A5000	Ethash factor	Nvidia GTX 1080Ti	Ethash factor	Nvidia RTX 3060Ti	Ethash factor
Ethash	36.58	-	119.5	-	39.545	-	102.05	-	43.95	-	60.105	-
EtcHash	37.08	1.013669	119.5	1	41	1.036794	102.05	1	51.84	1.179522	60.605	1.008319
Autolykos	62.475	1.7079	266.45	2.258037	79	1.997724	224.11	2.19608	89.135	2.0281	148.5	2.470676
KawPow	16.95	0.463368	48.095	0.410622	27.165	0.686939	42.145	0.412984	23.41	0.532651	30.005	0.49921
kHeavyHash	352	9.622745	995	8.495923	510	12.8967	630	6.173444	480	10.9215	464.91	7.734964
Octopus	10.5	0.287042	94	0.814669	48.8	1.234037	84.5	0.828025	13.6	0.309443	48	0.798602
FiroPow	16.5	0.451066	43	0.387739	23	0.581616	-	-	24.81	0.564505	25	0.415939
Argon2d-NIM	0.3	0.008201	0.95	0.008112	0.45	0.011379	-	-	0.4	0.009101	-	-
ProgPow	14.73	0.402679	47.89	0.408914	21.05	0.532305	26.34	0.258109	21.54	0.490102	25.24	0.419932
Verthash	0.52	0.014215	1.9	0.016223	0.6	0.015173	-	-	0.79	0.017975	1.19	0.019799
Ubqhash	36.09	0.986605	105.95	0.904666	36.83	0.931344	86.6	0.848604	41.01	0.933106	42.49	0.70693
ProgPowZ	-	-	47.7	0.407292	21.6	0.546213	26.4	0.258697	21.52	0.489647	22.91	0.381166
Algorithm	AMD RX 6800	Ethash factor	AMD Radeon VII	Ethash factor	AMD RX 5700XT	Ethash factor	AMD RX 6600XT	Ethash factor	AMD RX 6900XT	Ethash factor	AMD RX 480	Ethash factor
Ethash	36.58	-	119.5	-	39.545	-	102.05	-	43.95	-	60.105	-
EtcHash	63.09	1.001429	97.3	1.015393	54.28	0.986909	32.91	1.018255	63.54	1	27	0.915254
Autolykos	115	1.825397	217.05	2.265067	100	1.818182	61	1.887376	114	1.794145	60.5	2.050847
KawPow	32.7	0.519048	31.5	0.328724	25	0.454545	16	0.49505	32.35	0.509128	12	0.40678
kHeavyHash	730	11.5873	530.5	5.536134	330	6	384	11.88119	960	15.10859	203	6.881356
Octopus	28.695	0.455476	17.325	0.180798	15.5	0.281818	-	-	5.2	0.176271	-	-
FiroPow	32.7	0.519048	37.31	0.389356	23.49	0.427091	15.28	0.472772	33.35	0.524866	12.75	0.432203
ProgPow	22.65	0.359524	29.04	0.303052	14.425	0.262273	12.61	0.390161	32.03	0.504092	9.63	0.326441
Verthash	0.875	0.013889	0.74	0.007722	0.765	0.013909	0.45	0.013923	0.915	0.0144	0.435	0.014746
Ubqhash	58.23	0.924286	86.29	0.900496	49.73	0.904182	29.76	0.920792	58.47	0.920208	25.78	0.873898
ProgPowZ	21.58	0.34254	33.62	0.350848	17.5	0.318182	12.29	0.38026	29.57	0.465376	9.88	0.334915

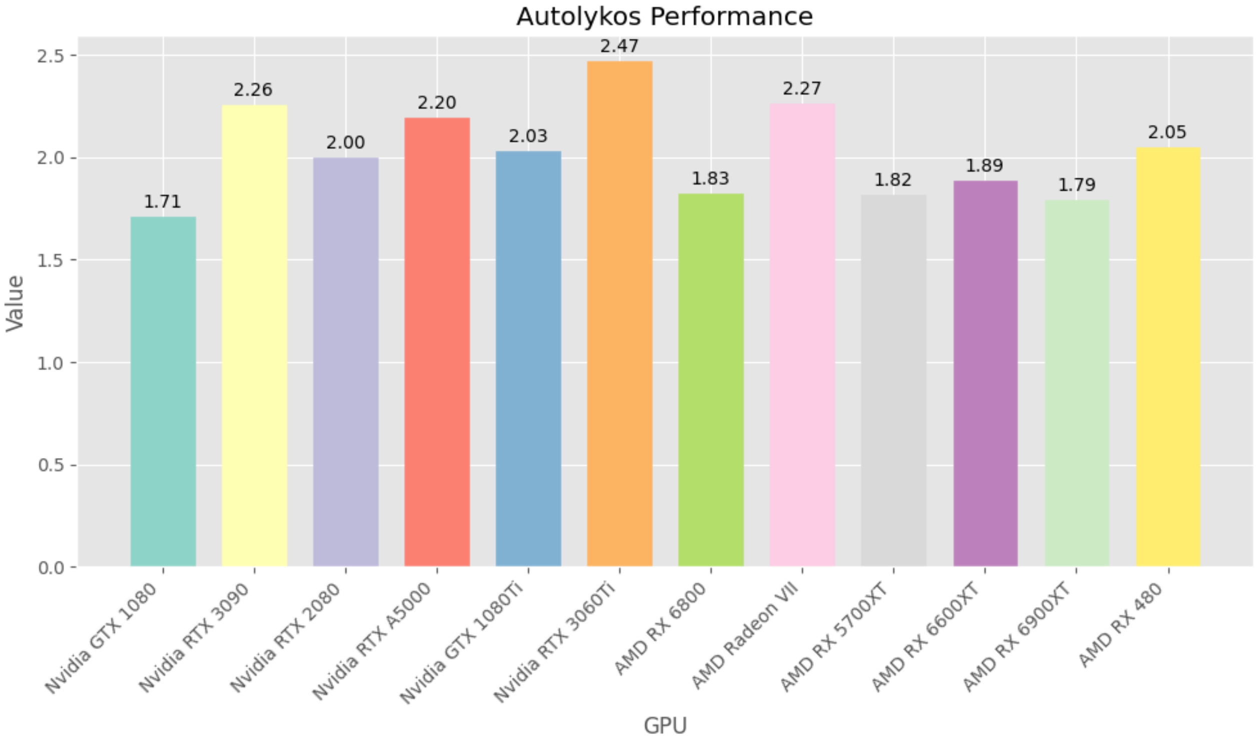

Figure 2.1: Visualization Autolykos factors

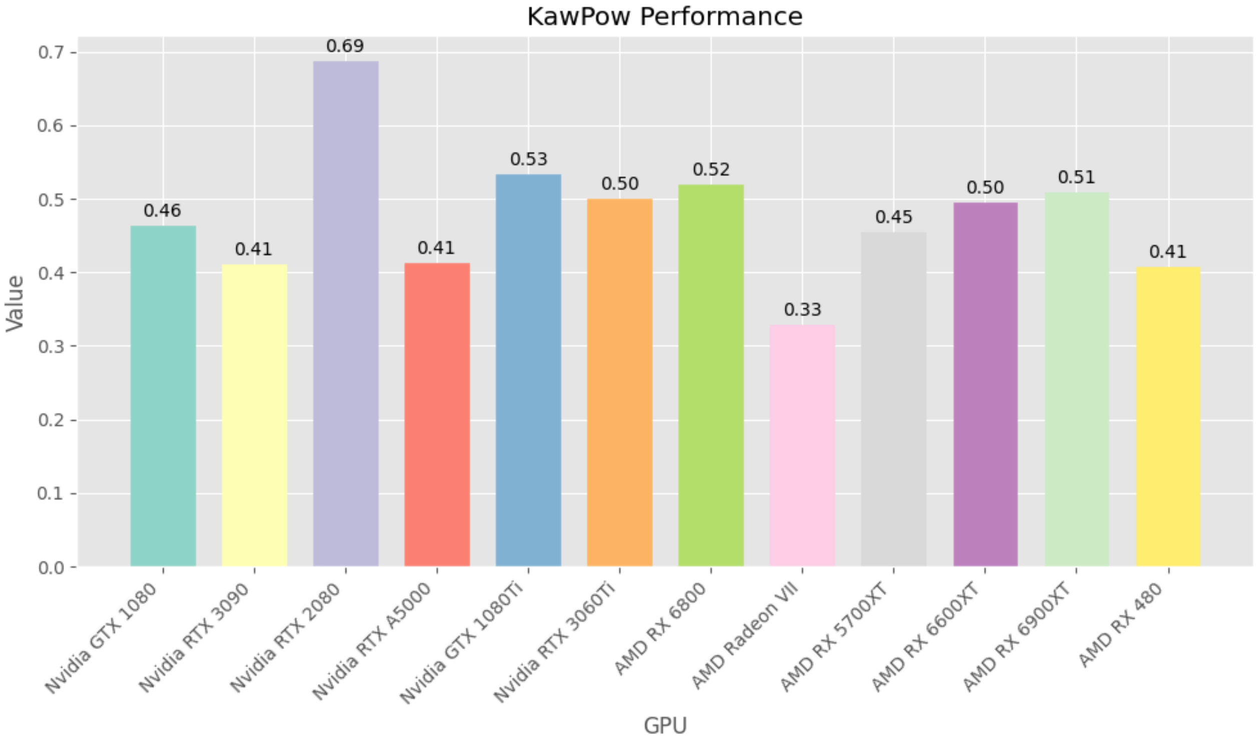

Figure 2.2: Visualization KawPow factors

Table 2.3: Median and Max Ethash factors (rounded to 2 decimals)

Algorithm	Median factor	Max factor
Ethash	-	-
EtcHash	1.00	1.18
Autolykos	2.01	2.47
KawPow	0.48	0.69
kHeavyHash	9.06	15.11
Octopus	0.38	1.23
FiroPow	0.45	0.58
Argon2d-NIM	0.01	0.01
ProgPow	0.40	0.53
Verthash	0.01	0.02
Ubqhash	0.91	0.99
ProgPowZ	0.38	0.55

Table 2.4: Hashrate Increase due to The Merge in Ethash equivalence

Coin	Algorithm	Median Increase in Ethash	Minimum Increase in Ethash
EthereumClassic	EtcHash	258’320	218’915.25
Ergo	Autolykos	61’323.4	49’902.8
Ravencoin	KawPow	31’229.17	21’724.64
EthPOW	Ethash	46’163	46’163
Ethereum Fair	Ethash	5’926	5’926
Neoxa	KawPow	3’833	2’666.67
Conflux	Octopus	4’459.26	1’320.6
Kaspa	kHeavyHash	2’209.7	1’324.95
Firo	FiroPow	762.53	591.6
EtherGem	Ethash	446.53	446.53
Sero	ProgPow	332.65	251.1
Expanse	Ethash	239.1	239.1
Nimiq	Argon2d-NIM	207	207
Vertcoin	Verthash	203	101.5
Etho	Ethash	79.5	79.5
Ubiq	Ubqhash	72.04	66.27
Quarkchain	Ethash	58.05	58.05
Callisto	Ethash	30.84	30.84
Zano	ProgPowZ	25.99	17.96
Total		**415’920.76**	**350’033.36**

2.1.3 Top currencies

Definition 2.3 (Blockchain fork)**.** A fork is a technical phenomenon that occurs when a blockchain splits into two separate branches. These two branches share their transaction history up until the point of the split. From there on, they each go independently each in their own direction[10].

- **Accidental fork:** At any given moment, thousands of miners are competing to create a new block. With so much mining going on at once, two or more miners sometimes mine a new block at the same time. When this happens, an accidental fork is created. The problem is solved when new blocks are added to one of the chains. When that happens, the network continues working on the longer chain and abandons the shorter one.

- **Intentional fork:** When an intentional fork is made, the network doesn't reconverge on a single chain. This type of fork is used by blockchain developers to implement changes to the protocol. For instance, developers may use an intentional fork to increase block size, reduce block time, or even implement an entirely new consensus algorithm. An intentional fork can be hard or soft. The two differ from each other in terms of compatibility with the other chain and their applications.

Utilizing the cryptocurrencies selected from Table 2.1, we convert their respective hash rate increase due to The Merge to ethash-based increases using the conversion factors derived from Table 2.3. This conversion facilitates a direct and standardized comparison of the hash rates.

Additionally, we include two Ethereum-forked coins, Ethereum PoW and Ethereum Fair. These coins commenced mining operations after "The Merge" as a form of resistance against the implementation of Proof-of-Stake by Ethereum and have gained support from certain miners who disagreed with Ethereum's transition. In Table 2.4, we present the converted ethash equivalents for each coin's initial increase, using both the median and maximum conversion factors. By comparing the increases across different coins, we can identify the subset of currencies that account for the majority of the overall hash rate increase. As shown in Figure 2.3, the first five coins listed in the table represent approximately 96.8% of the median increase. Therefore, for the purpose of our analysis, we will focus on these five coins.

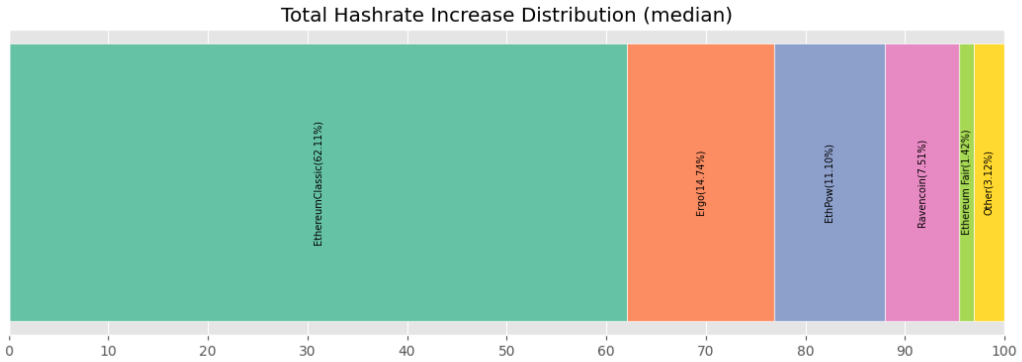

Figure 2.3: Hashrate Increase Distribution

2.2 API Data Collection

To conduct a more in-depth analysis of the selected currencies' hashrate, we extracted data and computed our own hash rates using the respective explorer APIs. Since the hash rate can vary among different mining websites, understanding how it is calculated, the reasons for its variability, and the extent of its variation becomes even more crucial. To get the blockchain data of the selected currencies, we utilized various sources: OKLink explorer for Ethereum Classic, Ethereum PoW, and Ethereum Fair; ErgoPlatform for Ergo; Solus RavenCoin and Explorer for RavenCoin.

To collect the data for each currency, we initially identified the block heights corresponding to September 1st (two weeks prior The Merge) and September 30th (two weeks after). Subsequently, we employed a straightforward process of iterating over the blocks within the specified height range. By making URL calls with the corresponding block height, we successfully obtained the necessary data for our analysis. Table 2.5 presents the extracted data fields from each block of the Ethereum Classic (ETC) blockchain.

Table 2.5: Extracted ETC Block Data

chainFullName	**chainShortName**
Ethereum Classic	ETC

hash
0x2796b50318548d0b6db9639ebd8197ad2ef152768759876cff67a43d8332b052

height	**validator**	**blockTime**	**txnCount**	**amount**	**blockSize**
15849585	unknown		6	23.943804586	1452

mineReward	**totalFee**	**feeSymbol**	**ommerBlock**
2.56022329	0.00022329	ETC	0

merkleRootHash
0x6a20ef95ec56d734e6b35152749ca32d96e38cc16facfef70706dfb183784aca

gasUsed	**gasLimit**	**gasAvgPrice**	**state**	**burnt**	**netWork**	**txnInternal**
223290	8015630	0				

miner	**difficulty**	**nonce**
0x54286566de3b4e14998b27587475334608a7eb97	59847763503655	ac8d050f423cc008

tips	**confirm**	**baseFeePerGas**	**timestamp**
	1738910		1661983207000

Chapter 3

Data Processing

3.1 Hashrate theory

Hashrate refers to the computational power used in cryptocurrency mining. It represents the number of calculations or guesses per second a miner can make to solve a cryptographic puzzle and add a new block to the blockchain network.

3.1.1 Hashrate types

To analyze hashrate, it's essential to understand different types and their distinctions[11].

Definition 3.1 (Network actual hashrate)**.** The network actual hashrate refers to the true measure of the combined computational power contributed by all active miners within a network. However, accurately determining the precise value of the network's actual hashrate is challenging due to the fact that miners often work on different blocks, leading to unintentional forks that are difficult to track.

Definition 3.2 (Network effective hashrate)**.** The network effective hashrate represents the computational power that was utilized in successfully adding blocks to the blockchain. In other words, it pertains to the hashrate of blocks that were deemed effective and incorporated into the blockchain. This value, which we will refer to as the network hashrate, is estimated based on factors such as block pace and difficulty target, although alternative approximations can also be employed.

3.1.2 The link between network hashrate, difficulty, and block time

Block time

Each cryptocurrency has a "block time" parameter, indicating the time it ideally takes to find a new block. The network strives to maintain a steady block time regardless of the number of miners connecting to the network.

Definition 3.3 (Expected blocktime)**.** The expected block time is set at a constant value to control the issuance of new coins and to make sure miners cannot impact the security of the network by adding more computational power.

Definition 3.4 (Average blocktime)**.** The average block time of the network is evaluated after n number of blocks, and if it is greater than the expected block time, then the difficulty level of the proof of work algorithm is reduced, and if it is less than the expected block time then the difficulty level is increased[12].

In Figure 3.1, we observe that, before The Merge, ETC's average block time consistently aligns with the expected 13-second block time. However, as The Merge happens, increased miner participation to the network accelerates block discovery temporarily, resulting in a lower block time. As the network adjusts its difficulty, the block time gradually returns to a level closer to the expected value, maintaining network stability.

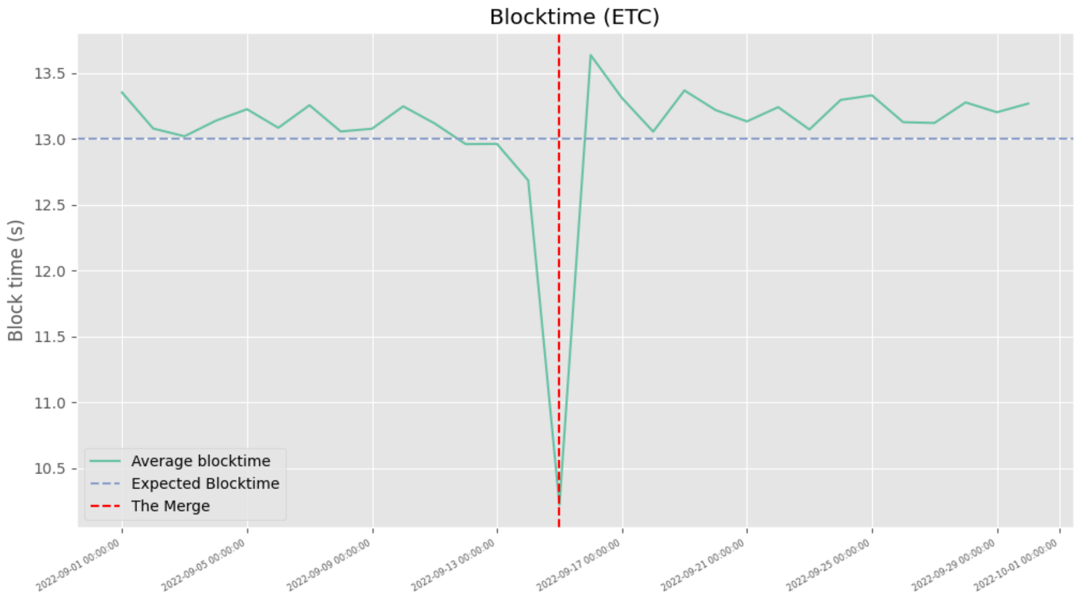

Figure 3.1: ETC average vs expected block time

Difficulty

The difficulty of a system refers to the level of complexity involved in the task that miners need to solve in order to create a block. In this context, complexity refers to the average number of attempts made by miners to find a cryptographic hash value that is either equal to or lower than the target hash value. The difficulty is used to establish the target hash value, which is obtained by inputting the difficulty into a specific mathematical formula and converting it into a hexadecimal number.

The difficulty adjusts based on the network hashrate. If there are few miners, the difficulty decreases, allowing for more frequent block finds. Conversely, with a high number of miners, the difficulty increases, making it harder for an individual miner to find a block.

The purpose of difficulty is to regulate the rate of coin issuance and maintain consistent block confirmation intervals over time. When the value of a cryptocurrency increases on exchanges, the block reward in US dollars also rises, attracting more miners to join and increasing the network hashrate. Consequently, the difficulty must be adjusted higher to maintain the desired block time. The frequency of difficulty adjustments varies depending on the currency (for example Bitcoin, every 2016 blocks)[13].

3.2 Hashrate Computation

The network hashrate of a cryptocurrency is typically determined by the current network difficulty and the average block find time as defined by the cryptocurrency network. The network difficulty is adjusted dynamically to maintain a target block time according to the current network hashrate. The relationship between difficulty, network hashrate, and block time is given by the formula[14]:

$$difficulty/nethash = blocktime$$

Having retrieved the difficulty and average block time for the selected coins, we can estimate the network hashrate using the formula: $nethash = \frac{difficulty}{blocktime}$ While this computation serves as the "base" calculation, some coins may incorporate an additional factor. For instance, Ravencoin's hashrate computation uses the following factor: $nethash = \frac{difficulty \cdot 4'295'032'833}{blocktime}$.

The computation of hashrates was carried out using different approaches. These methods are outlined below, along with an example showcasing the computation for Ethereum Classic. Additional plots demonstrating the results for other cryptocurrencies can be found in the appendix (see Appendix A).

Definition 3.5 (Expected network hashrate)**.** The expected network hashrate is computed based on the expected block time (indicated for each currency in Table 2.1).

$$expected\ nethash = \frac{difficulty}{expected\ blocktime}$$

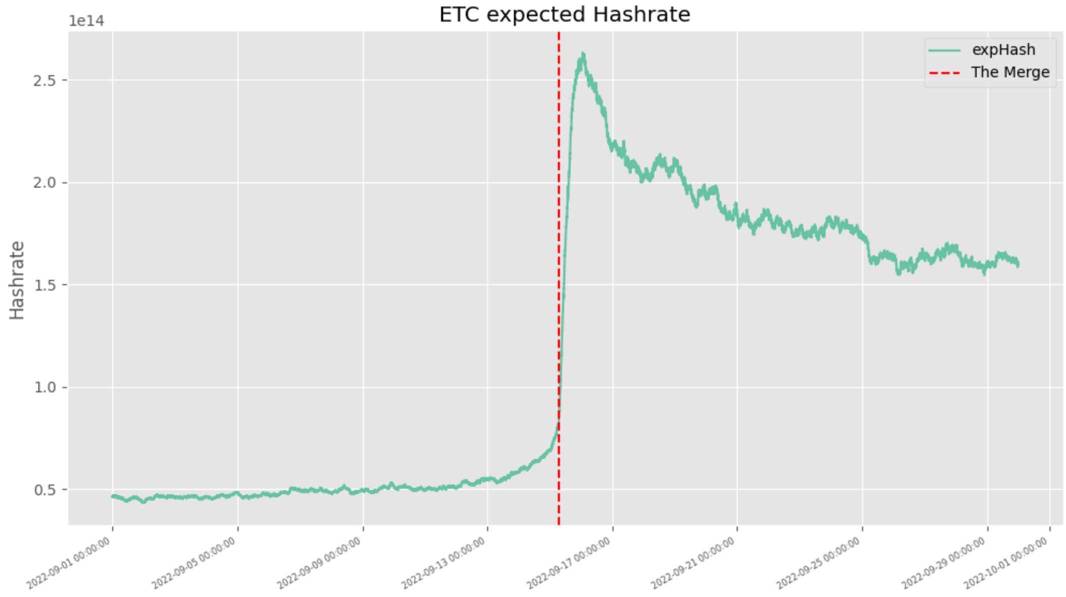

Figure 3.2: ETC expected hashrate

Definition 3.6 (Averaged network hashrate)**.** The averaged network hashrate is calculated using the averaged block time, which is evaluated over different block intervals, including 50, 100, 200, and 500 blocks.

$$expected\ nethash = \frac{difficulty}{averaged\ blocktime}$$

3.3 Hashrate comparison

In order to verify our computational process for determining hashrates, we sought to cross-reference our results by obtaining hashrate data from external sources. We retrieved the relevant information, including the hashrate data and the corresponding block time data, from the 2miners and MiningPoolStats website's source code which were subsequently converted into a JSON file.

In the presented figures (Figures 3.4, 3.5, and 3.6), it is evident that there are disparities in the hashrate measurements between 2miners and MiningPoolStats. Although the variations observed are relatively similar in the cases of Ethereum Classic (ETC) and Ergo (ERG), they are not identical. Conversely, in the case of Raven Coin (RVN), while MiningPoolStats initially demonstrates a comparable hashrate to other measurement sources before The Merge, as the network's hashrate increases, it deviates significantly from all other recorded hashrate values, including those reported by 2miners. Consequently, it is apparent that there are discrepancies in the calculation of hashrates among official mining websites.

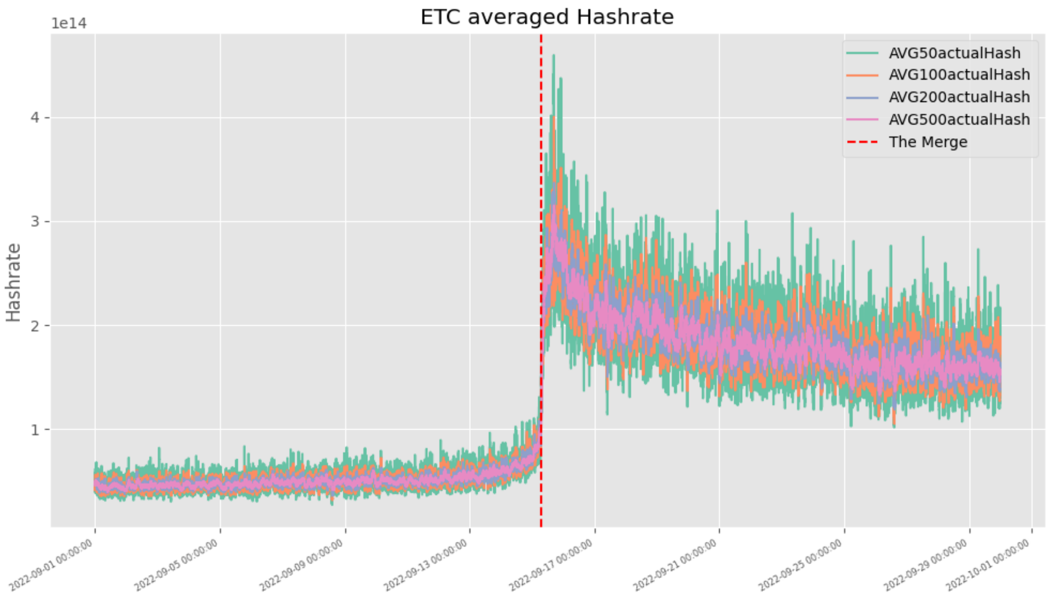

Figure 3.3: ETC averaged hashrate (50, 100, 200, 500 last blocks)

Upon analyzing our own hashrate computations, it becomes apparent that the averaged hashrate provides a more accurate estimation compared to the expected hashrate. This observation is logical, considering that the expected hashrate relies on the assumption that the expected block time is consistently adhered to. However, as depicted in Figure 3.1, practical evidence reveals that the expected block time is not consistently met, thereby rendering the expected hashrate an imperfect reflection of reality.

Next, we want to look in more detail which average seems to be the best. For that, we look closer and observe the week after The Merge.

In our analysis, it appears that the method we employed to compute the averaged hashrate aligns more closely with the approach used by 2miners rather than MiningPoolStats. As indicated in Appendix section A.6, except for Ergo, the hashrates reported by MiningPoolStats consistently appear higher than those from other sources. One plausible hypothesis to explain this discrepancy is that MiningPoolStats may account for forks, wherein miners actively mine blocks that ultimately do not become part of the blockchain.

The accuracy of our average hashrates in relation to the 2miners data seems to be influenced by the fluctuation in the network hashrate. For instance, in the ETC plot (Figure 3.7), on the day of The Merge when substantial hashrate fluctuations occurred, the 50-block average demonstrated closer alignment with the 2miners data. This can be expected since a shorter average responds more quickly to changes in the hashrate. Later, on the 17th and 18th, when the hashrate exhibited less variation, the 500-block average displayed a stronger resemblance to the 2miners results. Regarding the ERG plot (Figure 3.8), it consistently showed that the 100-block average was the closest to the 2miners data. Lastly, the RVN plot (3.9) demonstrated oscillations between the 100-, 200-, and 500-block averages.

In conclusion, determining the network hashrate entails various calculation methods, and there is no universally accepted formula that is uniformly utilized. For the purpose of our subsequent findings, we have opted to employ the average hashrate over a span of 500 blocks. This approach minimizes fluctuations and provides a more conservative estimate.

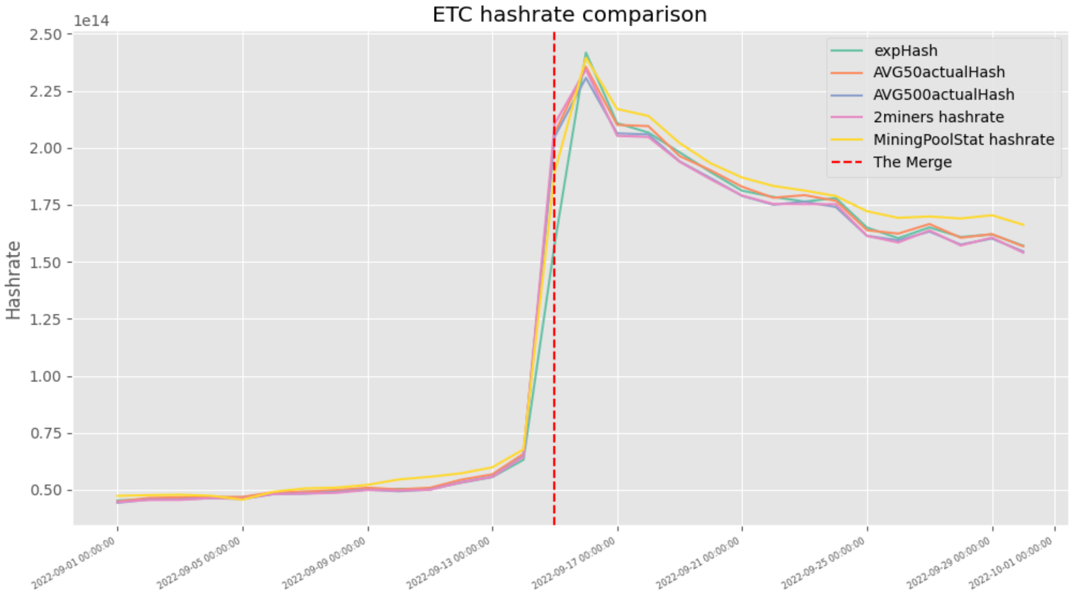

Figure 3.4: ETC hashrate comparison

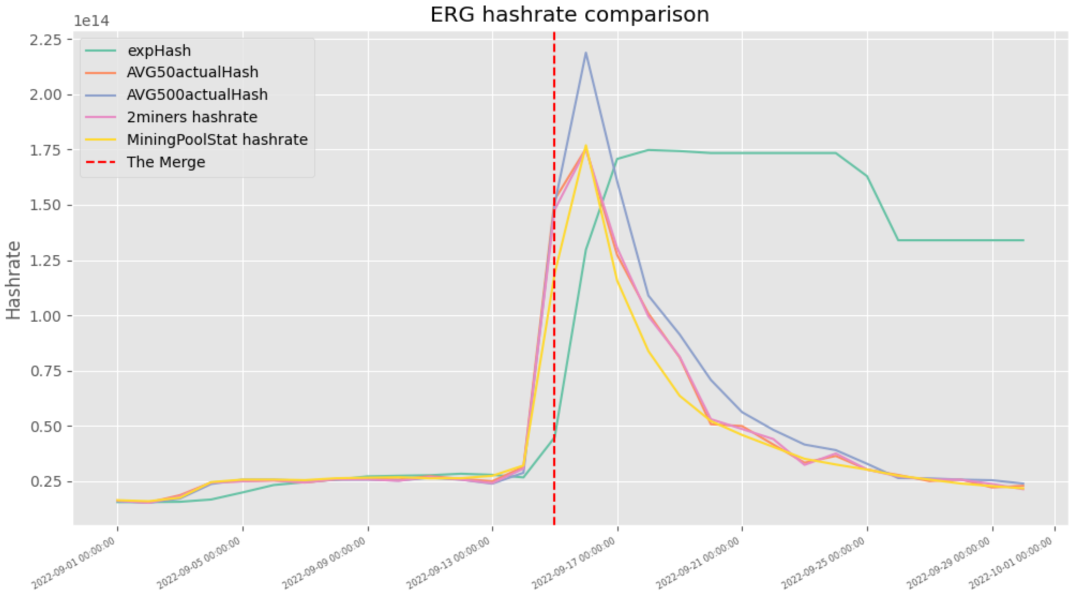

Figure 3.5: ERG hashrate comparison

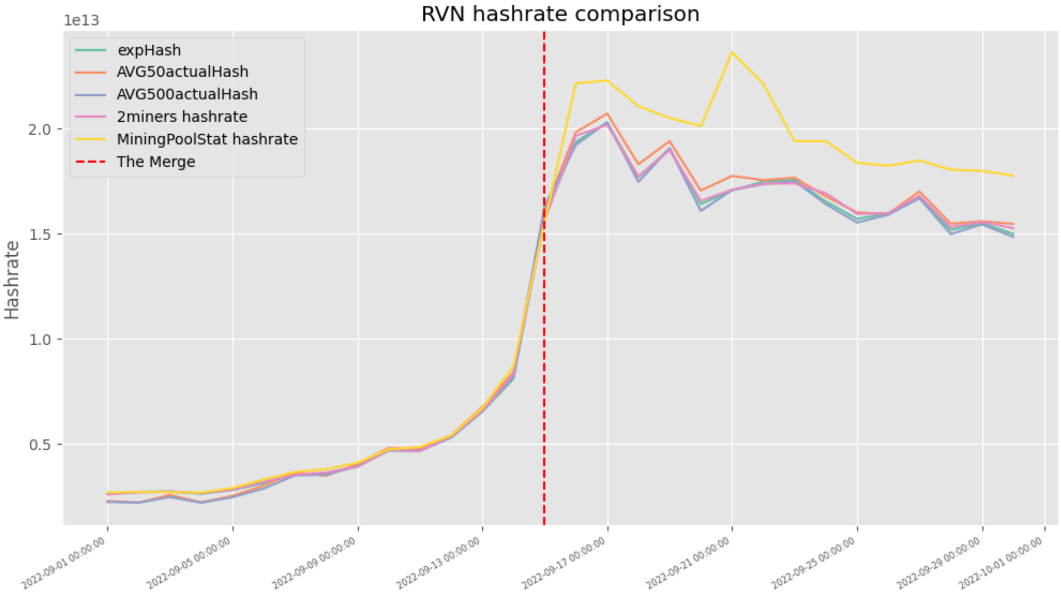

Figure 3.6: RVN hashrate comparison

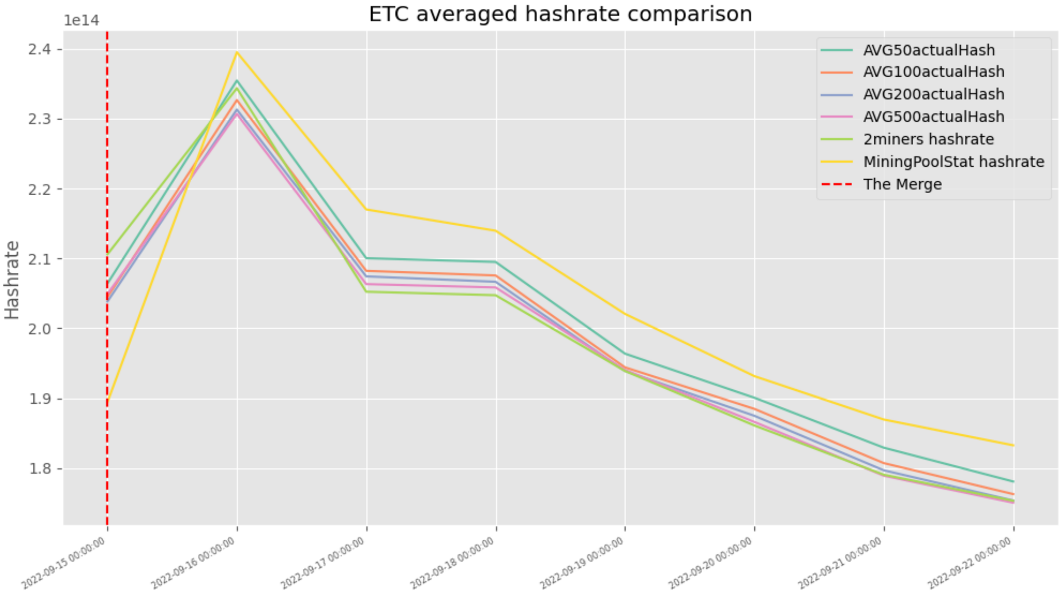

Figure 3.7: ETC averaged hashrate comparison

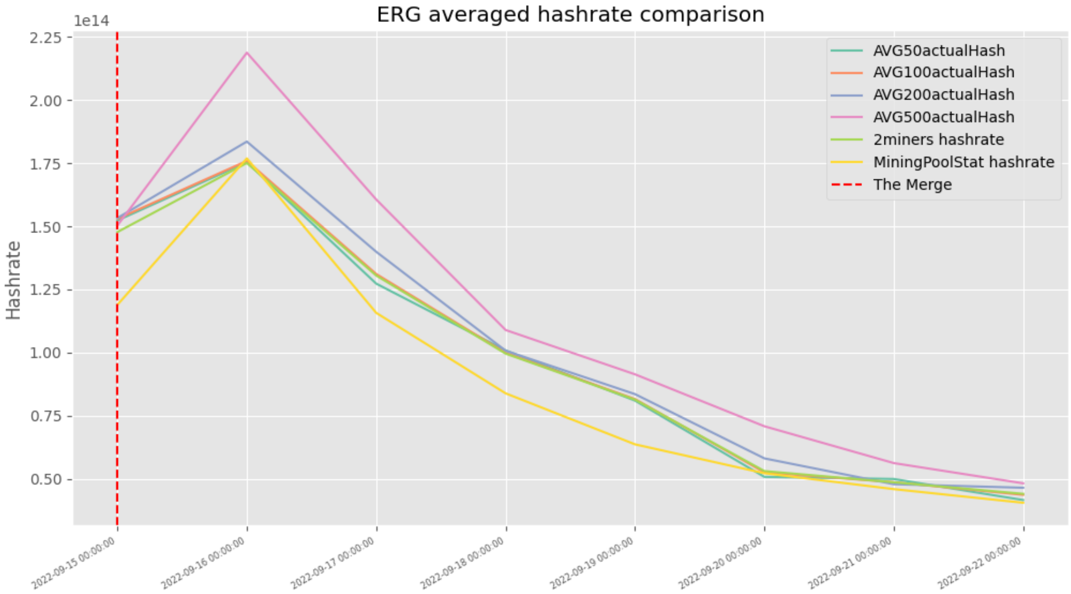

Figure 3.8: ERG averaged hashrate comparison

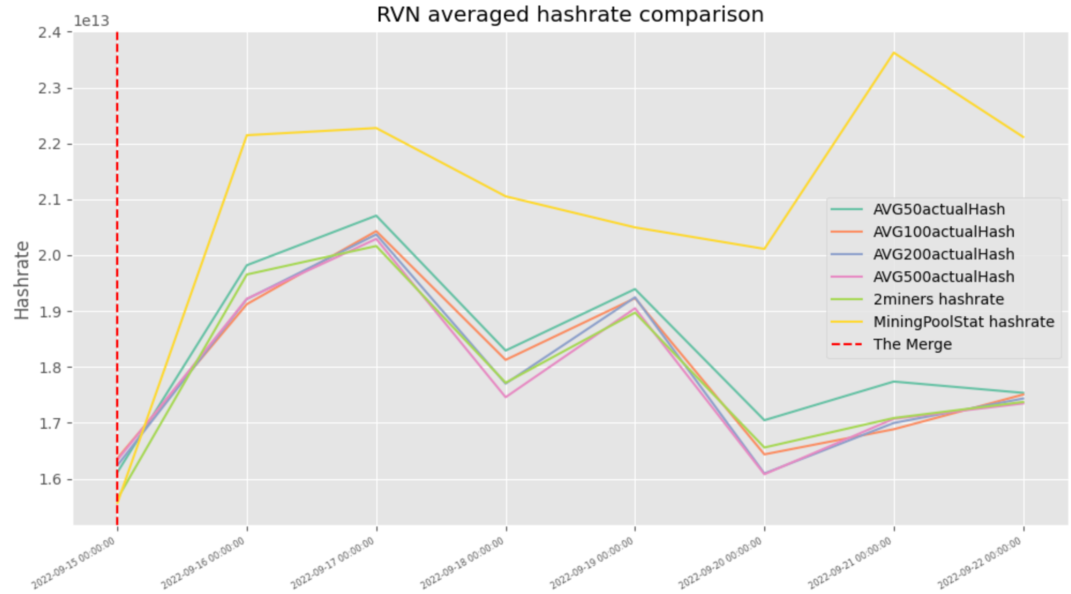

Figure 3.9: RVN averaged hashrate comparison

CHAPTER 4

Results

After deciding upon the chosen method for measuring hashrate (average hashrate over the last 500 blocks), we can now convert each hashrate into its equivalent in the ethash algorithm. This conversion allows us to compare the network hashrate of different cryptocurrencies. We calculate two different hashrates for each currency: one using the median factor and another using the maximum factor (lower bound) as indicated in Table 2.2. By applying these factors, we determine the relative computational power consumed by each currency compared to Ethereum.

To present the distribution of computational power, we created a stacked chart that displays the hashrates of Ethereum and the five other cryptocurrencies for which we have obtained data. This chart enables us to visualize the cumulative computational power absorbed by these currencies in relation to Ethereum. The first chart represents the median increase, while the second chart represents the minimum increase (lower bound).

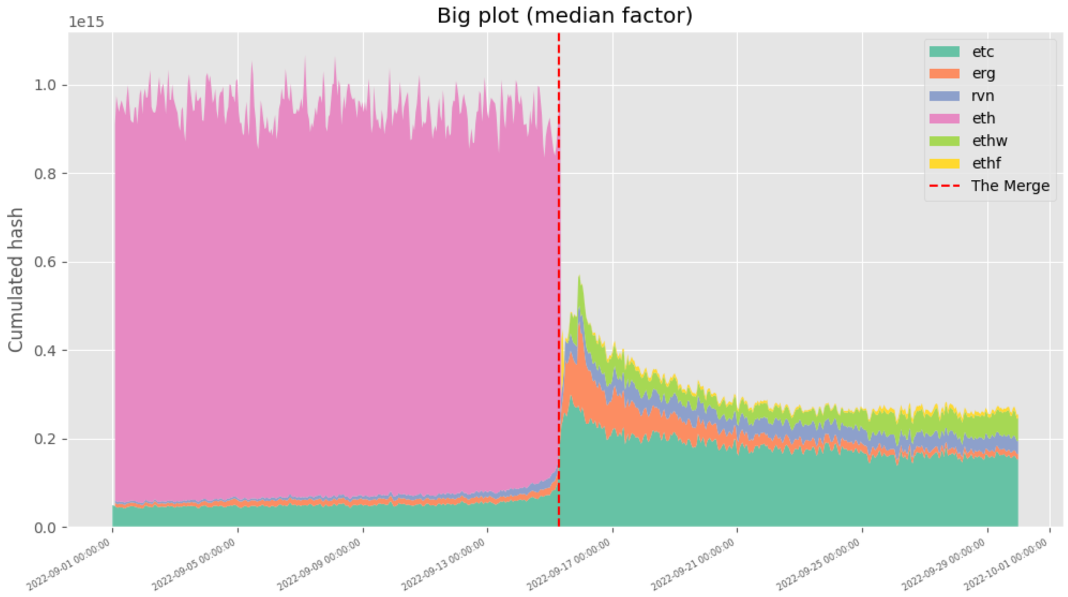

Figure 4.1: Cumulated hashrates in term of ethash equivalent (using median factor)

In Figure 4.1, we can observe that during the peak of the cumulative hashrate after The Merge, the combined hashrate of the top five coins accounted for 96.8% of the overall increase. This indicates that these coins acquired a significant portion of Ethereum's computing power, almost half of it. This finding is further supported by Table 4.1, where it is shown that the cumulative increase in hashrate represents 53.43% of Ethereum's total hashrate just before The Merge. Among the selected coins, ETC absorbed the largest share at 27.79%, followed by ERG at 12.67% and Ethereum Proof-of-Work (ETHW) at 7.51%.

However, over time, we observe a decline in the cumulative hashrate, suggesting that many miners

Table 4.1: Cumulated hashrates in percentage (using median factor)

Date	ETC	ERG	RVN	ETHW	ETHF	Total
2022-09-15	24.62	8.91	4.03	5.27	1.73	44.56
2022-09-16	27.79	12.67	4.89	7.51	0.57	53.43
2022-09-17	24.89	9.44	5.04	5.58	0.92	45.87
2022-09-18	24.82	6.48	4.37	4.71	0.91	41.29
2022-09-19	23.39	5.43	4.79	3.74	0.84	38.19
2022-09-20	22.50	4.21	4.07	3.79	0.67	35.23
2022-09-21	21.57	3.37	4.29	3.86	0.63	33.71
2022-09-22	21.11	2.87	4.34	3.50	0.58	32.40
2022-09-23	21.25	2.50	4.34	3.73	0.36	32.17
2022-09-24	20.99	2.33	4.20	4.09	0.38	31.98
2022-09-25	19.45	1.99	3.94	5.63	0.84	31.85
2022-09-26	19.21	1.58	3.98	5.77	1.19	31.73
2022-09-27	19.70	1.58	4.19	5.66	1.15	32.27
2022-09-28	18.99	1.54	3.78	5.89	1.03	31.23
2022-09-29	19.33	1.52	3.90	6.22	0.92	31.90

may have realized the lack of profitability. Two weeks after The Merge, it is estimated that approximately one-third (31.9%) of Ethereum's original hashrate has been taken over by the aforementioned five coins. These five coins account for 96.8% of the total increase in computational power observed in other proof-of-work currencies after The Merge. Consequently, we can infer that by the end of September, approximately 33% of Ethereum's hashrate has been taken over.

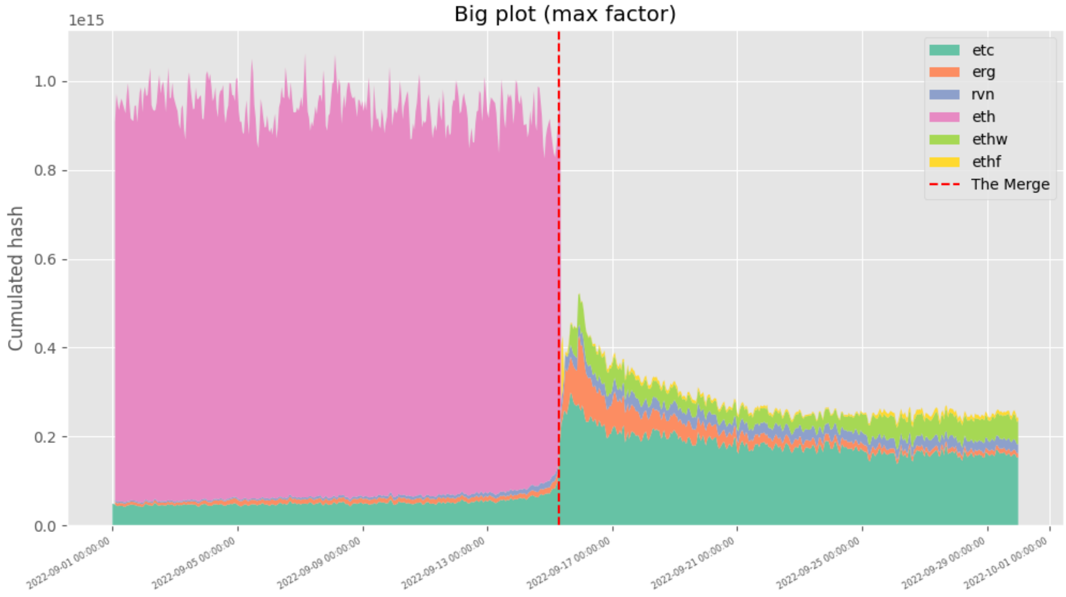

Figure 4.2: Cumulated hashrates in term of ethash equivalent (using max factor)

The disparity between the median and minimum increase is relatively small as the last column of Table 4.2 shows. We can see that, immediately after The Merge, the acquired computational power amounted to nearly half, with a percentage of 49.59%. After two weeks, this percentage decreased to approximately one-third (30.43%).

Table 4.2: Cumulated hashrates in percentage (using maximum factor)

Date	**ETC**	**ERG**	**RVN**	**ETHW**	**ETHF**	**Total**	**Difference median**
2022-09-15	24.62	7.25	2.80	5.27	1.73	41.68	-6.46%
2022-09-16	27.79	10.31	3.40	7.51	0.57	49.59	-7.19%
2022-09-17	24.89	7.68	3.51	5.58	0.92	42.57	-7.19%
2022-09-18	24.82	5.27	3.04	4.71	0.91	38.75	-6.15%
2022-09-19	23.39	4.42	3.33	3.74	0.84	35.72	-6.47%
2022-09-20	22.50	3.42	2.83	3.79	0.67	33.21	-5.73%
2022-09-21	21.57	2.74	2.98	3.86	0.63	31.78	-5.73%
2022-09-22	21.11	2.33	3.02	3.50	0.58	30.55	-5.71%
2022-09-23	21.25	2.04	3.02	3.73	0.36	30.39	-5.33%
2022-09-24	20.99	1.90	2.92	4.09	0.38	30.27	-5.35%
2022-09-25	19.45	1.62	2.74	5.63	0.84	30.29	-4.9%
2022-09-26	19.21	1.29	2.77	5.77	1.19	30.22	-4.76%
2022-09-27	19.70	1.28	2.91	5.66	1.15	30.70	-4.87%
2022-09-28	18.99	1.25	2.63	5.89	1.03	29.79	-4.61%
2022-09-29	19.33	1.24	2.71	6.22	0.92	30.43	-4.61%

Chapter 5

Discussion

5.1 Where did the rest go?

Based on our research, we have discovered that approximately 30% of Ethereum's computational power has been redirected towards other proof-of-work cryptocurrencies. However, this leaves the remaining 70% of computational resources to be examined. We conduct separate investigations for mining companies and individual miners, as their assets and infrastructure vary significantly. Consequently, it is likely that these two groups employed different strategies concerning their mining activities.

5.1.1 Mining Companies

Certain mining companies experienced significant losses, primarily due to the devaluation of their hardware investments, which amounted to more than hundred millions of dollars[15]. Hut 8 Mining and Hive Blockchain Technologies, once prominent Ethereum mining companies, have had to reassess their strategies and make critical decisions about their future.

Hut 8's response

Hut 8 Mining, a well-known participant in the Bitcoin and Ethereum mining sector, has acknowledged the impact of The Merge on its Ether mining operations. To adapt to the changing landscape, the company claims that they are actively exploring opportunities to repurpose its Ether mining machines and optimize its ASIC deployments at its Bitcoin mining sites. By increasing its hashrate, Hut 8 aims to maintain its competitiveness in the dynamic crypto mining industry.

As part of its strategy, Hut 8 has announed its plan to repurpose its primary data center in Canada, which was previously used for Ether mining with 180 Nvidia GPUs. The company intends to utilize this facility for offering services related to artificial intelligence, machine learning, and VFX rendering. This decision enables Hut 8 to diversify its sources of revenue and cater to the growing demand for high-performance computing. In February 2023, the company successfully launched purpose-built data center infrastructure, cloud computing services, and Dynamic High-Performance Computing infrastructure. These offerings are designed to support businesses across various sectors such as visual effects, the metaverse, machine learning, and AI[16, 17, 18].

HIVE's response

It is estimated that Hive lost around 40% of its revenue due to The Merge. To compensate for the loss, Hive decided to repurpose its Ethereum mining facilities for BTC mining. By February 2023, the company increased its Bitcoin mining capacity from 2.8 EH/s to 3.3 EH/s [19, 20].

In addition, Hive highlighted its focus on "high performance computing" (HPC) and artificial intelligence (AI). The company stated that its HPC strategy is experiencing rapid month-over-month growth, and it has the potential to increase 10 times over the next year. Hive believes there is a strong demand for its high-quality chips in various AI projects such as Chat GPT, medical research, machine learning, and rendering. Hive plans to launch the "HIVE Performance Cloud" in the second quarter of 2023. A proof-of-concept test using Hive's GPU fleet showed promising results, generating over $1 million in annualized revenues from high-performance computing workloads. The company claims that HPC is approximately 25 times more profitable than Bitcoin mining based on dollar per MWHR (megawatt-hour) basis. However, it should be noted that Hive will face stiff competition from major industry players like Amazon's AWS, Microsoft's Azure, and Google's Cloud, as well as other dedicated competitors. The true value and advantage of Hive's GPU fleet in the AI market will become clearer once operational results from the HIVE Cloud are available[21].

Furthermore, Hive mentioned its involvement in balancing the electrical grid and reselling excess energy.

Mining companies making decisions about their future

The main strategies engaged by mining companies in response to the impact of The Merge include repurposing mining hardware for alternative uses, such as artificial intelligence (AI) and high-performance computing (HPC) and exploring new opportunities in other cryptocurrencies like Bitcoin.

One of the challenges for mining companies venturing into the high-performance computing domain is the competition they face from major data service providers such as Microsoft Azure and Amazon Web Services. These platforms already have well-established tooling systems and dedicated support staff available for their AI clients. However, mining companies can leverage their expertise in energy management, which gives them a competitive advantage. AI, like crypto mining, is highly energy-intensive[22], and the experience gained from mining operations can be applied to optimize energy usage in AI applications.

In contrast to the all-encompassing nature of massive cloud computing platforms, mining companies can focus on providing flexible and cost-effective GPU cloud computing solutions specifically tailored for the startup community. This presents an opportunity for mining companies to carve out a niche in the HPC market by offering specialized and accessible GPU cloud computing services[23].

5.1.2 Private Miners

To gain insights into the actions taken by miners after the transition to PoS, we delved into numerous posts on Reddit and collected testimonials that shed light on their reactions and strategies before, during and after The Merge[24, 25, 26].

Before the Merge

@cyberspacedweller, Apr 14, 2022 *"It's been "around 6 months time" since what, 2016? Every time it gets within a few months, it's "merge delayed. Will be a few more months... maybe"."*

@Jasquirtin, Apr 14, 2022 *"I sold late January for maximum profits and I can't believe I actually timed something so well. Just in time to get 3.2k on cards I paid 4k for that mines be about 2.5 ETH and to avoid the summer heat and high rising power cost. I'm quite happy I sold. Now cards are dropping and I've thought of getting a couple to put in my gaming rig but decided against cause of LHR"*

During the Merge

@MoarWhisky, Sep 23, 2022 *"GPU mining for profit is dead right now. That doesn't mean it's dead forever, but not all of us mine for pure profit. I heat my shop with rigs in the winter time. My GPUs have all paid for themselves. I'll be bringing them all online this winter for nothing other than cheap heat. Even at negative profit it's cheaper to use as a heat source than propane. It's also a lot more fun!*

I personally love maintaining the rigs and tweaking things when needed. I'll probably add more cards as prices plummet."

@mecca666, Sep 23, 2022 *"The time to liquidate was 6-9 months ago. If you are left with cards now, you had no idea about what was coming."*

@SpeedRacer *"I thought GPU mining profits were going to get lower, but not negative across the board like that."*

@AffectionateAd6009 *"It's only going to get tougher in the upcoming months. With winter coming I foresee many, myself included, still running GPUs for heat, even if not profitable because it is still cheaper than running a traditional heater."*

@unknown *"I am shutting down my rigs tomorrow. I used to mine on hive pool; now, I am looking for a new pool to mine Ergo and Raven."*

After the Merge

@unknown, Jan 23, 2023 *"Sold off my GPUs in late 2021 and staked all my mining profits into Eth 2.0. I may have jumped the mining ship early but I made it up selling GPUs during a shortage."*

@HonestDrilling, Jan 23, 2023 *"I was baffled by how many miners bought GPUs near the ATH only to dump them on the market for pennies during or after the merge. Did they believe in the Merge will be delayed further? Or that ETHW will win?"*

@Simple-Nobody6857, Jan 22, 2023 *"Well, eth going away + the bear market + sky rocketing energy prices put home miners like myself in a difficult spot. Most people have shut off their rigs waiting for prices to go up on the other mineable coins. Others have sold their gpus and some mine at a loss. Few people have free power and grind away."*

@0xNefu, Jan 23, 2023 *"i sold my equipment 30k worth and bought eth and staked"*

@LorenStecklein, Jan 23, 2023 *"selling GPUS and starting staking"*

Interestingly, many miners seemed unprepared for the implementation of The Merge. This lack of preparedness can be attributed to the multiple delays and uncertainties surrounding the transition, as discussed in an article published three months before The Merge: "The Merge is expected to take place in August, though no official date has been given. It's already been pushed back multiple times, and many miners hope that'll happen again. 'I don't think they're going to be able to pull it off' anytime soon," says Aydin Kilic, Chief Operating Officer at Hive, an industrial Ethereum miner. However, other individuals involved with Ethereum view The Merge as inevitable. Tim Beiko, a computer scientist coordinating Ethereum developers, states that the odds of it not happening this year are very low, ranging from 1% to 10%[27]."

Miners who did not anticipate The Merge typically continued mining until the very end to maximize their returns and recoup their equipment investments. Testimonials reveal that these miners attempted to switch to other coins, mining multiple cryptocurrencies simultaneously in an effort to remain profitable. Despite their efforts, mining alternative coins proved less lucrative than Ethereum. Consequently, many miners found themselves waiting for the next profitable opportunity post-Merge, utilizing their GPUs to heat their homes during winter. Selling mining equipment after The Merge was generally not profitable, as the portion of miners who foresaw the transition to PoS had already begun selling their equipment in early 2022, driving prices down as we can see in Figure 5.1 and 5.2.

Despite the lower resale prices, most miners chose to sell their equipment to acquire ether (ETH) and participate in staking, allowing them to continue earning profits through Ethereum's PoS consensus mechanism.

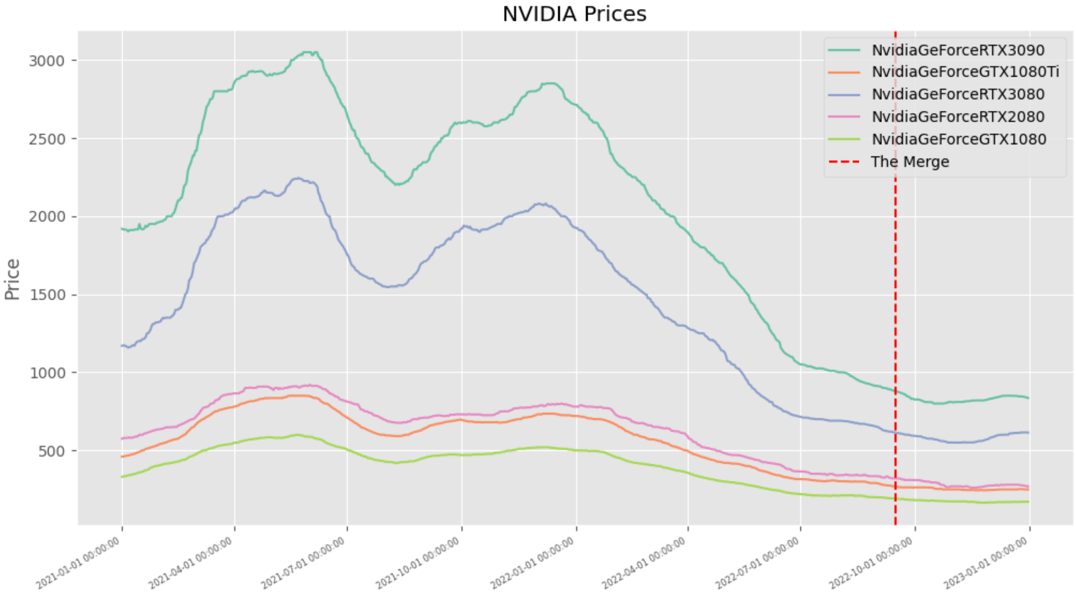

Figure 5.1: Nvidia GPU resale price (2021 - 2022)

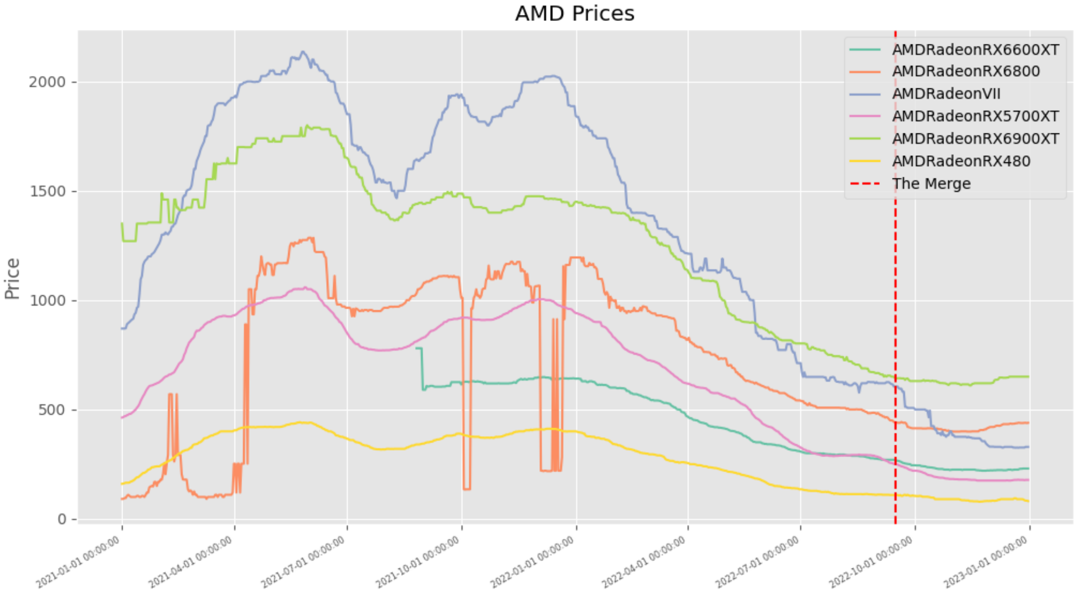

Figure 5.2: AMD GPU resale price (2021 - 2022)

5.1.3 Strategies for GPU Utilization after the PoW to PoS Transition

The transition from Proof of Work (PoW) to Proof of Stake (PoS) in Ethereum had a significant impact on Ethereum miners, forcing them to adapt and find new ways to utilize their GPU machines. This shift affected public miners like Hut 8 Mining (HUT) and HIVE Blockchain (HIVE), who relied on

GPUs in their mining operations, and private miners whose equipment became less profitable. Here the various options that miners pursued with their GPUs:

- **Switching currencies**: A considerable portion, approximately 30% of the computing power used for mining Ethereum, was redirected towards mining other cryptocurrencies. Miners explored alternative coins that still relied on PoW consensus algorithms, aiming to maintain profitability with their existing GPU infrastructure.
- **Selling GPUs**: Some miners chose to sell their GPUs on the market. Some sold early for good prices, while others missed out. Many miners used the proceeds to buy Ether and participate in staking, aiming to continue profiting from the crypto market.
- **Heating homes**: Interestingly, a creative solution emerged where miners repurposed their GPUs to generate heat for their homes during colder seasons. By harnessing the high energy consumption of mining rigs, they could effectively utilize the excess heat generated as a byproduct, thereby offsetting heating costs.
- **Waiting for more profitable coins to mine**: With the cryptocurrency market being highly dynamic, some miners opted to hold onto their GPUs and wait for new cryptocurrencies or mining algorithms that could offer higher profitability in the future. This approach allowed them to remain prepared for potential shifts in the market landscape.
- **Repurposing GPUs**: Miners, especially those with significant equipment resources like public mining companies, actively sought new applications for their GPUs outside of cryptocurrency mining. These versatile graphics cards can be repurposed for tasks such as rendering, high-power computing, or even gaming. By exploring other industries that require GPU-intensive processes, miners aimed to leverage their existing hardware investments effectively.

Chapter 6

Conclusion

The purpose of this thesis was to investigate what happened to the computational power that was previously used for mining Ethereum once The Merge occurred. We first determined the most probable alternative cryptocurrencies by examining the hashrate behavior of GPU-minable currencies during The Merge. In order to determine our own network hashrate, we extracted data from the blockchains of selected currencies. While calculating our network's hashrate, we observed that there were multiple possible approaches and by comparing the hashrate data obtained from different mining websites, it became apparent that distinct methods were employed to compute the network hashrate. We decided upon a specific method that minimizes fluctuations and involves calculating the average hashrate over the last 500 blocks. We then conducted an analysis of how much computational power had shifted to other proof-of-work currencies, as well as which currencies had attracted most of the most computational power.

Our findings revealed that approximately 30% of Ethereum's hashrate was reallocated to alternative currencies by the end of September. The majority of this computational power was redirected to Ethereum Classic, followed by Ergo and Ethereum Proof-of-Work. Furthermore, we identified alternative uses for the remaining GPUs. Many individual miners who did not transition to other cryptocurrencies chose to sell their equipment and stake Ether instead. Some miners decided to wait for more profitable opportunities and occasionally utilized their GPUs as heating devices during winter. Mining companies, on the other hand, made significant investments in Bitcoin to maintain competitiveness and repurposed their equipment for the emerging field of artificial intelligence.

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Appendix A

All plots

A.1 Factors

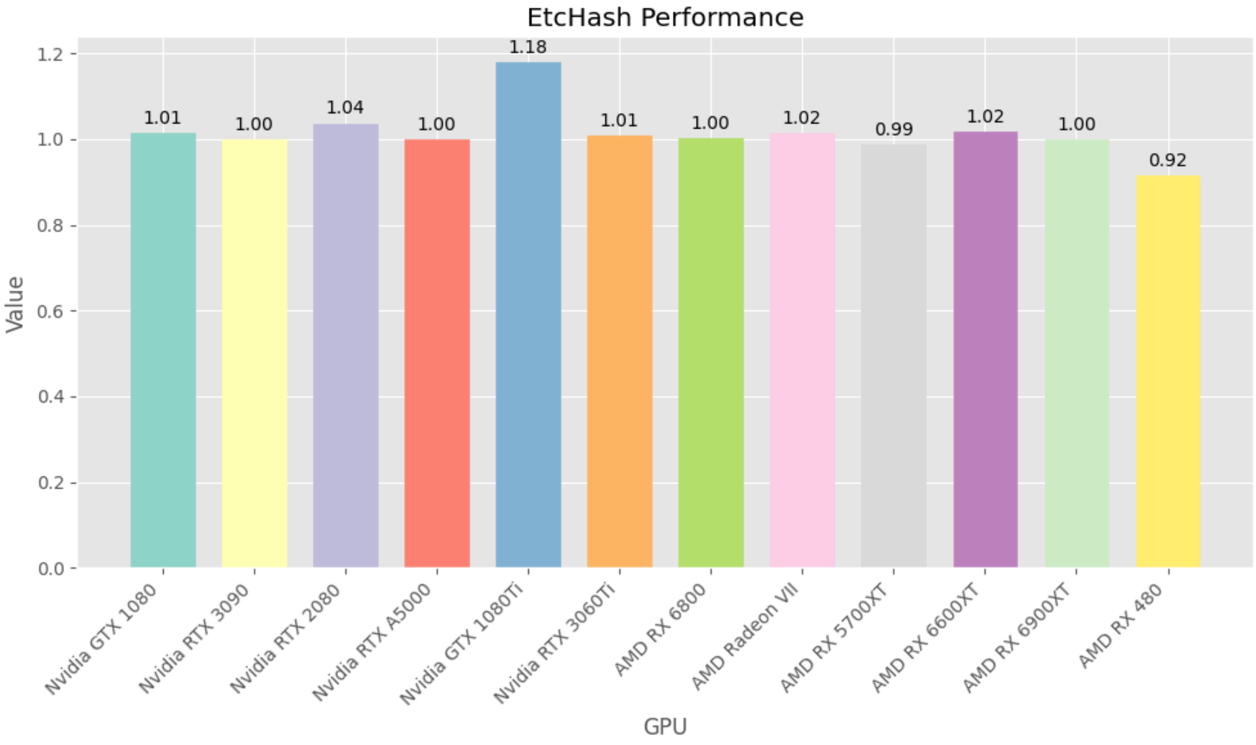
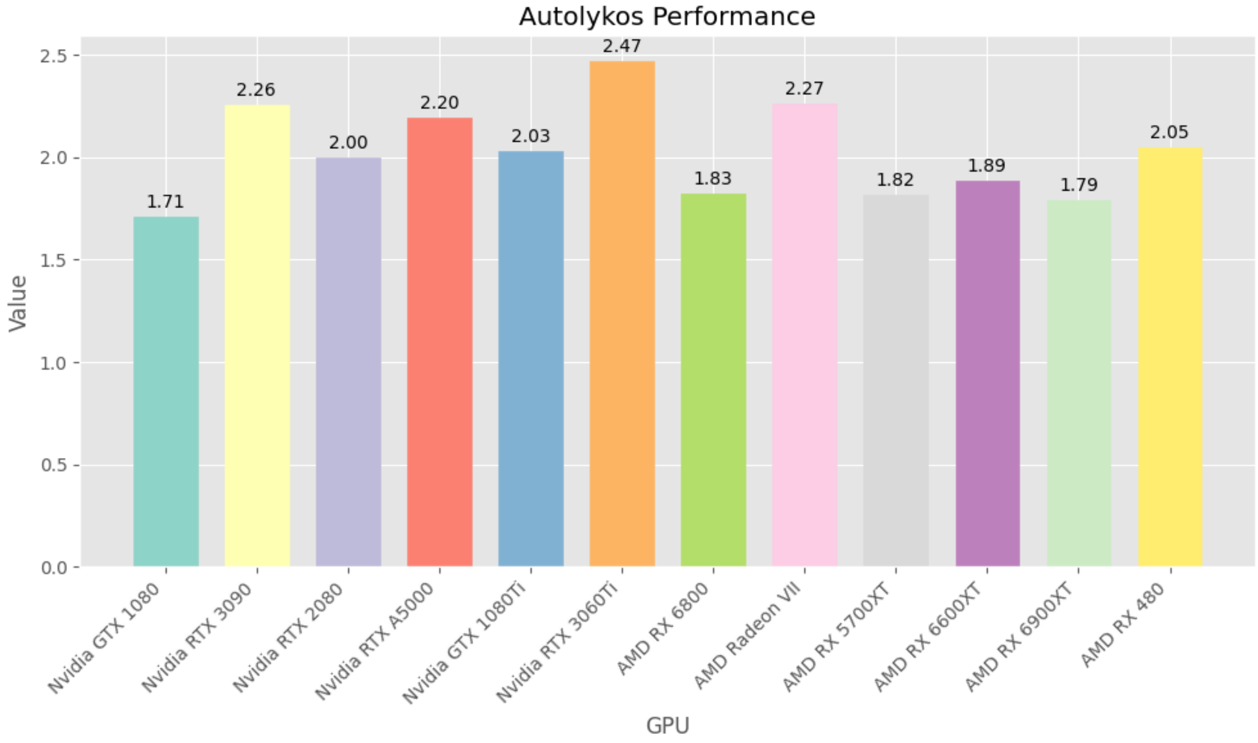


Figure A.1: Visualization ETC factors



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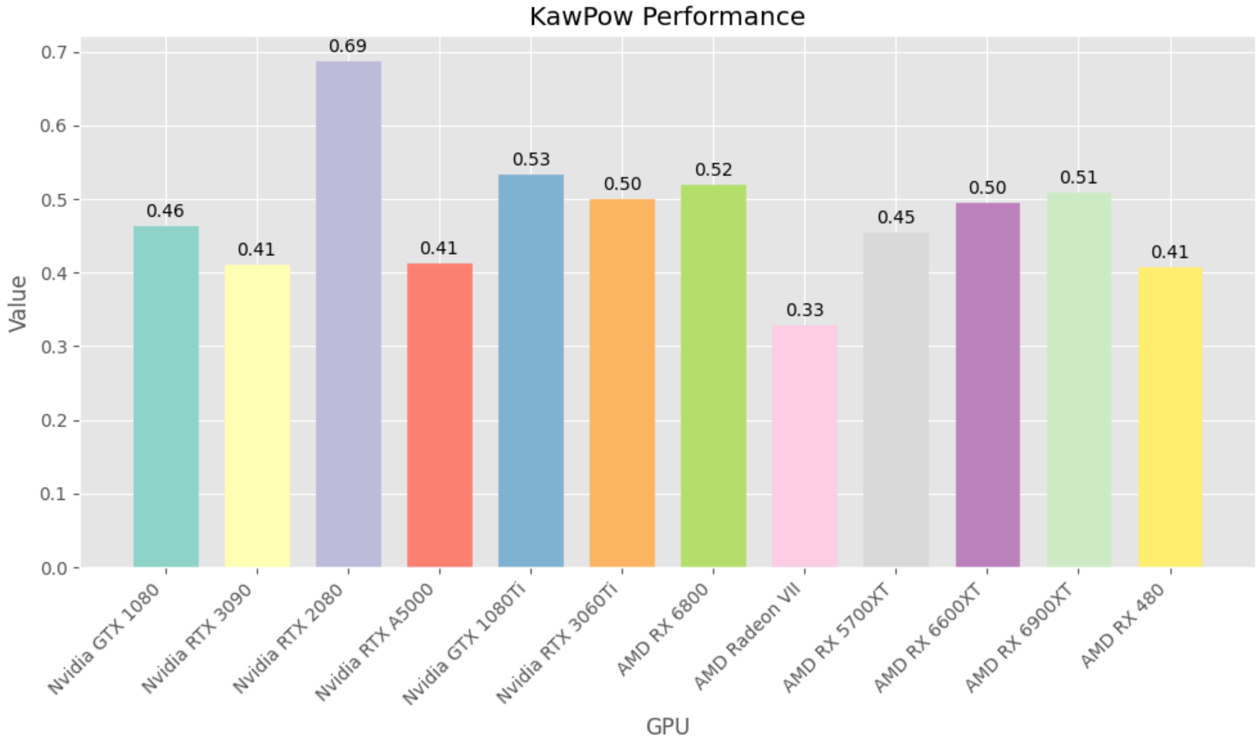

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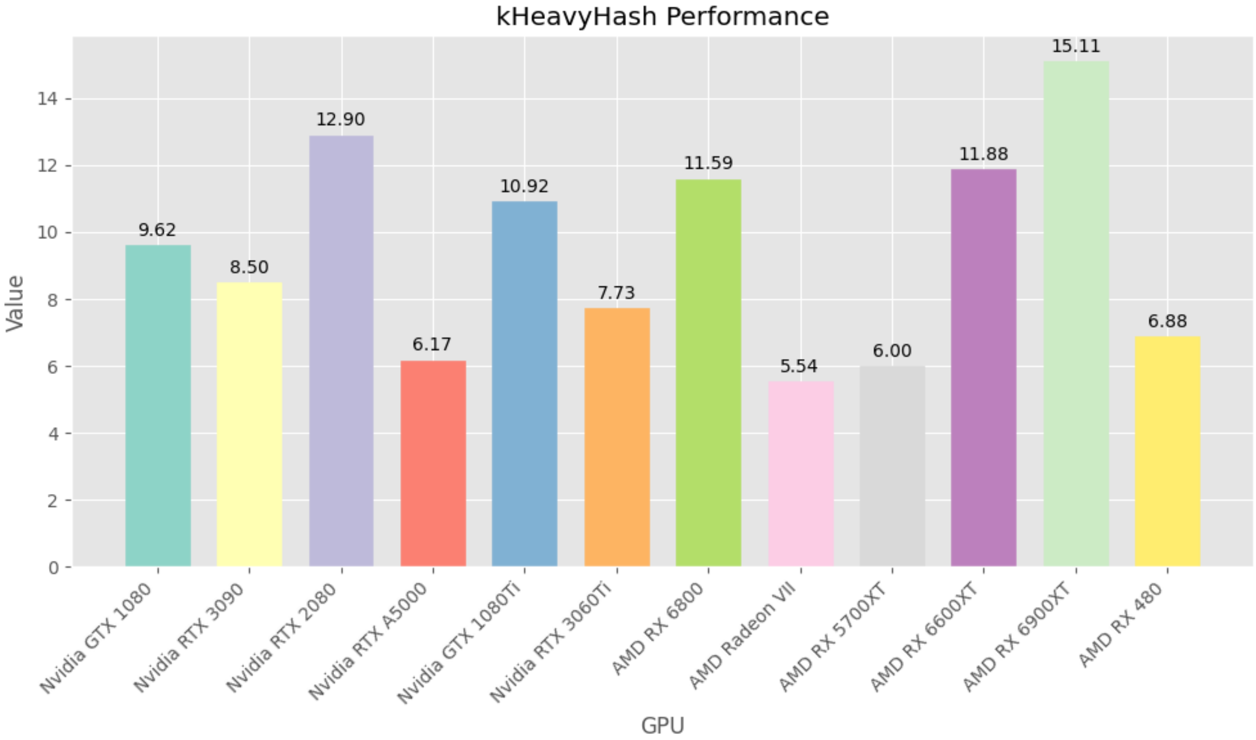

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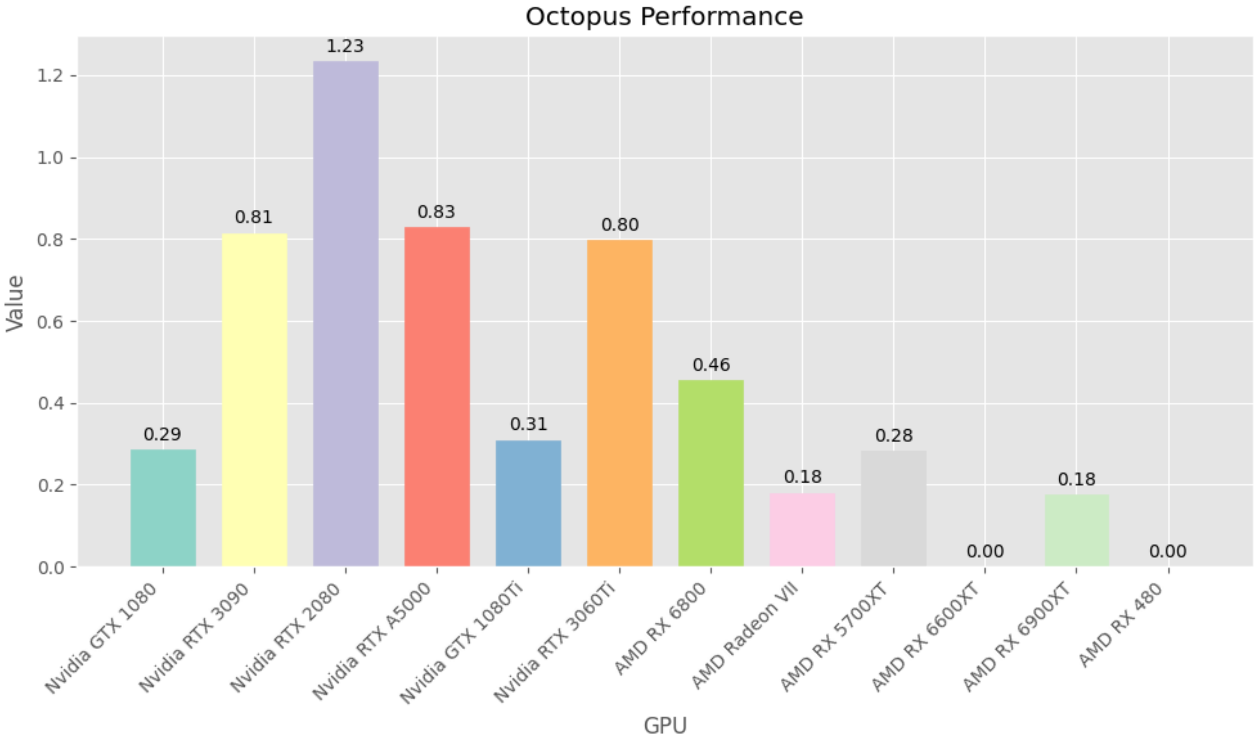

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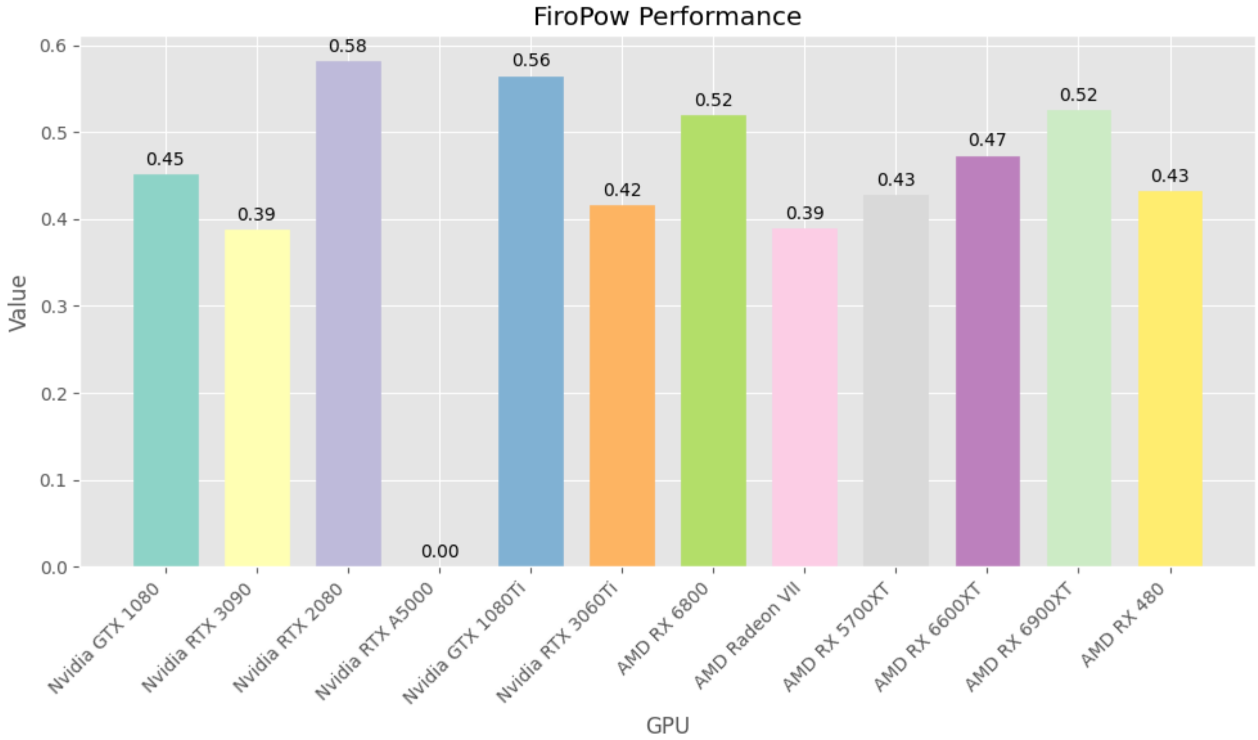
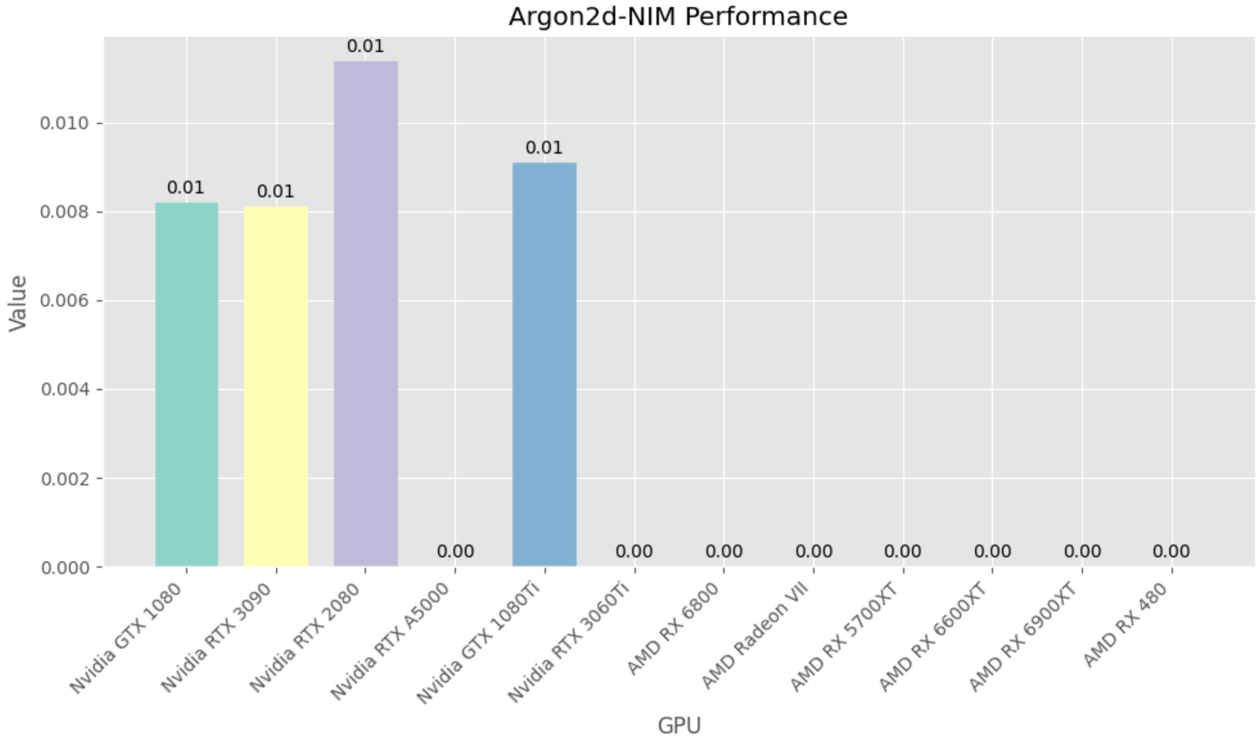


Figure A.6: Visualization FiroPow factors



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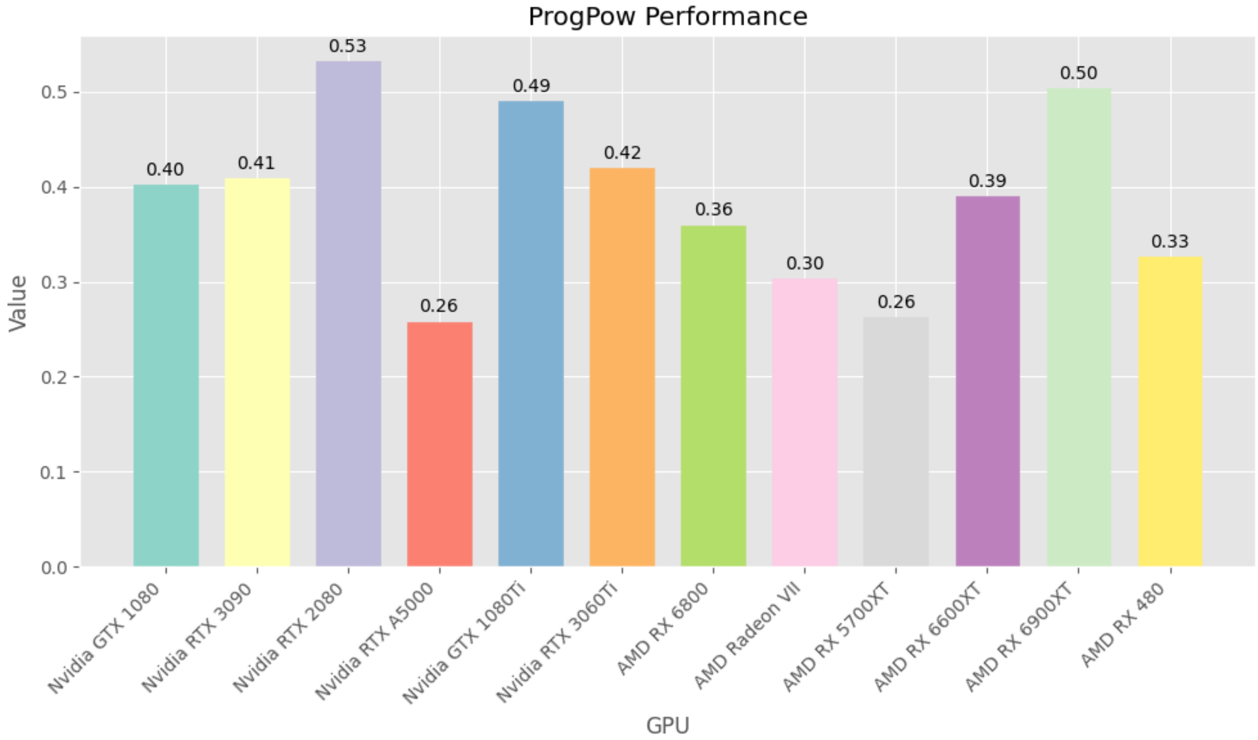
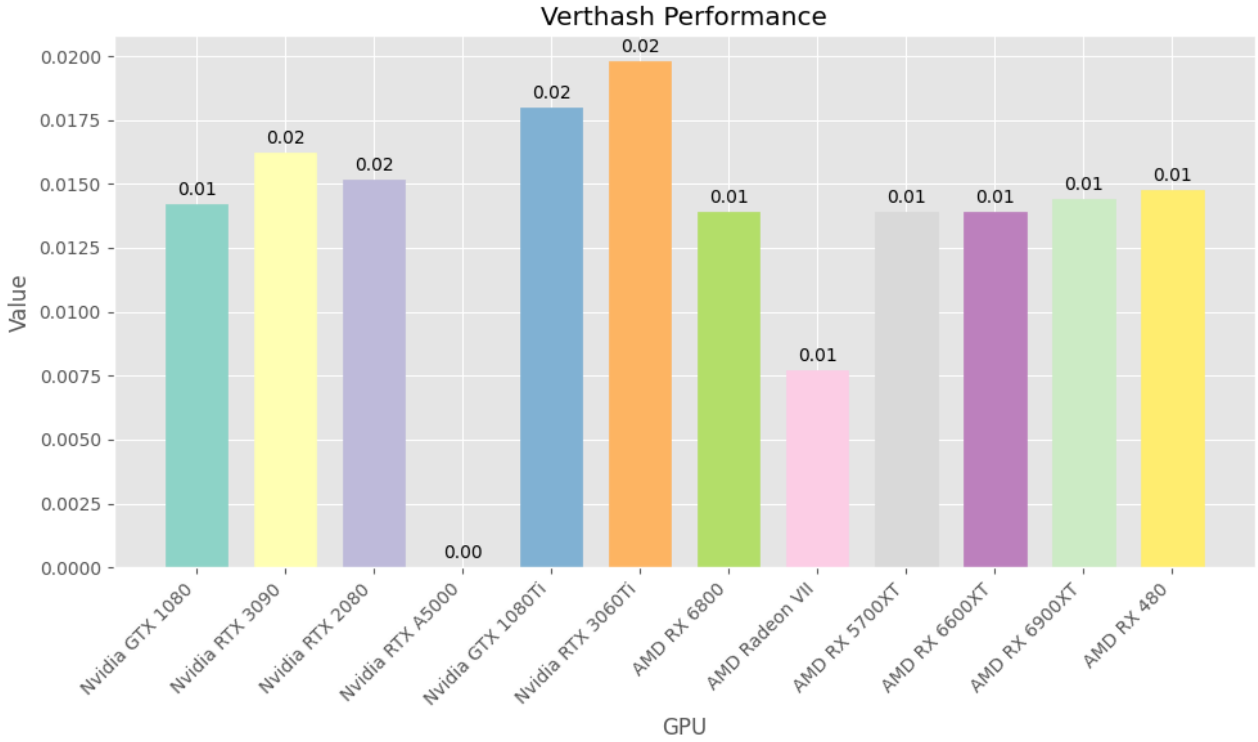


Figure A.8: Visualization ProgPow factors



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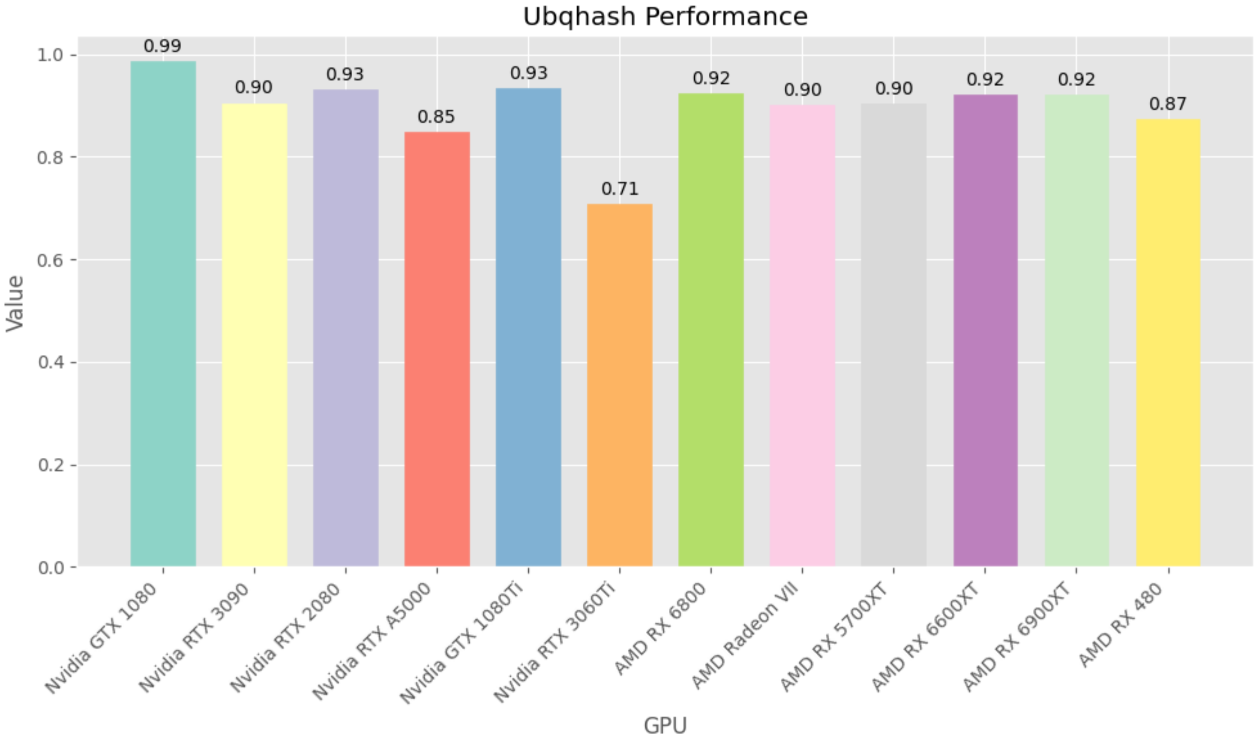

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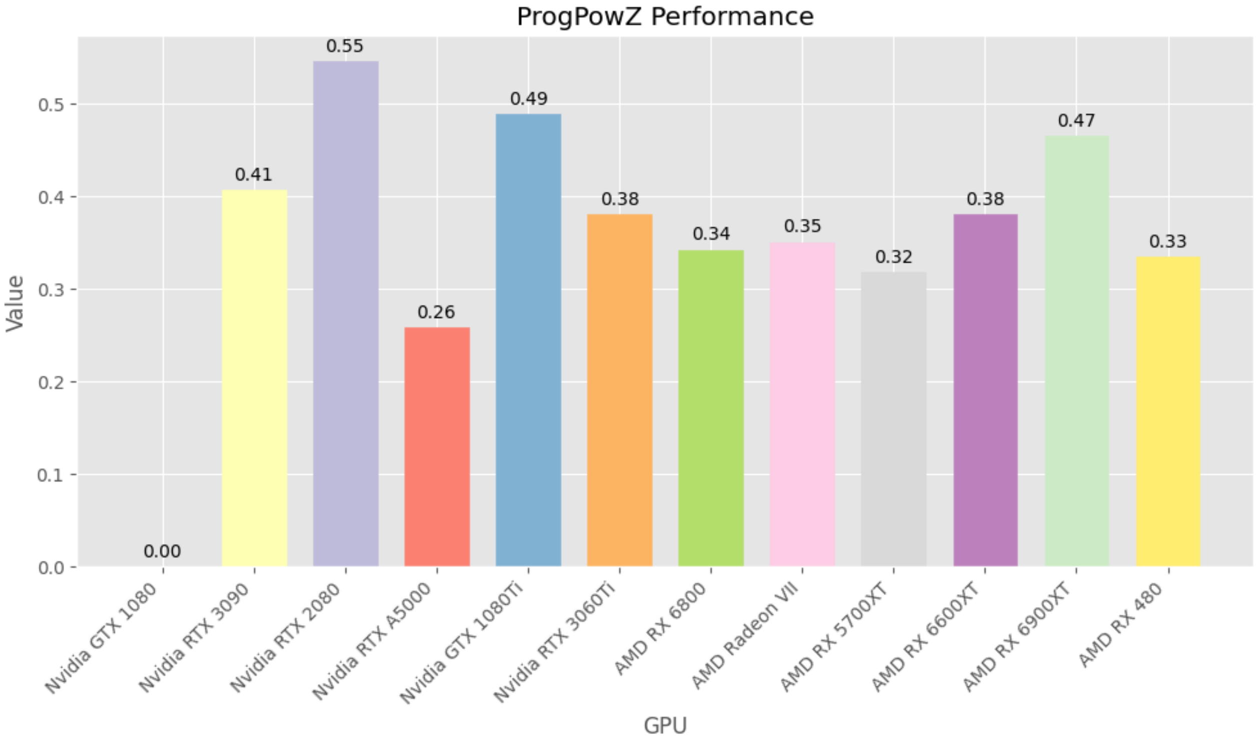


Figure A.11: Visualization ProgPowZ factors

A.2 Blocktime

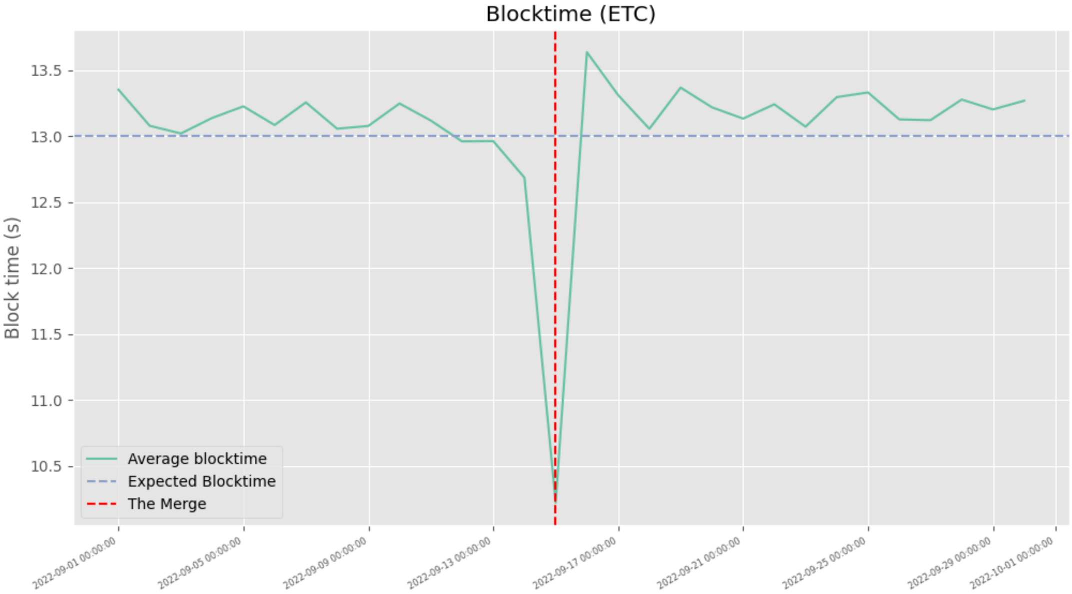


Figure A.12: ETC average vs expected blocktime

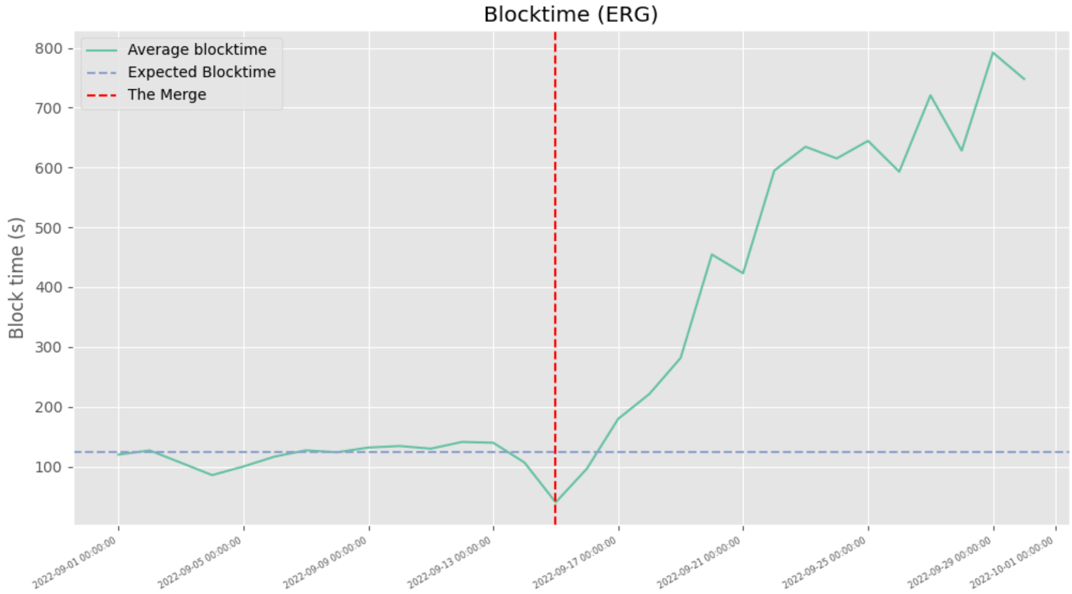


Figure A.13: ERG average vs expected blocktime

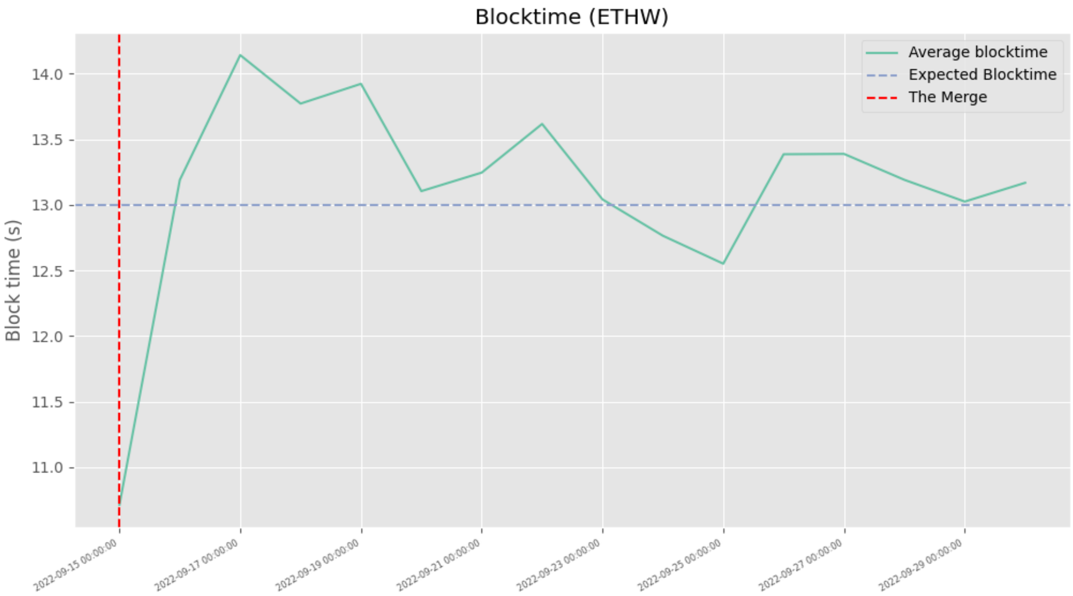


Figure A.14: ETHW average vs expected blocktime

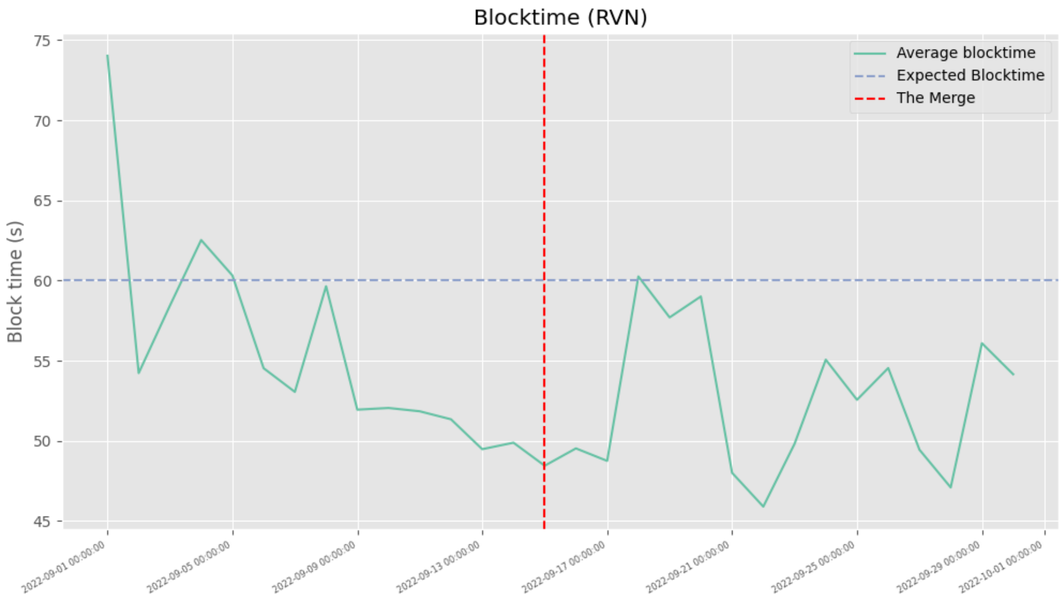


Figure A.15: RVN average vs expected blocktime

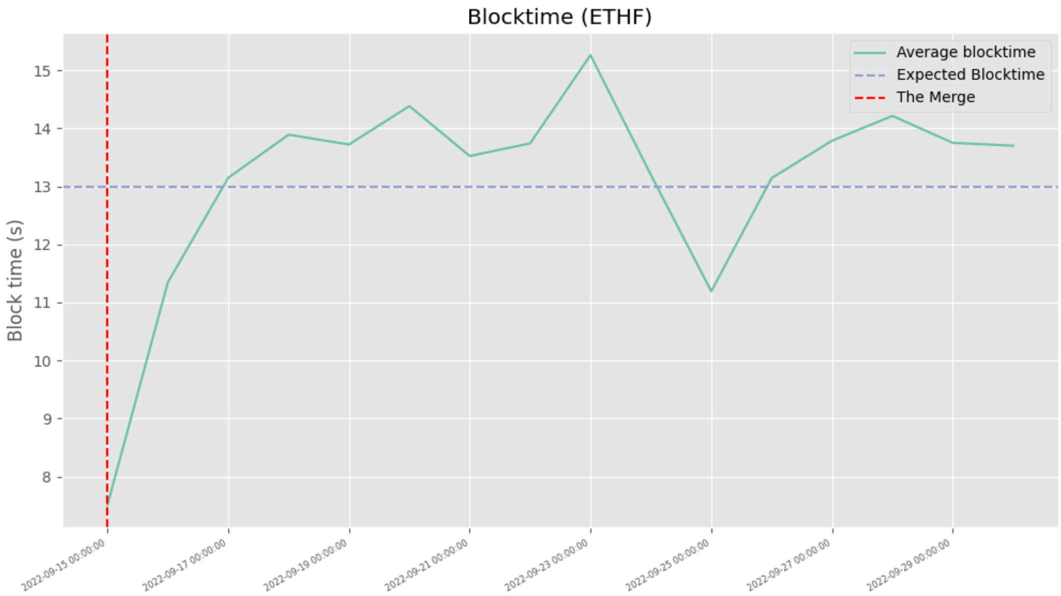
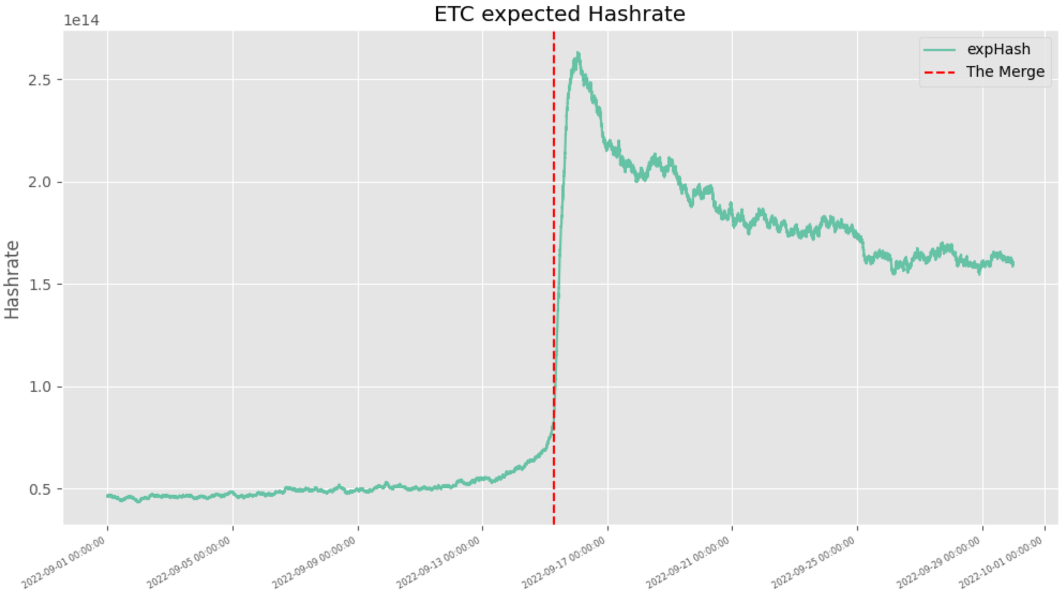


Figure A.16: ETHF average vs expected blocktime

A.3 Expected Hashrate



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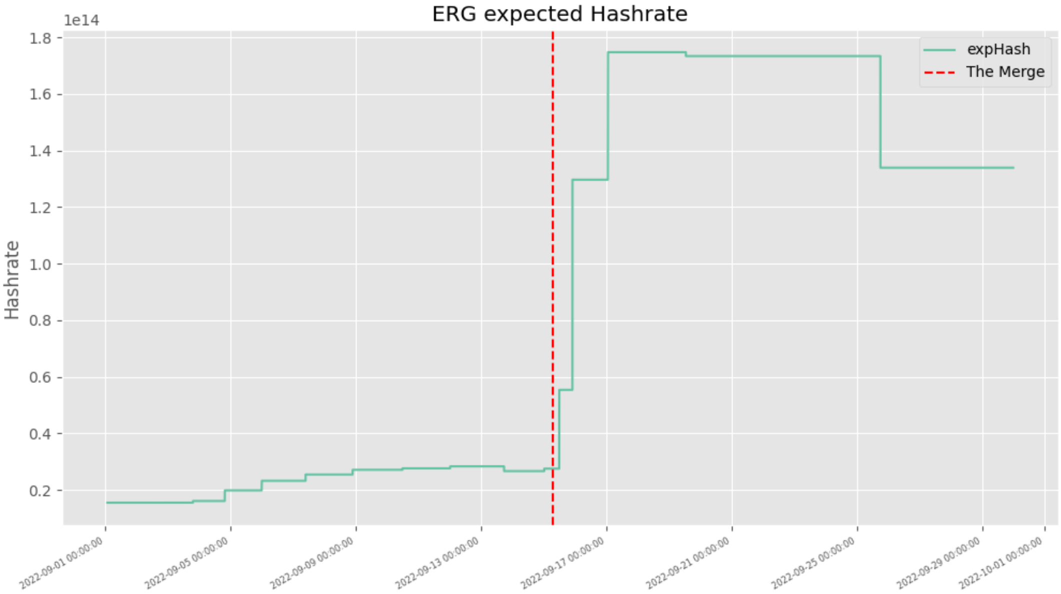


Figure A.18: ERG expected hashrate

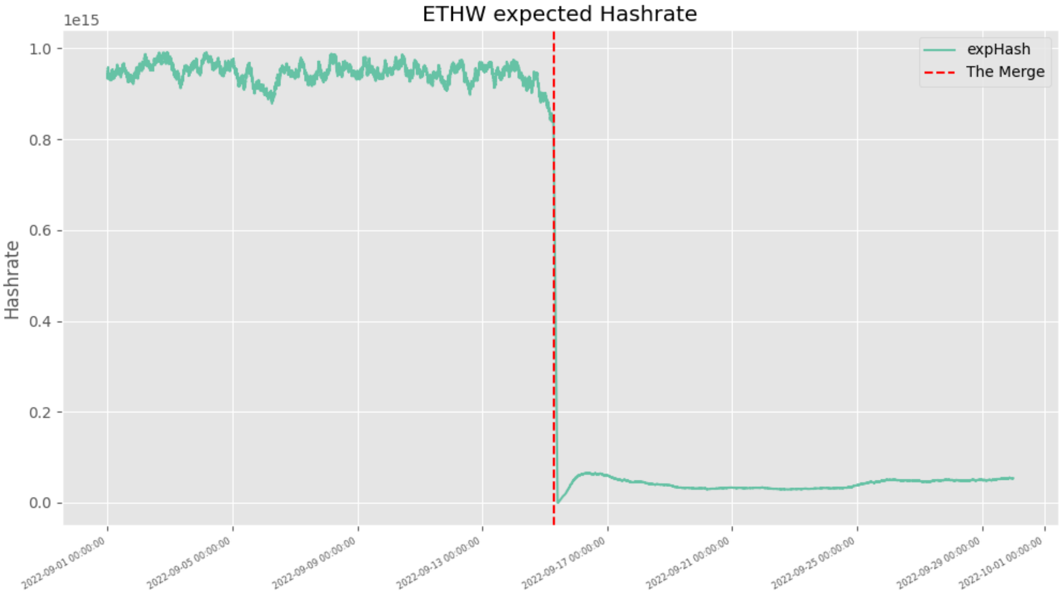


Figure A.19: ETHW expected hashrate

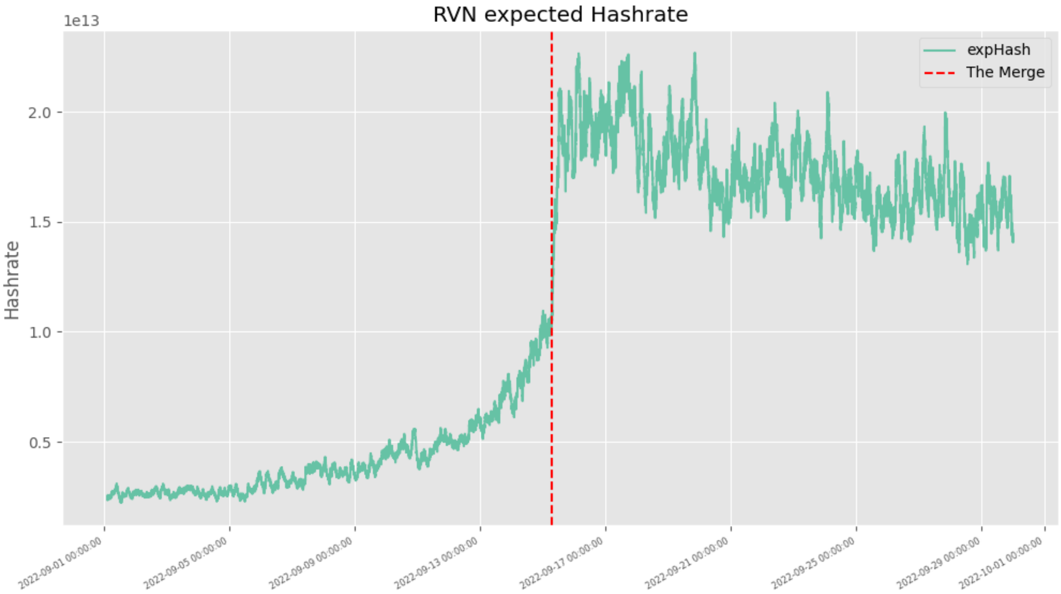


Figure A.20: RVN expected hashrate

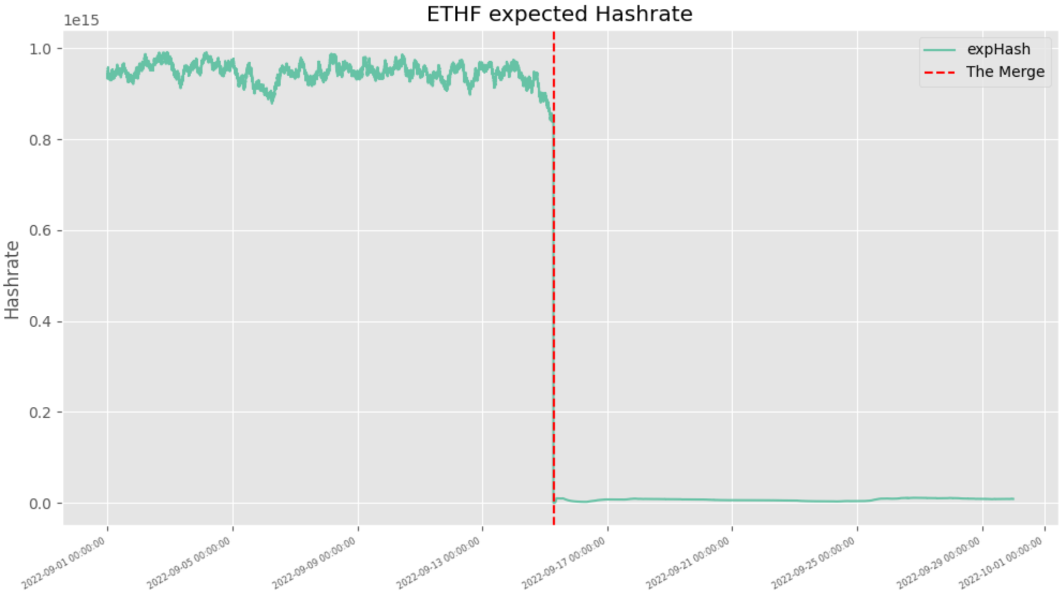
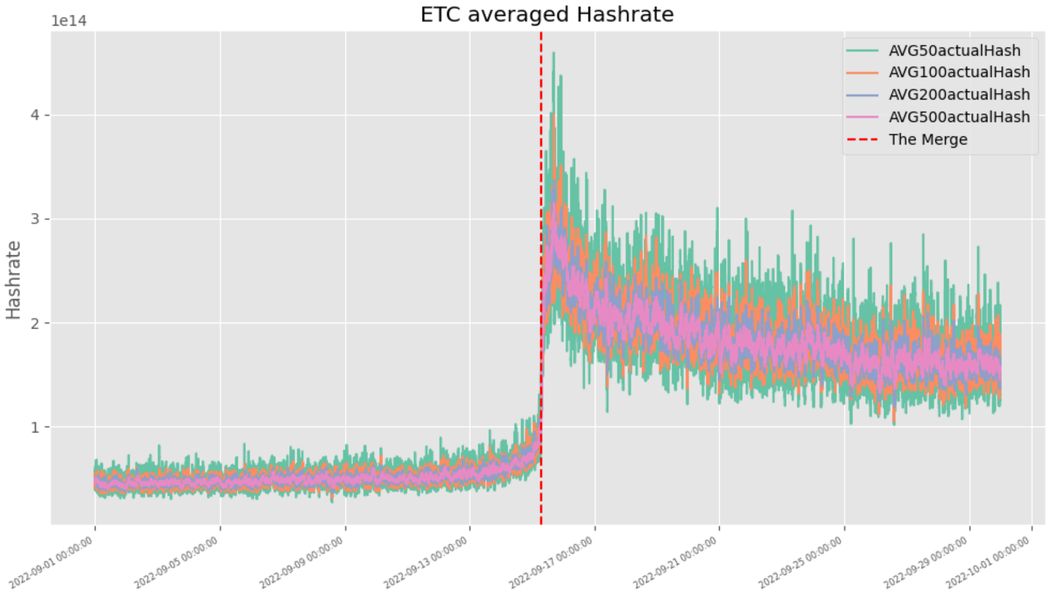


Figure A.21: ETHF expected hashrate

A.4 Averaged Hashrate



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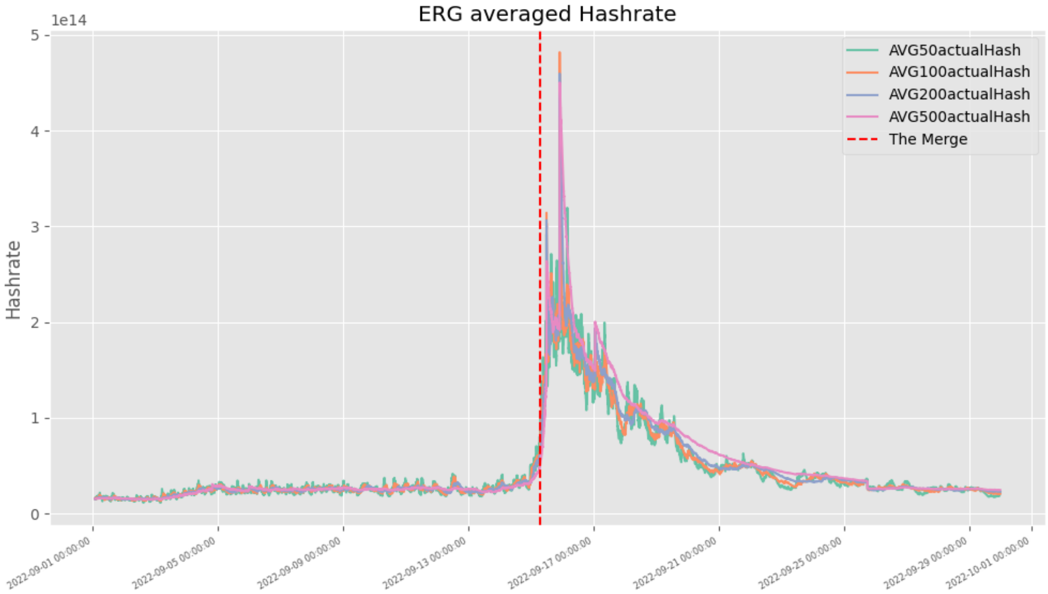


Figure A.23: ERG averaged hashrate

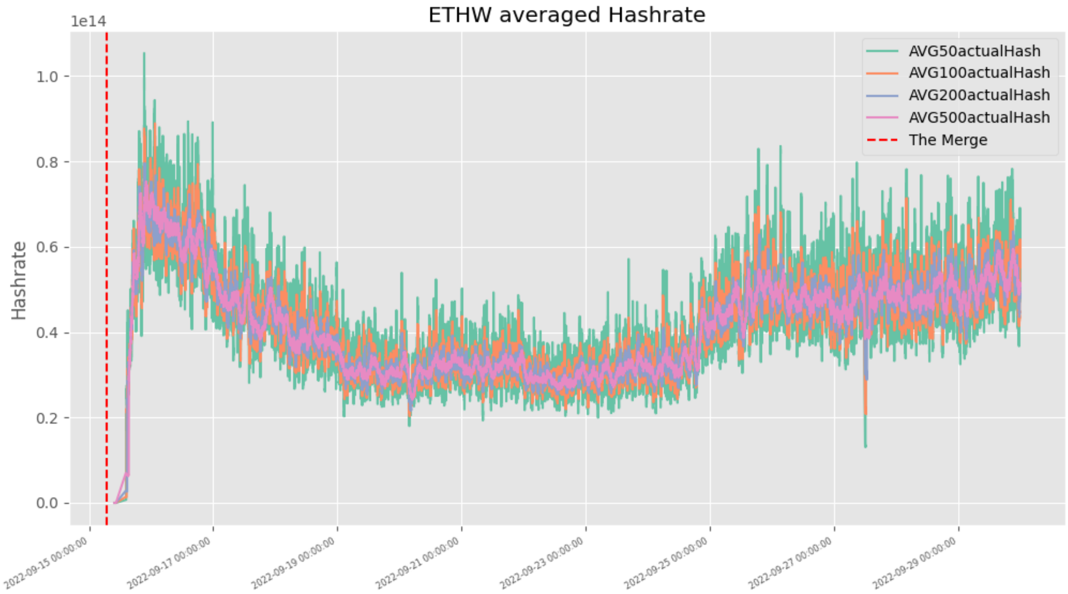


Figure A.24: ETHW averaged hashrate

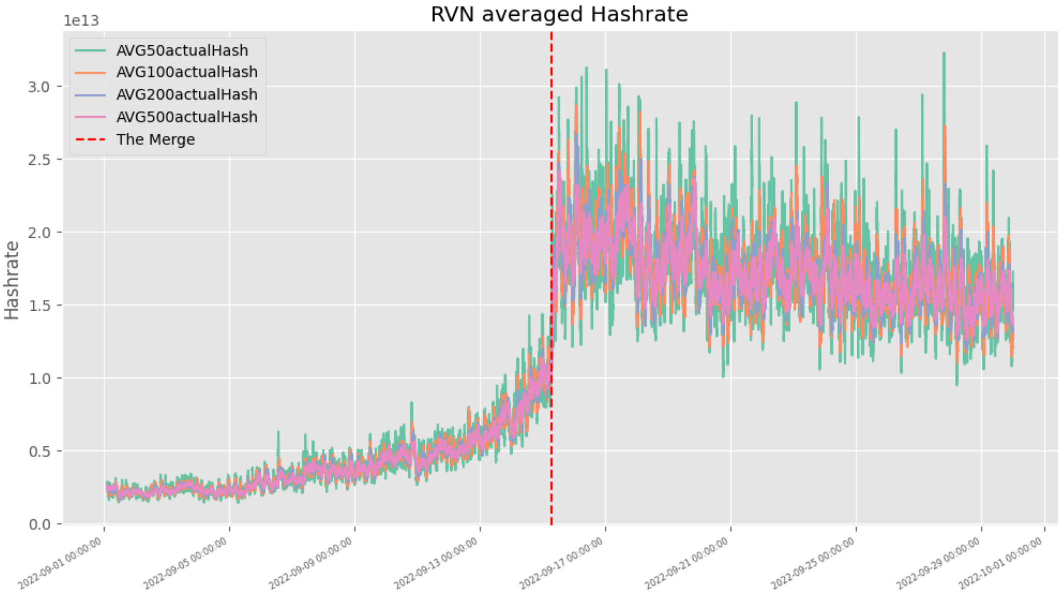


Figure A.25: RVN averaged hashrate

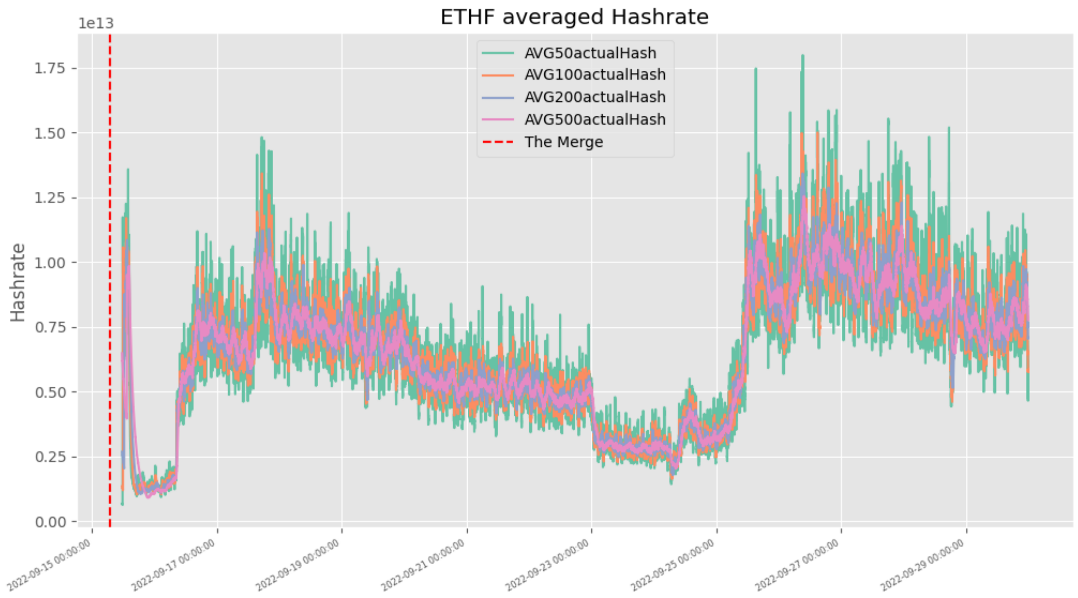


Figure A.26: ETHF averaged hashrate

A.5 Hashrate comparison

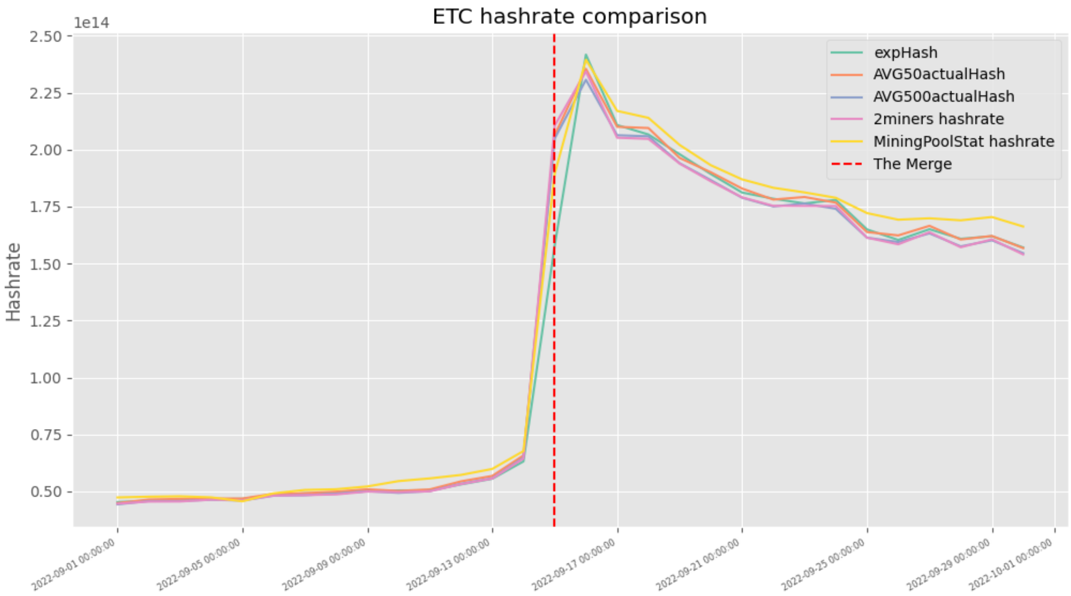


Figure A.27: ETC hashrate comparison

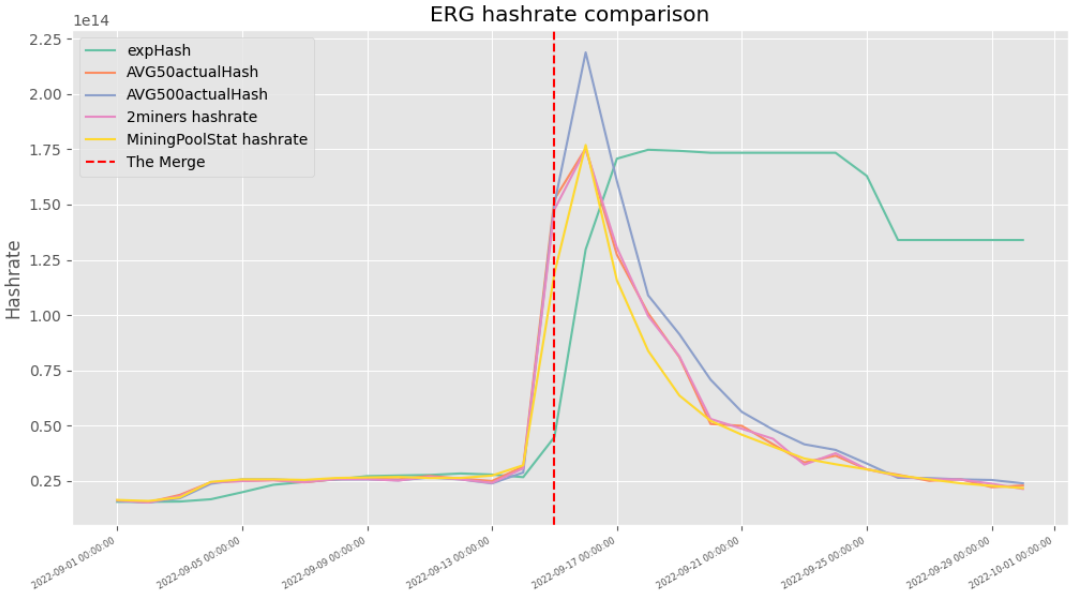


Figure A.28: ERG hashrate comparison

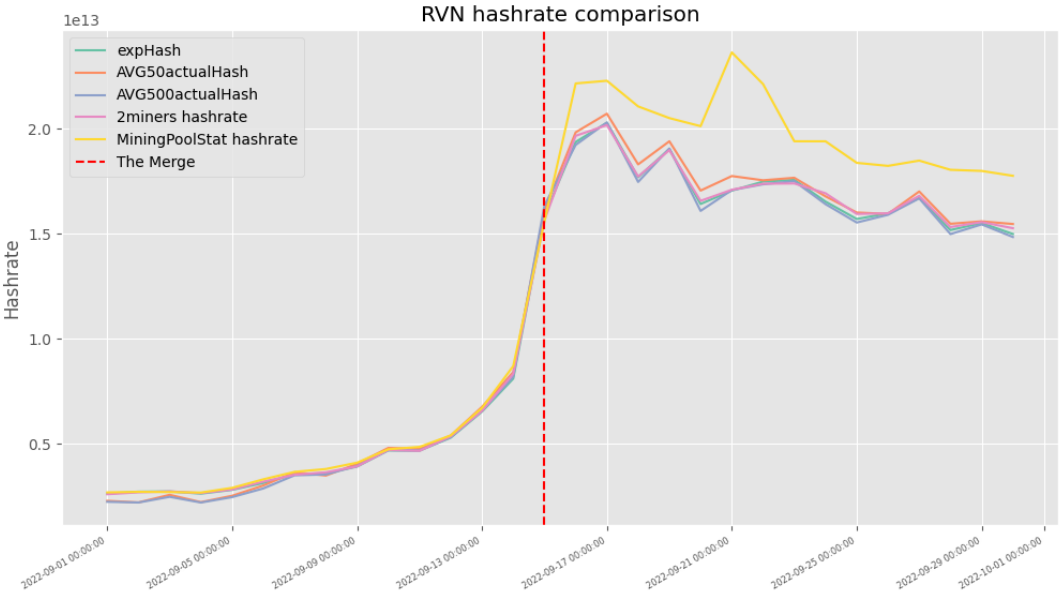
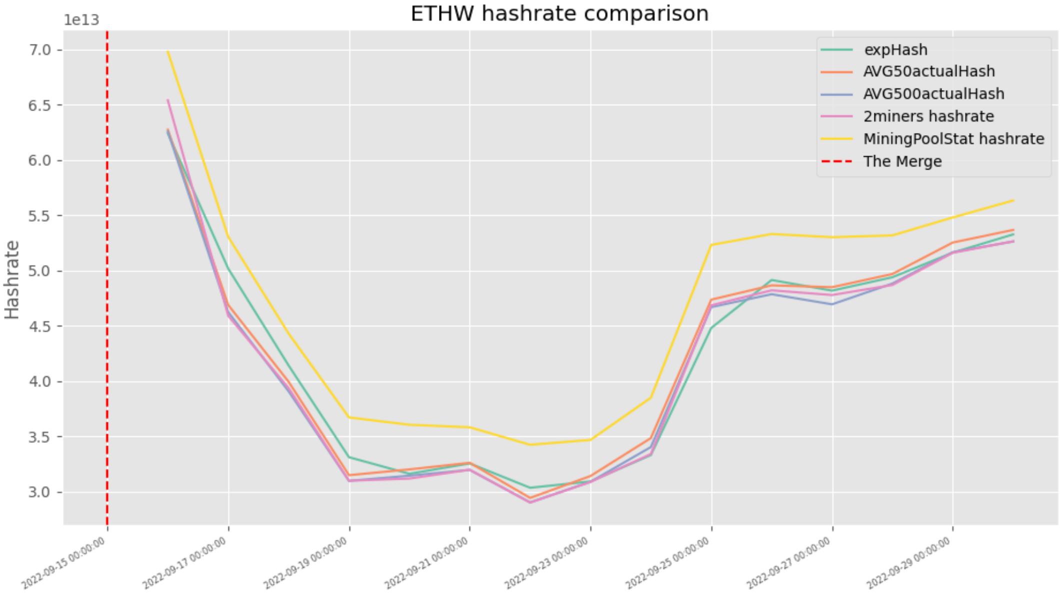


Figure A.29: RVN hashrate comparison



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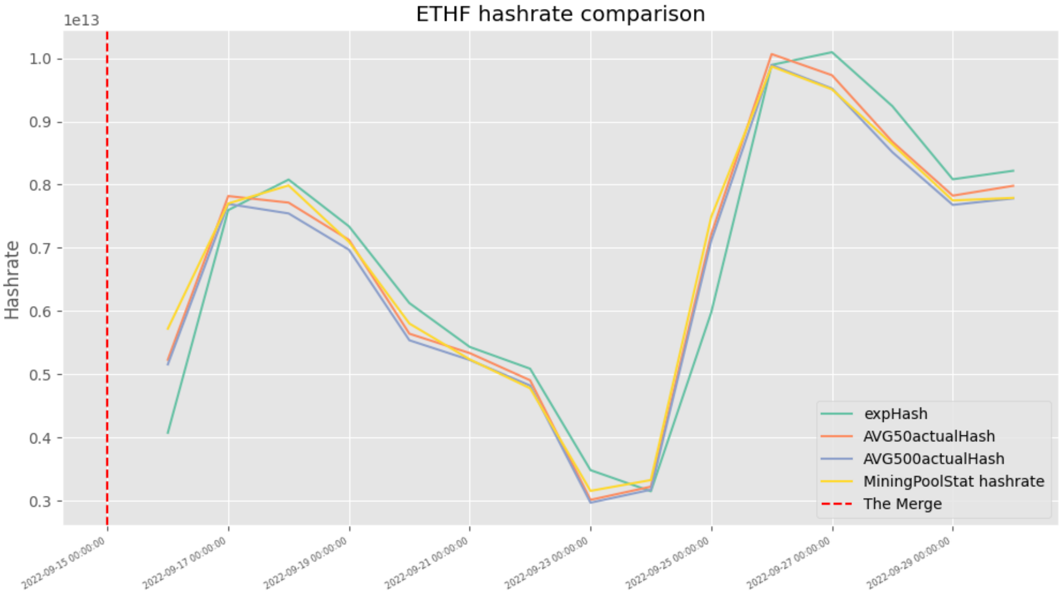
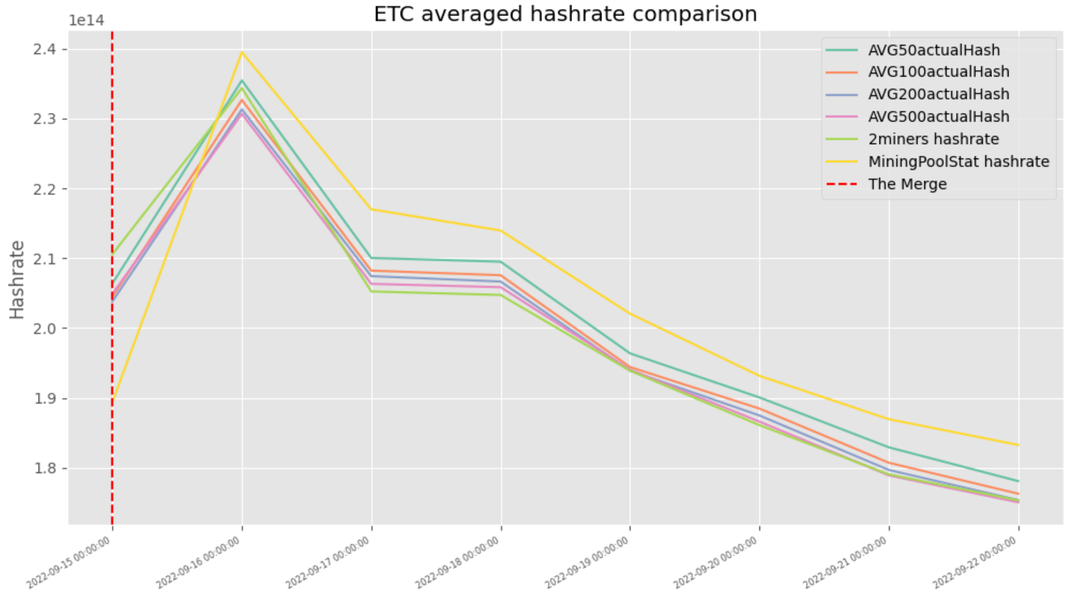


Figure A.31: ETHF hashrate comparison

A.6 Averaged hashrate comparison



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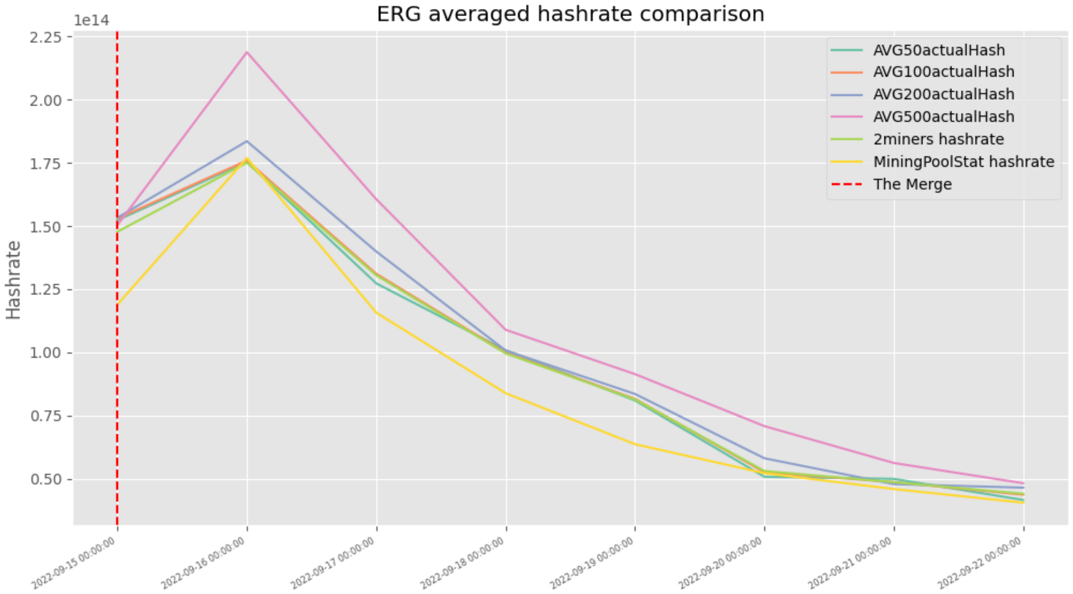

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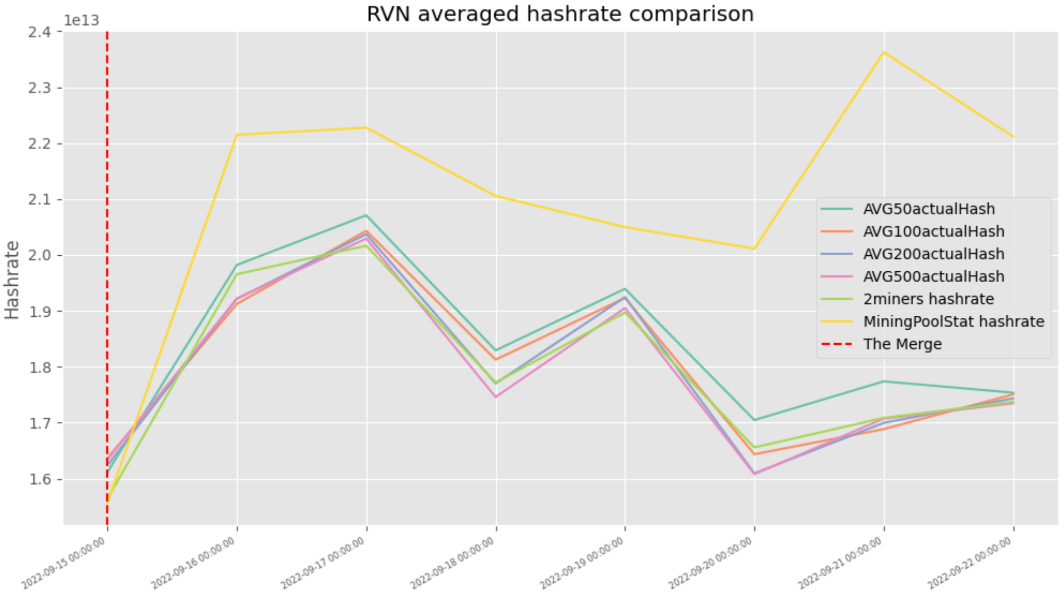

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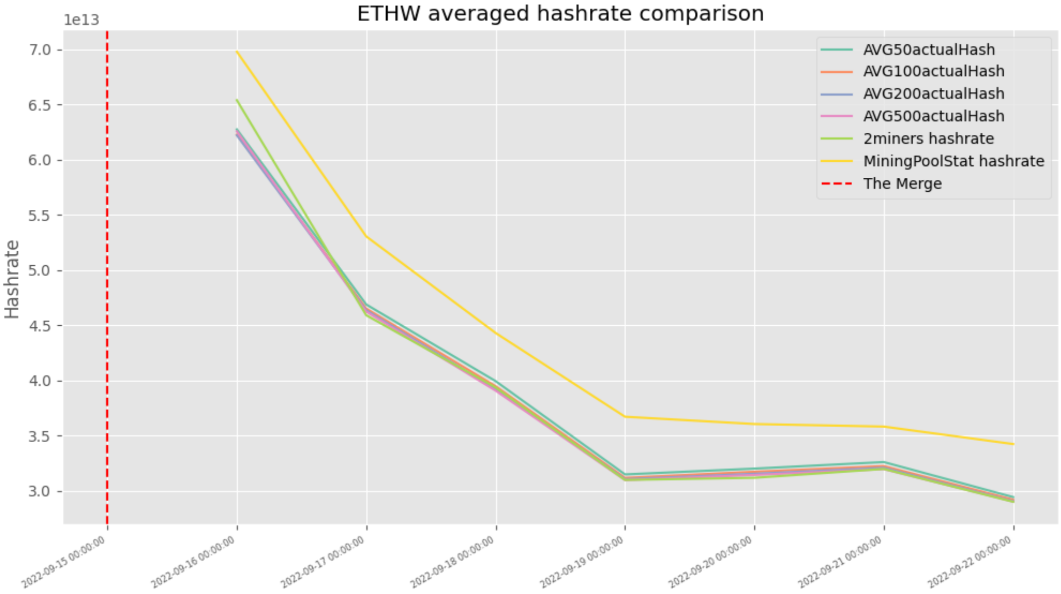

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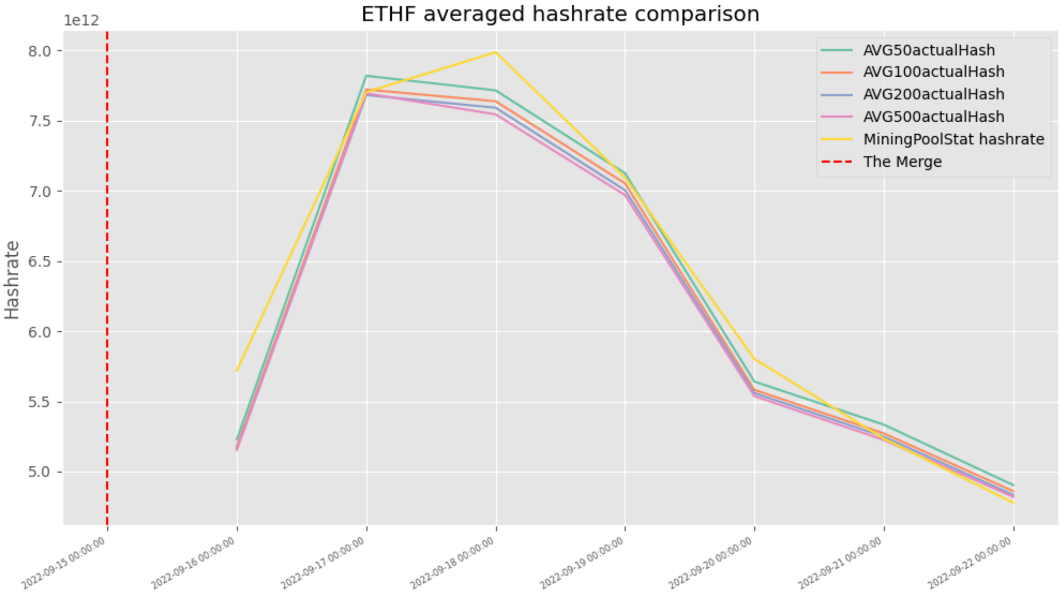

Figure A.36: ETHF averaged hashrate comparison