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"Evaluation of computer hardware performance data in cryptocurrency energy consumption estimation"

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The present dissertation entitled

"Evaluation of computer hardware performance data in cryptocurrency energy consumption estimation"

was submitted by **Andreas Dimakopoulos, ID 1067668** , in partial fulfillment of the requirements for the degree of Master of Science in *"Applied Economics & Data Analysis"* at the University of Patras and was approved by the Dissertation Committee Members.

I would like to dedicate my thesis to my parents who have provided me with unconditional love and support throughout the years and my dear friend Maria for being a constant source of inspiration and encouragement. I would also like to thank my friends and colleagues Andreas, Giannis and Panagiotis for sharing concerns and motivating each other over the past year. Finally, I would like to dedicate this thesis to my grandparents who sadly passed away, thank you for everything.

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Abstract

The aim of this thesis is to aid the academic community, specifically in the field of cryptocurrencies that have the issue of scarce data and lack of information. Data are essential in order to better understand the problem of cryptocurrency mining consumption, so that ways can be found to regulate it. After presenting the related academic literature over the point at issue which is the continuously rising electrical energy consumption, we continued with addressing the profitability of miners today and emphasized on the lack of data at hand. We handled that by building a database of daily data from June 2nd, 2022 to July 28,2023 that contains information about ASIC mining machines and their power consumption, their cost of electricity per day, their computational power and income per day among others. Finally, by exhibiting the top cryptocurrencies of today by market cap and the algorithms that are used to mine them, we used a subset of a full calendar year from July 15th,2022 to July 15th, 2023 in order to display the top 2 ASIC mining models of each of the top 5 algorithms by using the total profit of the past year.

Keywords: Cryptocurrency, Database, Energy consumption, Profitability

Περίληψη

Ο στόχος της παρούσας διπλωματικής εργασίας είναι η υποστήριξη της ακαδημαϊκής κοινότητας και συγκεκριμένα στο πεδίο των κρυπτονομισμάτων όπου υπάρχει το πρόβλημα των σπάνιων δεδομένων και της έλλειψης πληροφοριών. Τα δεδομένα είναι απαραίτητα ώστε να καταλάβουμε καλύτερα το πρόβλημα της κατανάλωσης ενέργειας από την εξόρυξη κρυπτονομισμάτων ώστε να βρεθούν τρόποι να ρυθμιστεί το πρόβλημα. Αφού παρουσιάσαμε την σχετική ακαδημαϊκή βιβλιογραφία του θέματος το οποίο είναι η συνεχής άνοδος της κατανάλωσης ηλεκτρικής ενέργειας, συνεχίσαμε με την αντιμετώπιση του προβλήματος της κερδοφορίας των ανθρακορύχων κρυπτονομισμάτων και δώσαμε έμφαση στην έλλειψη των δεδομένων που είναι διαθέσιμα. Καταπολεμήσαμε αυτό το πρόβλημα με το να δημιουργήσουμε μια βάση δεδομένων με ημερήσια δεδομένα απο την 2 Ιουνίου του 2022 εώς και της 28 Ιουλίου του 2023 όπου περιέχει πληροφορίες για τα μηχανήματα που χρησιμοποιούνται στην εξόρυξη κρυπτονομισμάτων σχετικά με την κατανάλωση ενέργειας, το κόστος ηλεκτρικής ενέργειας ανά ημέρα, την υπολογιστική τους δύναμη και τα έσοδα τους ανά ημέρα μεταξύ άλλων. Τέλος, αφού παρουσιάσαμε τα κορυφαία κρυπτονομίσματα του σήμερα με βάση την κεφαλαιοποίηση τους και τους αλγόριθμους που κάνουν χρήση για την εξόρυξη τους, χρησιμοποιήσαμε ένα υποσύνολο των δεδομένων όπου επιλέξαμε μία ολόκληρη χρονιά από τις 15 Ιουλίου 2022 έως και τις 15 Ιουλίου 2023 ώστε να παρουσιάσουμε τα 2 καλύτερα μηχανήματα από τον καθένα από τους 5 κορυφαίους αλγόριθμους με τη μέθοδο της συνολικής κερδοφορίας την τελευταία χρονιά.

Λέξεις κλειδιά: Κρυπτονόμισμα, Βάση Δεδομένων, Κατανάλωση ενέργειας, Κερδοφορία

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Chapter 1

Introduction

1.1 Introduction

In the past couple of years global markets have experienced substantial fluctuations mainly as a result of the Covid-19 breakdown in 2020. Entire countries were forced to go into general lock downs leading the universal economy to a sharp decline. These events and the lack of renewable energy sources has caused the world to enter an energy crisis. While world leaders are actively looking for ways to reduce energy consumption and induce alternate ways to produce it, cryptocurrency mining continues to expend huge amounts of electrical energy and emit carbon emissions sparking discussions among the academic community. The lack of data and information of how many machines miners are using, which type of computers they are using and methods to calculate exactly how much electrical energy each network is consuming has been an issue for academics and governments over the past decade so that they can be informed of the severity of the problem and try to find ways to regulate it. Not until recently more data have been available and even though we still do not have the knowledge of how many machines each network is using, we can make a more accurate guess based on the hash rate of the network, the difficulty of creating a new block and the current prices of energy with some academics trying to quantify the total consumption.

To put things on a comparative scale and show the seriousness of the problem, if the Bitcoin network was a country it would be in the top 30 energy users utilizing 177.43 TWh annually surpassing countries like Argentina (Islam et al., 2022). Amidst this plight, with general inflation accompanied by energy prices going through the roof, miners continue to switch territories and countries in order to find the perfect conditions to carry through their mining operations. The aim of a miner is to maintain his profit gained from fees acquired via transactions and the creation of new blocks participating in a mining pool or on his own, while also keeping the cost of electricity as low as he possibly can. With cryptocurrencies preserving and increasing their popularity and demand with digital currencies and wallets being more and more used in the modern world, miners are striving to detect the most profitable computers and algorithms they can utilize to mine the top cryptocurrencies available in the market. Our intention is to produce a pipeline that handles the data and creates a database with information about ASIC machines used in mining that is very much needed in the academic community due to the lack of data available. We managed to create this database by extracting data from the internet, clearing the duplicates, filling and dropping the missing values and turning our raw dataset into a form that can be used to gain insightful information. We used this information to showcase the most profitable ASIC machines of the past year, that can be used to mine the top cryptocurrencies by using the leading algorithms on the market.

Chapter 2

Background

2.1 Background

The purpose of this section is to provide some background information about cryptocurrencies that are essential for the understanding of this dissertation. At first, a definition of cryptocurrencies and the two different mechanisms used in order to ensure the security of the transactions is introduced, continued by the most important aspects of cryptocurrencies. Furthermore, we present the computers that are used in the mining process and briefly discuss about mining pools.

2.1.1 Cryptocurrency

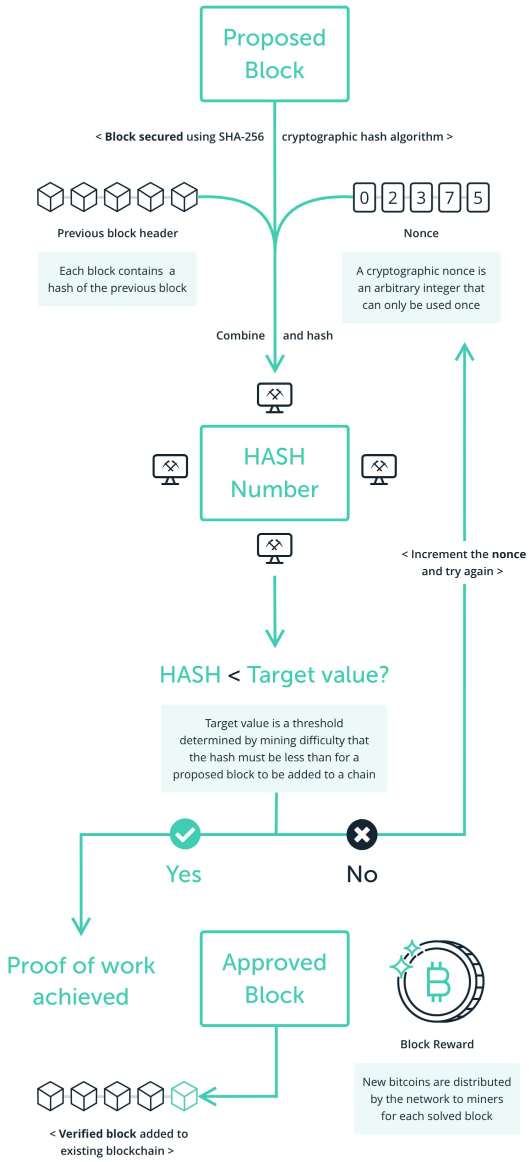
A cryptocurrency is solely digital payment system secured by cryptography, that protects it from double-spend and counterfeit. It is a peer-to-peer system that connects the buyer and the seller directly without needing a third party or an intermediary. A cryptocurrency differs from Fiat money that are carried physically, in the sense that it is a purely digital currency existing in a digital wallet and the transactions or payments made are entered in an online database. Lastly, when a user buys a cryptocurrency he is issued two keys: a public key that it is shared with others in order to buy or receive funds and a private key that is the access to the user's virtual vault (Coinbase). Some of the most popular cryptocurrencies that exist are Bitcoin, Ethereum, Tether, Binance Coin and XRP.

2.1.2 Bitcoin and Proof of Work

Bitcoin is the first cryptocurrency, which was revealed as an idea to the general public in 2008 by a person or group using the pseudonymous Satoshi Nakamoto Nakamoto (2008). The white paper published, talked about a peer to peer electronic cash system that aimed to work as a form of payment directly between people without needing a third party institution to verify or to secure the transactions. Since then it has become the most popular cryptocurrency yet that has widely spread, with many banks and stores accepting Bitcoin as a method of payment. It is the first coin in market capitalization in the world (589 billion $ as of July 2023), reaching an all-time high price of $68,789.63 on Nov 10, 2021 (YahooFinance, 2023).

Cryptocurrencies and more specifically Bitcoin use blockchain technology, a distributed ledger which is a database that helps secure the transactions with an encryption method ensuring a secure and decentralized record of transactions. This record of transactions is distributed across multiple network nodes and in order to be valid they must all match. This prevents altering any record on the database by using the other network nodes to prevent that. Once the blockchain is full, the encryption algorithm is ran which creates a hexadecimal number called the hash. Then this number is inserted into the following block header and encrypted with other information in the block. This connects a series of blocks that are chained together. When a transaction occurs, it is stored in a memory pool and must wait until a miner validates it. Once it is entered into a block and the block fills up with transactions, it follows the process mentioned. Then, the network of miners are simultaneously trying to solve the hash by generating a random number until a miner finds the right hash, completing the validation process creating a new block approximately every 10 minutes and receiving transaction fees and a reward of 6.25 bitcoins as of July, 2023 (Figure 2.1). This is a fixed reward that is halved every four years. The hash target increases its difficulty every 2,016 blocks to ensure the 10 minutes remain as the amount of time required to create a new block. The number of hash guesses per second is called a hash-rate and Bitcoin uses the SHA-256 consensus algorithm which refers to the bit size of the hash output. This consensus process of transaction verification is called Proof of Work. Not all cryptocurrencies use this method to execute the validation process.

Figure 2.1: Proof of Work consensus mechanism process

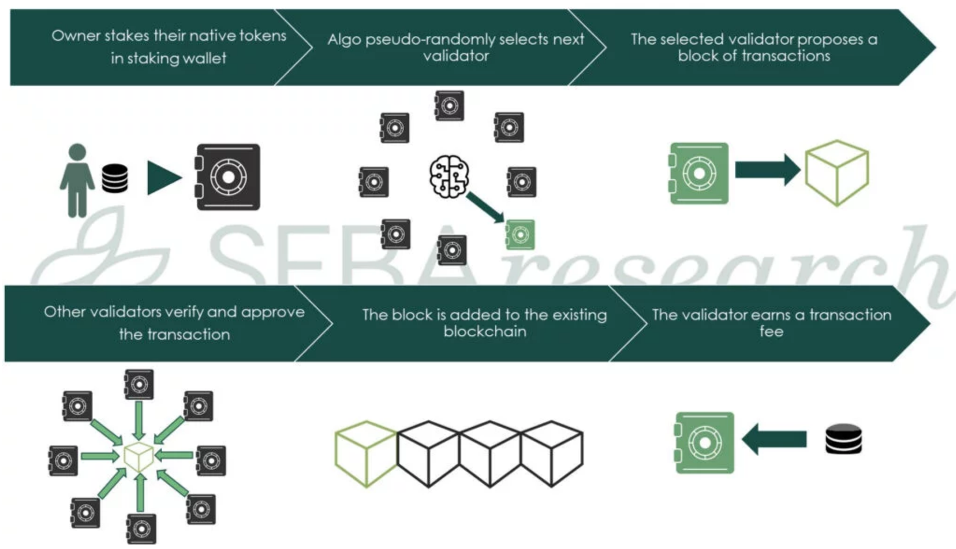


Source: (Ledger, 2023)

2.1.3 Ethereum and Proof of Stake

For example, another cryptocurrency called Ethereum, which is the second cryptocurrency in the world in terms of market capitalization, switched from the Proof of Work consensus process to another one called Proof-of-Stake. Ethereum completed this change on September, 2022 in order to reduce the power demand needed in the mining process and achieved that by reaching levels of approximately 99% power reduction (De Vries, 2023). In Proof of Stake block creators are called validators. In order to participate in the validation of block information and confirm transactions you have to own an amount of coins and stake them for the chance to be randomly selected and gain the opportunity to take part in the voting process and be rewarded. The selected validators then propose a block of transactions and if that block is voted to be valid in the voting process then the validator earns a transaction fee (Figure 2.2). This system differs from Proof of Work in the sense that it substitutes massive computational power and energy demand that machines require in order to mine coins that use PoW with staking coins.

Figure 2.2: Proof of Stake consensus mechanism process



Source: (SEBAResearch, 2020)

2.1.4 Characteristics of cryptocurrencies

Cryptocurrencies are widely used in the modern world because they carry important aspects that people see benefit in. Some of the most significant characteristics of cryptocurrencies include its decentralized structure, the impenetrable security and the user anonymity. Furthermore, we will discuss elements of mining and the market of cryptocurrencies.

Decentralized Structure

Thanks to the blockchain technology, cryptocurrencies are decentralized networks that do not require a central authority or organization to mediate between a buyer and a seller. Each individual has the exact identical copy of data in the shape of shared ledger that can't be edited or distorted in any capacity because the other members will reject it. Also, thanks to this characteristic, cryptocurrencies cannot be affected by inflation that is a result of government policy increasing the money supplies. Finally, since this digital currency is not tied down to any national or economic system and cannot be subject to any monetary policies.

Security and user anonymity

Another benefit to the decentralized structure is security. With the use of cryptography blockchain, transactions are protected by high difficulty and power demanding mathematical equations that are almost impossible to hack. All cryptocurrency transactions are stored in different blocks with time stamping and thus cannot be manipulated. To further ensure security, users are issued with two keys. A public key in order for other members to find them and initiate a transfer of assets and a private key for the purpose of unlocking their own wallet to access their funds. On that premise, users retain their anonymity and do not have to provide their financial information and history to financial institutes.

Increasing difficulty

Difficulty of a cryptocurrency is an expression of the amount of power that is needed to mine a new block. A greater cryptocurrency difficulty indicates that more computer resources are required in order to verify the transactions that are entered on the blockchain. For instance, difficulty of bitcoin mining as can be seen in figure A.1 is recalculated as we mentioned every 2,016 blocks in order to maintain the average time needed to mine a block as the total network hash rate is changing. With this technique, security is also ensured since higher difficulty would mean hackers or attackers in the network would have to apply substantial amounts of computer resources in order to alter and manipulate the system.

Reward halving

A noteworthy aspect of the cryptocurrency and its mining process is reward halving. We already mentioned that when a miner solves the hash and creates a new block he is rewarded an amount of cryptocurrency coins and a sum of transaction fees. After a certain amount of coins is mined, that reward is halved. For example, back in 2009 the reward for a new block in bitcoin was 50 bitcoins. This number was halved in 2012 to 25, in 2016 to 12.5 bitcoins and the last halving occured in 2020 which the amount received for a new block is 6.25 bitcoins. In Bitcoin, the halving is every four years on average due to the fact that it takes place every 210,000 blocks which each one is mined every 10 minutes approximately. Not all cryptocurrencies require the same amount of coins to be mined before the reward is halved as Litecoin halving is happening every 840,000 blocks.

Limited supply of coins

Each cryptocurrency on its creation, issues a certain amount of coins that can be mined. This parameter generates additional value on the wealth of the crypto due to the fact that there will be a limited amount of coins and high demand. When that number is reached no more coins can be created and the only incentive members of the network will have is to obtain the transaction fees from the validation. For example Bitcoin has a maximum number of 21,000,000 coins that based on calculations will be reached around year 2140. On the other hand, some coins like Dogecoin and Ethereum have no maximum supply.

High volatility and risk

Cryptocurrencies are characterized by substantial price fluctuations and are considered high-risk investments. This happens because they are heavily relied on supply and demand due to the limited number of coins available in the market, the media actions and on the sentiments of users. For example, a notable event occurred on April 3rd, 2023 when the widely known CEO of Twitter Elon Musk changed the platform's logo to a Shiba Inu icon which is the mascot of the Dogecoin causing a spike of 31% increase in the cryptocurrency's price on the same day. Another major price fluctuation happened with Bitcoin dropping from 58,803$ (May 2nd, 2021) to 31,533$ on July 17th, 2021 only to rise again to a record high of 64,459$ on the same year on November 7th(Figure A.2).

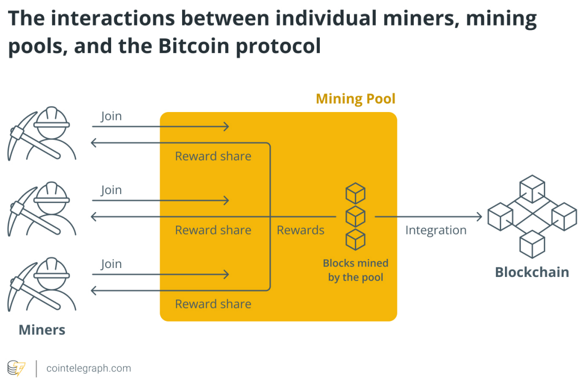
2.1.5 Mining Hardware

While people used to mine cryptocurrency in their own home using their regular computer CPU (Central Processing Unit), the increasing difficulty of new block mining has made it more computational power demanding to have a chance of being rewarded. This resulted in a change from CPUs to GPUs (Graphics Processing Unit) and later to FPGAs (Field Programmable Gate Array). Nowadays, in order to mine cryptocurrency that uses the PoW consensus mechanism you are required to own high quality expensive devices to have a better chance to be the one to mine a new block. These computers use an integrated circuit chip called Application-Specific Integrated Circuit (ASIC). These computers are specifically designed to solve mining algorithms. While the creator of Bitcoin originally intended for mining to be on regular computers using CPUs (Central Processing Unit) and GPUs (Graphic Processing Unit) with the increase in the popularity of the coin and the need for more computational power they were quickly replaced. Even though ASIC machines are more energy efficient than ordinary computers they still require tremendous power to participate in the mining process. With the intent of increasing their chances to be the one to mine a new block and be rewarded, miners join mining pools.

2.1.6 Mining Pools

Mining pools are joint groups of cryptocurrency miners who combine their computational power over a network to have a higher chance of successfully finding a new block. Mining pool members contribute in the total processing power of the network and earn a reward if someone on this network mines a new block. When a new block is mined, the reward is shared among the members according to their contribution (Figure 2.3). Some of the largest mining pools in the world are Foundry USA with a hash-rate share of 29%, Antpool with a hash-rate share of 20%, F2Pool with a hash-rate of 15% and Binance Pool with a hash-rate share of 10%.

Figure 2.3: The mining pool process of rewarding the members



Source: (CoinTelegraph, 2022)

Chapter 3

Literature Review

3.1 Literature Review

The global energy crisis that has afflicted the world in recent years has been the focus of talks all across the world, with cryptocurrency mining becoming a hot topic due to its high energy consumption. Many academics have established in recent years that it is in fact high energy consuming, and they make an effort to propose alternative lower energy consuming ways to carry out the procedure. The academic community has tried to quantify the amount of electrical energy cryptocurrencies are using with early calculations back when people would mine Bitcoin with CPUs, GPU and early models of ASIC machines. Karl J. O'Dwyer and David Malone using the hash rate of the network and the energy efficiency of mining hardware estimated the Bitcoin mining network to have an energy demand lower bound of 0.1 GW and a top bound of 10 GW while Ireland would consume around 3 GW on average showing the scale of power needed in mining (O'Dwyer and Malone, 2014). Using the total mining reward available to miners De Vries found that the average electricity per unique transaction ranges from 491.4 KWh to 765.4 KWh, calculating a total energy consumption lower bound of 40 TWh and an upper bound of 62.3 TWh. On top of that, since the only purpose of ASIC machines is to mine cryptocurrencies, once they reach the end of their economic lifetime they become electronic waste afterwards. De Vries calculated the Bitcoin cycle every 1.5 year to produce 16,442 metric tons of mining equipment, that means 10,948 metric tons annually (De Vries, 2019). Supposing that Bitcoin mining machines are achieving claiming efficiencies of 0.098 joule per gigahash, estimations show the lower bound of energy required to be 2.55 GW and could even reach country-level numbers of 7.67 GW by 2018 (De Vries, 2018) while Mishra, Jacob and Radhakrishnan estimated the demanded energy to be 17.96 GW assuming the network processes 100 million transactions per week (Mishra et al., 2017). Vranken using the earnings of bitcoin mining and taking in fact that a bitcoin is mined every 10 minutes estimated the lower bound of energy consumption to be around 45 MW if the latest models were used and an upper bound of 1.3 GW when using an average price of electricity 60\$/MWh (Vranken, 2017). Gauer in 2017, created a formula to estimate an average electricity consumption of the bitcoin network by using the aggregate hashing power usage, the total fees, the reward from mining a new block, the average price of a bitcoin in USD and the average cost of a kWh. That year the average price of bitcoin was 3,524\$, the block reward was 12.5 bitcoin per block and the cost of 1 kWh was 0.05\$. This resulted in a total electricity consumption of the entire Bitcoin network to be 33.56 TWh on average and an average energy demand of 3.8 GW(Gauer, 2017). A group of academics from Italian universities have calculated the bitcoin network to emit 4.6 CO_{2eq} per 1\$ expended on electricity required in mining. On top of that, the energy efficiency has decreased over the years from 10^4 hash/J to 10^{10} hash/J forcing miners to switch to more energy efficient machines to maintain their profitability (Giungato et al., 2017). Furthermore, Krause and Tolaymat using the energy mixes of India, China, The United States, Canada, Korea, Japan and Australia and also applying the highest and lowest carbon emission factors of India and Canada used data from January 1st, 2016 to June 30th, 2018 and estimated the Bitcoin network CO_2 emissions to be in the range of 3 - 13 million metric tonnes. Using this same method they also estimated the networks of Ethereum, Litecoin and Monero to generate 300,000 - 1.6 million tonnes of CO_2 emissions combined. They also compared these cryptocurrencies with mining of commodities like aluminum, gold, copper and platinum and found that Bitcoin, Ethereum, Litecoin and Monero consumed 17, 7, 7 and 14 MJ respectively to generate 1$ while the aforementioned commodities required 122, 4, 5, 7 to generate 1$. Note also that these are low bound estimations due to the fact that they ignore costs for cooling equipment, maintenance costs and infrastructure requirements (Krause and Tolaymat, 2018). John Truby, after showcasing that the estimating KWh consumption per transaction is 200 KWh for Bitcoin, 37 KWh for Ethereum and 0.01 for a Visa transaction is proposing ways to reduce this consumption. Firstly, he suggests introducing a tax on mining machines that are imported based on their electrical energy consumption and a mandatory registration for each machine, to impose tax charges based on its carbon emissions. In order to reduce this emission output, he suggests disallowing transactions that emit emissions above a specific threshold. Finally, he proposes taxing on miner's profit in cryptocurrencies that are using an excessive amount of energy (Truby, 2018). After determining that the hash rate and the thermal design power, which is used by CPUs and GPUs mining Monero, have a linear relationship, they where then able to predict the hash rate in 2018 by using an Auto Regressive Moving Average Model and the current at the time hash rate. Then, the electricity consumption of the Monero mining network was estimated to be 645.62 KWh in Europe, Asia and the United States. Finally, assuming all miners are a part of the F2Pool mining pool and the intensity of carbon is 0.63-0.64 kg $\mathrm{CO_2}$/KWh in China they might generate a minimum of 19.12 - 19.42 thousand tons of carbon dioxide (Li et al., 2019). Kufeoglu and Ozkuran using data from 269 different hardware including GPU, CPU, FPGA and ASIC machines and historical data of bitcoin found the highest peak of energy demand to be on December 18th, 2017 with a minimum demand of 1.3 GW and a maximum demand of 14.8 GW. Finally, they estimated the annual energy consumption on 2018 to be in the range of 15.47 TWh and 50.24

TWh (Küfeoğlu and Özkuran, 2019). Defining the lower limit as the instance where all miners utilize the most effective equipment and the upper limit as the point where earnings from mining and cost of electricity are equal, the annual power consumption as of November, 2018 would reach 45.8 TWh (Stoll et al., 2019). Stoll, Klaaßen and Gallersdorfer using the same method as Krause and Tolaymat, have estimated the Bitcoin network to consume 4.3 GW. In addition, they estimated the other 19 of the top 20 cryptocurrencies by market cap (Bitcoin being the first), to amount to the remaining 1/3 of the total electrical energy expenditure (Gallersdörfer et al., 2020). Moreover, while the Cambridge Bitcoin Electricity Consumption Index (CBECI) and the Bitcoin Energy Consumption Index (BECI) estimate that the Bitcoin network is consuming 73.1 to 78.3 TWh of electrical energy annually, De Vries uses an alternate approach by dividing the Bitcoin mining market development in three different stages: growth, stability and decline. The growth stage is identified by looking at the increasing amount of hashrate in the network. Stability and decline can be identified by observing the flat or decreasing amount of hashrate. Using this method he estimates the Bitcoin network to consume 87.1 TWh of electrical energy annually as of September 30, 2019 (De Vries, 2020). Sedlmeir used data until May 2020 to form a method to calculate the minimum power consumption using the total power consumption along with the aggregate hash rate and minimum energy estimating the lower bound to be at least 60 TWh annually. Adding, the rewards and transaction fees the upper bound was estimated to be 125 TWh per year (Sedlmeir et al., 2020).

With the increasing prices of electricity over the past decade and the difficulty recalculated based on the uprising demand for cryptocurrencies, mining requires more computational power with members of mining networks seeking to maintain their profitability. Alex Heid suggests that miners who start their mining process right after the difficulty has notably increased, are unlikely to gain profit from market volatility and instead might be affected negatively by the fluctuations due to the fact that it will take longer to break even with the initial capital investment

(Heid, 2013). After establishing that ASIC is the most profitable and energy-efficient mining machine Krishnan, Saketh and Vaibhav used a 11 month period of Bitcoin and concluded that the difficulty increased by 7.5% and the network hash rate increased by approximately 347%. This results in a reduced profitability for miners that would now require more computational power to participate in the process. Finally they propose switching to cloud mining by renting ASIC machines to utilize and a platform to run their applications or rent the hashing power of the machines that are owned by mining corporations (Hari et al., 2015). Mohatar, Rota and Herraiz quantified the cost of one hash operation and assuming the formula MP=MC from the economic theory were able to calculate the minimum price at which miners would continue their mining process. They came to a conclusion that bitcoin mining is not profitable anymore for users that cannot find electricity prices below 0.14$/KWh and June 23rd of 2018 was the day which bitcoin stopped being profitable for non professional miners outside China (Delgado-Mohatar et al., 2019). Islam, Marinakis and Olson using data for GPU machines analyzed the profitability of the Ethereum mining network, conjecture that in order to stay profitable there has to be a 1% growth in the network has rate weekly and the increase in cryptocurrency prices has to make up for power consumption and the additional capital investment. They also mention that as the block mining rewards are halved, a substantial profitability source of a miner is transaction fees reaching 40% of income in 2020 (Islam et al., 2021). Albuquerque and Rodrigues analyzed the Zcash cryptocurrency and came to conclude that it is the best coin for solo mining due to the fact that it uses a protocol called zero knowledge that allows users to not disclose their public keys and the amount transferred. They evaluated breaking even with the initial capital investment, when mining Zcash with the most expensive KWh available in the United States of America, to be 555 days and 533 days with the least expensive KWh accessible (Albuquerque and da Silva Rodrigues, 2023).

Chapter 4

Methodology

4.1 Methodology

In the following chapter, we will present the sources of our data, as well as the methods we implemented to do the preprocessing and make sure they are well equipped to make use of. After collecting the data, we had to deal with cleaning them of missing values, duplicates and filling the gap of the preceding 91 days prior to the start of the downloading process. Then, we display the thought before displaying the top cryptocurrencies by market cap and proposing ways a miner can stay profitable.

4.1.1 Data collection

For the collection of the data we use the method of scraping by making a python script, called a webscraper, that extracted the information from the website asicminervalue. A webscraper is an algorithm that is used for the purpose of extracting data from the world wide web using a crawler that follows the website links that are provided in order to access the data and a scraper, which is a tool created to gather these data from that website. The webscraper was run once a day from September 1st, 2022 to July 28th, 2023, each day generating two csv files with data on that time. One csv file contained the full list of ASIC machines using multiple algorithms and the second csv file only contained a list of ASIC machines that used the SHA-256 algorithm. As it can be seen in table A.1 using this method we extracted panel data and created two databases with 123,393 observations which contain information about various different ASIC (Application-Specific Integrated Circuit) mining machines including the manufacturer of the computer, the specific model, the algorithm they are using to mine cryptocurrencies, their unique URL of which we downloaded the data, the power they are consuming, their income per day and their electricity consumption per day. The website calculates the cost of electricity by making the assumption it is priced at 0,12$ KWh. Some of the most well-known mining manufacturers that are also large mining pools include Bitmain, Goldshell, Baikal Electronics.

4.1.2 Preprocessing

When dealing with data many issues can exist such as variables needing transformation or noise induction in the dataframe. These problems can have a significant impact on the quality and the accuracy of the end product giving prompt to wrongful decision making. This is why in our data it is important to make sure they are in a correct format and ready for the analysis. Specifically in our research, some of the issues we encountered include filling missing data, variable transformation, identifying duplicate values, creating a new column by using other variables and correctly grouping the data.

Missing Dates

When you are engaged in doing a task every day for a long time, some mistakes have the possibility to occur. As the code is run, the data are downloaded in that current time and day. On some days, the script was executed after 12 AM so the data was for the following day resulting in a missing date for the previous one. In order to solve this issue and fill the gap in our data for the income and electricity per day columns, we employed the method of filling the values with the last available value we had in possession.

Missing values and duplicates

As stated above, when we ran the webscraper after 12 AM thinking it would include the data from the day we wanted it resulted in duplicate values due to the fact that we also ran the script the following day (after 12 AM) as the procedure demanded. We identified the duplicate values by grouping and locating which combination of ASIC manufacturer, model and URL existed more that once for each day. We dealt with this obstacle by keeping the last value of each duplicate to better capture the information in view of the fact that they contain better information in the middle of the day. Another important issue to address is dealing with missing values in the data. Some possible solutions are to fill them using the mean value of all data for each column, or use the mean value of the data for the missing's specific group. Another way to deal with this problem and this is the method we used in this dissertation is to drop the missing rows since they are 1% or less than the total of observations we contain.

Filling the previous days

In our webscraper, we implemented a method to download the graph provided for each machine that contained the profit for each day of the previous 91 days. With this thought in mind, we created random observations for each machine 91 days prior to the start of the data collecting process on September 1st. Then, we modified the values of these observations to take the appropriate profit values from the graph and in view of the fact that electricity cost per day is constant we also filled the income values by using the formula: Income = Profit - Electricity. This means that we managed to complete our dataset from June 2nd, 2022 to July 15th, 2023.

Filling the errors with the median

Our webscraper in some days, encountered an error and downloaded false values for income per day. After checking our data carefully, we noticed that this amount of false values was approximately 3-4% of our total data. In order to solve this issue and restore our values, we used the median of each model up until the day of each extreme value and corrected the data.

4.1.3 Empirical process

In order to find the most profitable ASIC machines for miners, we need to first discover the top 20 cryptocurrencies by market cap. Since the goal is more profit-making mining we will only utilize coins with Proof of Work consensus mechanism for the reason that Proof of Stake coins cannot be mined with hardware equipment. For this purpose, we made use of sources like CoinMarketCap (2023), Coinwarz (2023) and Poolbay (2023). As it is presented in Table 4.1, Bitcoin is the leading cryptocurrency by market cap as of July 15th, 2023 with its market cap being 589.51 billion US dollars, a network hash rate per second of 356.14 exahashes per second and a market price of 30.265,51$. The second in the list is Dogecoin with a 10.37 billion US dollars market cap, a network hash rate of 786.95 terahashes per second and a price of 0.07$ in the market. Litecoin is third with 7 billion US dollars in market cap, a network hash rate of 783.60 terahashes per second and a 94.94$ market price. Bitcoin Cash is the fourth coin in the list with 4.94 billion US dollars market cap, 2.67 terahashes in network hash rate and a 254$ price in the market. To complete the top 5 list, Monero is the fifth coin with 2.98 billion US dollars market cap, a network hash rate of 2.65 gigahashes per second and a price of 162.77$ in the market. It is important to note that Monero and other coins in the table are ASIC-resistant which means they cannot be mined with an ASIC machine but rather only with a GPU card.

Furthermore, the aim is to find the top 5 algorithms of the most profitable cryptocurrencies. The coins we mentioned above use only 3 different mining algorithms. Bitcoin and Bitcoin Cash utilize the SHA-256 algorithm, Dogecoin and Litecoin make use of the Scrypt algorithm while Monero uses an algorithm called randomx. Therefore, the top 5 algorithms that can be mined by ASIC in our list are SHA-256 mining Bitcoin, Bitcoin Cash and Bitcoin SV, Scrypt with Dogecoin and Litecoin, EtHash with Ethereum Classic, KHeavyHash with Kaspa and Equihash mining Zcash. A limitation in our research is that we did not have data of ASIC machines using the KHeavyHash algorithm and therefore, in its place we used the next algorithm called Blake2B-Sia which is operated to mine Siacoin.

Table 4.1. *Top 20 PoW Cryptocurrencies by Market Cap (As of July 15th, 2023)*

#	Cryptocurrency	Algorithm	Market Cap	Hash rate/s (network)	Price
1.	Bitcoin	SHA-256	589.51B	356.14 EH/s	30,265.51$
2.	Dogecoin	Scrypt	10.37B	786.95 TH/s	0.07$
3.	Litecoin	Scrypt	7.00B	783.60 TH/s	94.49$
4.	Bitcoin Cash	SHA-256	4.94B	2.67 TH/s	254.06$
5.	Monero*	randomx	2.98B	2.65 GH/s	162.77$
6.	Ethereum Classic	EtHash	2.76B	128.36 TH/s	19.41$
7.	Bitcoin SV	SHA-256	696.64M	493.94 PH/s	36.16$
8.	Conflux*	Octopus	597.97M	6.84 TH/s	0.19$
9.	Kaspa	KHeavyHash	550.41M	1.93 PH/s	0.03$
10.	ZCash	Equihash	522.47M	8.12 GH/s	32.00$
11.	Ravencoin*	KAWPOW	255.69M	6.06 TH/s	0.02$
12.	EthereumPoW	EtHash	207.77M	10.51 TH/s	1.93$
13.	Siacoin	Blake2B-Sia	188.48M	23.54 PH/s	0.003$
14.	Kadena	Blake2S	157.17M	439.17 PH/s	0.66$
15.	DigiByte	Groestl, Scrypt, SHA-256, Skein, Qubit	136.54M	74.90 PH/s	0.008$
16.	Flux*	ZelHash	133.64M	2.47 MSol/s	0.42$
17.	Nervos Network*	Eaglesong	121.45M	150.17 PH/s	0.003$
18.	Horizen	Equihash	118.22M	1.59 GH/s	8.50$
19.	Syscoin	SHA-256	89.15M	83.60 EH/s	0.12$
20.	Ergo*	Autolykos v2	71.09M	19.36 TH/s	1.21$

Notes: * Cryptocurrencies that cannot be mined by ASIC devices (ASIC-resistant)
Sources: CoinMarketCap, Coinwarz , Poolbay

Chapter 5

Empirical Results

5.1 Empirical Results

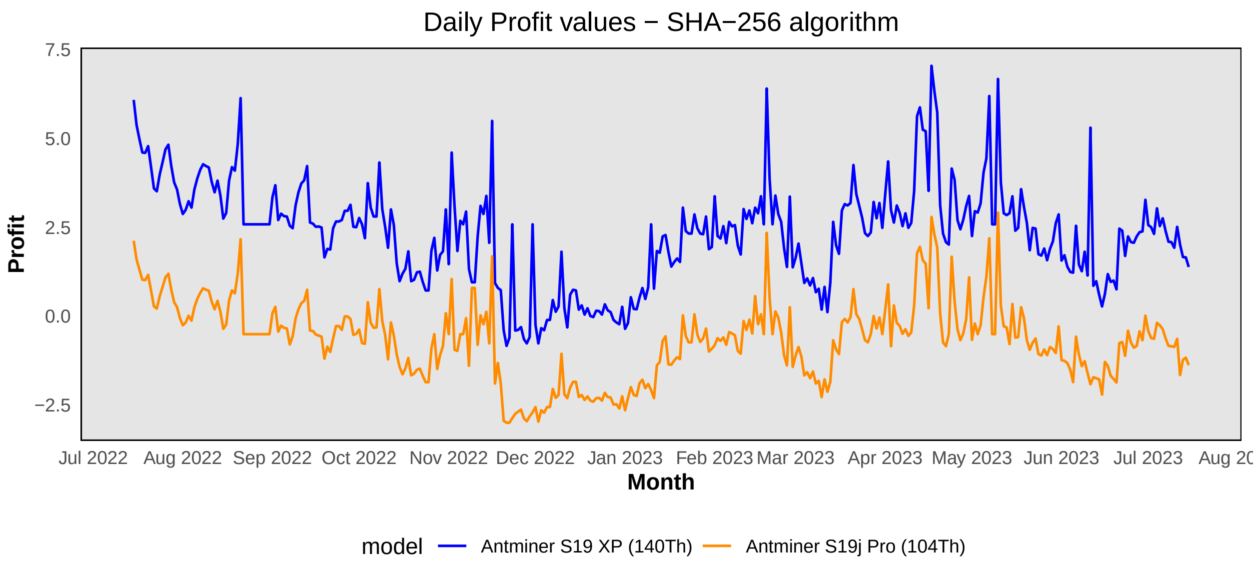
In this section, we are going to present the empirical results for the highest performing ASIC machines of the last year in terms of profitability. In order to achieve that, we split the dataset and only retained the machines that use one of the top 5 algorithms mentioned in the previous section. Subsequently, we made use of the total profitability of the full year for each computer to find the 2 most profitable ASIC device for each algorithm. Unfortunately, for the EtHash algorithm only one machine had data for the whole year.

SHA-256

SHA-256 algorithm can be used to mine some of the top cryptocurrencies in terms of market cap, including Bitcoin. Its most profitable ASIC machines of the past year are Antminer S19 XP with 140 Th per second computational power and Antminer S19j Pro with 104 Th hash rate per second which are manufactured by Bitmain. As it is presented in table 5.4, the former is the most profitable of the two with a total annual profit of 848.94$. With a hash rate of 140 Th per second, Antminer T19 displayed a median income per day of 11.17$ and a mean of 10.99$, while ranging from 7.83$ per day to 15.71$ daily (Table 5.1) while having a power usage of 3,010 W and a constant electricity cost per day of -8.67$ (Table

5.3) . Antminer S19 XP's daily profitability ranged from -0.84$ to 7.04$ with 75% of last year having a profit of 3.05$ and below. Additionally, it exhibited a median profitability of 2.50$ and a mean of 2.32$ (Table 5.2). Antminer S19j Pro on the other hand, had a negative total amount of profitability for the past year. With an aggregate loss of -250.43$ the mining computer's daily loss values ranged from -3.00$ to 2.91$ with median and mean values being -0.58$ and -0.68$ respectively. It averaged 8.16$ of income per day and 50% of the year showcased earnings below or equal to 8.25$ daily, with a constant electricity rate of -8.84$ and a power consumption of 3,068 W. The minimum amount of revenue was 5.84$ and the maximum was 11.74$, with 3 of the 4 quarters of the past year experiencing earnings below or equal to 8.76$. Below the daily profit values of the past year for each of the two ASIC machines is visualized and it can be observed as they mine the same coins, they experience the same volatility direction with Antminer S19 XP being the most profitable of the two. (Figure 5.1).

Figure 5.1: Top 2 ASIC machines profitability - SHA256

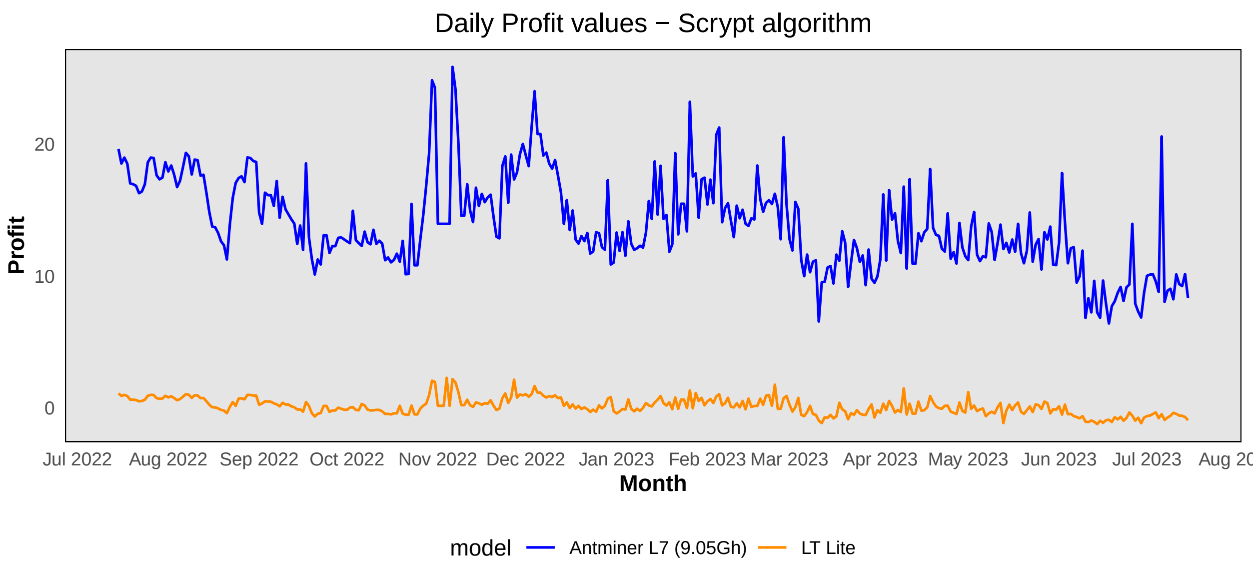


Scrypt

The second algorithm that is mining the highest-ranking cryptocurrencies is

Scrypt, with its most profitable mining computers being Antminer L7 manufactured by Bitmain with a hash rate 9.05 Gh per second and LT Lite created by Goldshell, with a hash rate of 1.62 Gh per second. Antminer L7's total profitability for the past year was 5,091.99$ (Table 5.4). Daily, the average income was 23.77$, ranging from 16.26$ minimum to 35.70$ maximum with a median value of 23.21$ (Table 5.1). Additionally 75% of the earnings were below or equal to 26.09$ and the electricity costs were constant at a daily rate of -9.86$ (Table 5.3) with a power consumption of 3,425 W. Moreover, Antminer L7 exhibited high daily profitability ranging from 6.40$ minimum to 25.84$ maximum. On average, the mean profits per day were 13.91$ and the median profit was 13.35 with 3 of the 4 quarters in the profit data being up to 16.23$ (Table 5.2). On the other hand, LT Lite's total annual profitability was 44.71$ with a daily mean income of 4.30$ and a median of 4.29$, ranging from 2.95$ each day to 6.46$ maintaining a constant electricity rate of -4.18$ with a power consumption of 1,450 W. Profit wise, values ranged from -1.23$ to 2.28$ with the median and the mean values being 0.11$ and 0.12$ respectively.

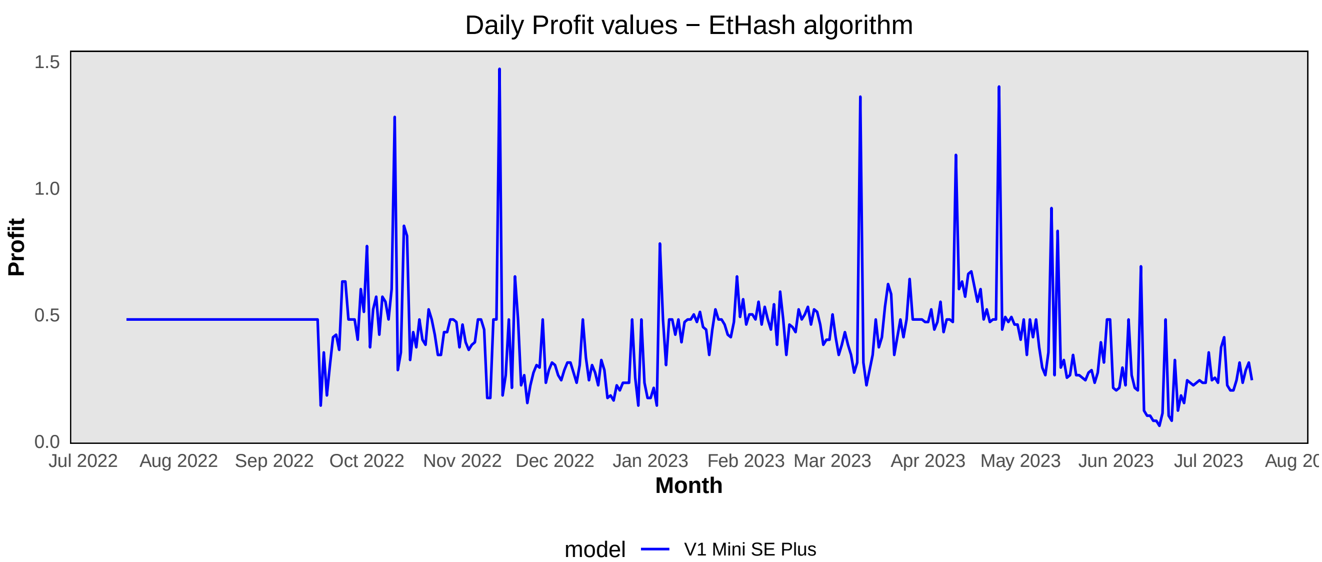
Figure 5.2: Top 2 ASIC machines profitability - Scrypt



EtHash

The third algorithm is EtHash with its most profitable ASIC mining machine being V1 Mini SE Plus with computational power of 400 Mh hash rate per second manufactured by iPollo. In total, V1 Mini SE Plus attained 151.76$ (Table 5.4) profit in this annual basis with 0.41$ mean profit per day and 0.46$ median. Values ranged from 0.06$ minimum to 1.47$ maximum with 75% of the year maintaining a profitability of 0.48$ or lower (Table 5.2). V1 Mini SE plus had an average income of 1.08$ and a median 1.13$ on a range from 0.73$ minimum to 2.14$ maximum with 75% of the year retaining earnings 1.15$ and below (Table 5.1). With a consumption power of 232 W it maintained a constant electricity cost rate of -0.67$ (Table 5.3) .

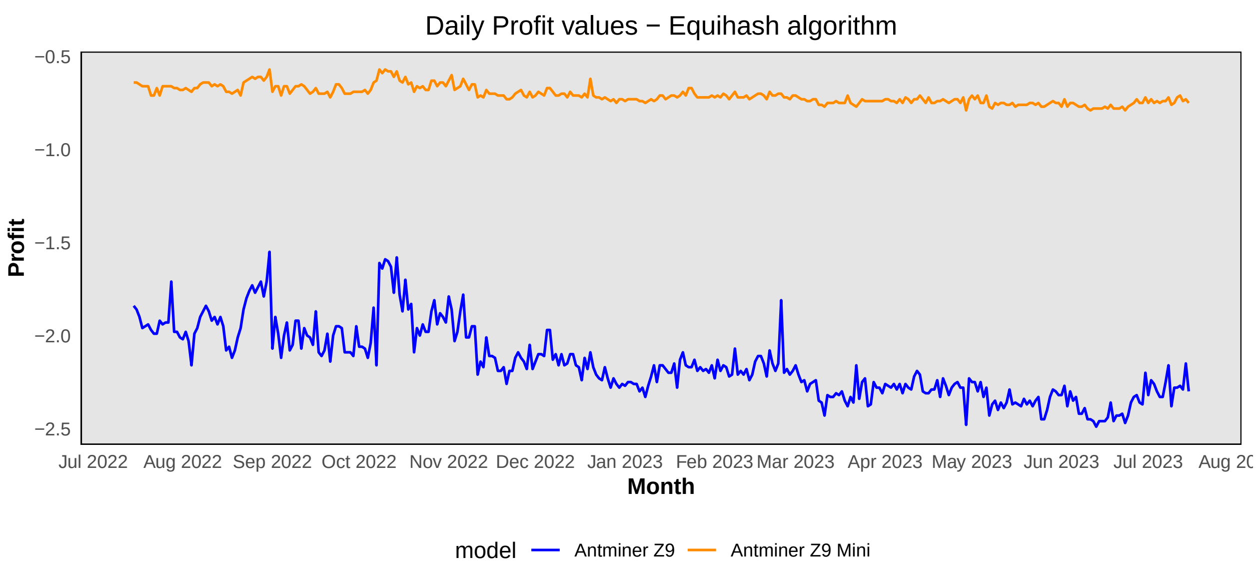
Figure 5.3: Top ASIC machine profitability - EtHash



Equihash

The fourth algorithm is Equihash with the top 2 ASIC mining machines being Antminer Z9 with a computational power of 42 ksol hash rate per second and Antminer Z9 Mini with computational power of 10 ksol hash rate per second, both manufactured by Bitmain. Antminer Z9 suffered an aggregate loss of -786.60$ in the past year (Table 5.4) with daily loss values ranging between -2.49$ minimum and -1.55$ maximum. The median loss was -2.18$ and the mean -2.15$ with 75% of days retaining a loss of -2.01$ and below (Table 5.2). Antminer Z9 had an income mean value of 0.64$ and a median of 0.61$ while ranging between 0.30$ minimum earnings to 1.24$ maximum and in 75% of days income was 0.78$ and below (Table 5.1). The electricity cost maintained a constant rate of 2.79$ with a consumption power of 970 W. Antminer Z9 Mini also suffered a total loss of -259.23$ (Table 5.4) in the past year. It had daily loss values ranging from -0.79$ to -0.57$ with median and mean values both being -0.71$ (Table5.2). On income, the mean was 0.15$ and the median 0.14$ with values ranging from 0.07$ minimum to 0.29$ maximum (Table 5.1). The mining computer maintained a constant electricity rate of -0.86$ (Table 5.3) with a power consumption of 300 W.

Figure 5.4: Top 2 ASIC machines profitability - Equihash



Blake2B-Sia

Finally, the fifth and last algorithm that is capable of mining one of the top cryptocurrencies by market cap is Blake2BSia with its 2 top ASIC computer being

HS3-SE with a hash rate of 930 Gh per second that is manufactured by Goldshell and SC1 Immersion with a hash rate of 2.2 Th per second, manufactured by Obelisk. The former mining machine, suffered a total annual loss of -53.13$ (Table 5.4) Throughout the year it preserved a mean loss of -0.14$ and a median of -0.18$ with profit or losses ranging from -0.85$ to 0.63$ (Table 5.2). The mean daily income was 1.29$ and the median was 1.26$, ranging from 0.59$ to 2.07$ with 75% income being 1.46$ or less (Table 5.1). The electricity cost for HS3-SE was constant at a rate of -1.44$ (Table 5.3) with a power consumption of 930 W. SC1 Immersion also suffered substantial losses in the past year in the level of -1,102.94$. It had a loss mean value of -3.01$ and a median value of -3.08$ with daily losses ranging from -3.72$ to -2.01$ and 75% of values being equal or less than -2.78$. On income the mean earnings were 1.59$ and the median 1.52$ with daily values ranging from 0.89$ to 2.58$ with 75% being less than or equal to 2.60$. The electricity consumption cost was at a constant rate of -4.61$ with a power consumption of 1,600 W.

Figure 5.5: Top 2 ASIC machines profitability - Blake2BSia

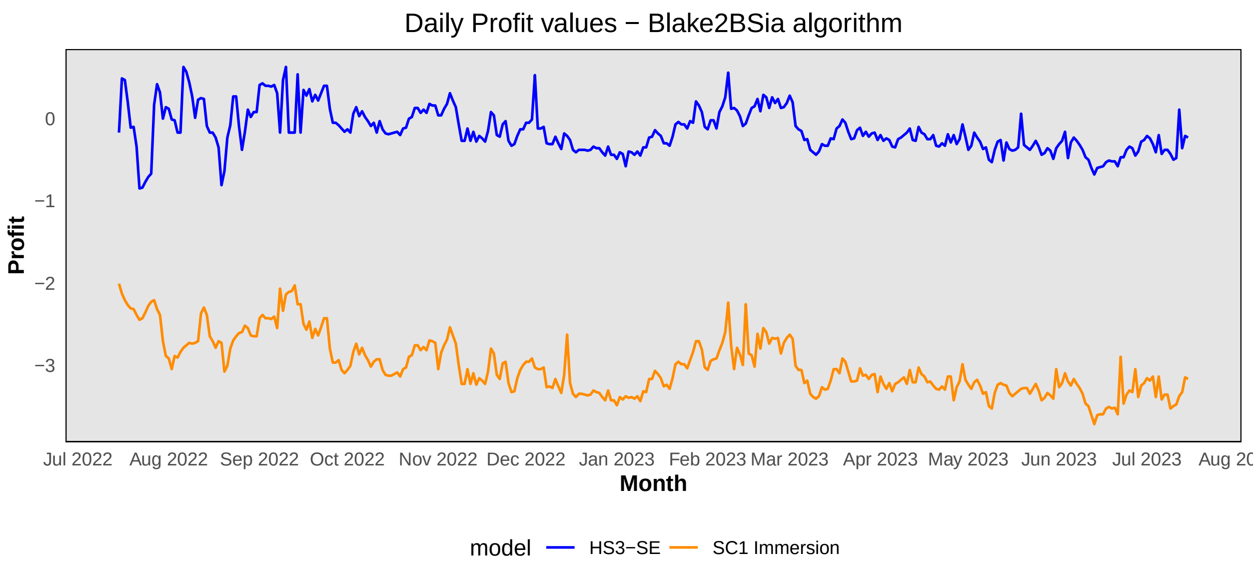


Table 5.1. *Income per day summary for the Top ASIC machines ($)*

Algorithm	Manufacturer	Model	Min	1st Qu.	Median	Mean	3rd Qu.	Max	N
SHA-256	Bitmain	Antminer S19 XP	7.83	10.05	11.17	10.99	11.72	15.71	366
	Bitmain	Antminer S19j Pro	5.84	7.45	8.25	8.16	8.76	11.75	366
Scrypt	Bitmain	Antminer L7	16.26	21.43	23.21	23.77	26.09	35.70	366
	Goldshell	LT Lite	2.95	3.86	4.29	4.30	4.71	6.46	366
EtHash	iPollo	V1 Mini SE Plus	0.73	0.96	1.13	1.08	1.15	2.14	366
Equihash	Bitmain	Antminer Z9	0.30	0.50	0.61	0.64	0.78	1.24	366
	Bitmain	Antminer Z9 Mini	0.07	0.12	0.14	0.15	0.18	0.29	366
Blake2B-Sia	Goldshell	HS3-SE	0.59	1.10	1.26	1.29	1.46	2.07	366
	Obelisk	SC1 Immersion	0.89	1.33	1.52	1.59	1.83	2.60	366

Table 5.2. *Profit per day summary for the Top ASIC machines ($)*

Algorithm	Manufacturer	Model	Min	1st Qu.	Median	Mean	3rd Qu.	Max	N
SHA-256	Bitmain	Antminer S19 XP	-0.84	1.38	2.50	2.32	3.05	7.04	366
	Bitmain	Antminer S19j Pro	-3.00	-1.39	-0.58	-0.68	-0.08	2.91	366
Scrypt	Bitmain	Antminer L7	6.40	11.56	13.35	13.91	16.23	25.84	366
	Goldshell	LT Lite	-1.23	-0.32	0.11	0.12	0.53	2.28	366
EtHash	iPollo	V1 Mini SE Plus	0.06	0.29	0.46	0.41	0.48	1.47	366
Equihash	Bitmain	Antminer Z9	-2.49	-2.29	-2.18	-2.15	-2.01	-1.55	366
	Bitmain	Antminer Z9 Mini	-0.79	-0.74	-0.71	-0.71	-0.68	-0.57	366
Blake2B-Sia	Goldshell	HS3-SE	-0.85	-0.34	-0.18	-0.14	0.02	0.63	366
	Obelisk	SC1 Immersion	-3.72	-3.28	-3.08	-3.01	-2.78	-2.01	366

Table 5.3. *Daily electricity costs for the Top ASIC machines ($)*

Algorithm	Manufacturer	Model	Electricity cost ($)	N
SHA-256	Bitmain	Antminer S19 XP	-8.67	366
	Bitmain	Antminer S19j Pro	-8.84	366
Scrypt	Bitmain	Antminer L7	-9.86	366
	Goldshell	LT Lite	-4.18	366
EtHash	iPollo	V1 Mini SE Plus	-0.67	366
Equihash	Bitmain	Antminer Z9	-2.79	366
	Bitmain	Antminer Z9 Mini	-0.86	366
Blake2B-Sia	Goldshell	HS3-SE	-1.44	366
	Obelisk	SC1 Immersion	-4.61	366

All machines

Even though it is not the most powerful device in terms of computational power or hash rate, Antminer L7 which is using the Scrypt algorithm to mine some of the top cryptocurrencies in the market like Litecoin, Dogecoin and Syscoin is the most profitable unit of the past year with a total profit of 5,117.75$, a computational power of 9.05 Gh hash rate per second and 3,425 W power consumption (Table 5.4). The second most profitable ASIC mining machine is Antminer S19 XP that utilizes the SHA-256 algorithm to mine top tier coins like Bitcoin, Bitcoin Cash and Bitcoin SV. It managed to gain a profit of 848.26$ with a computational power of 140 Th hash rate per second and 3,010 W power consumption. Finally, more than half of the top mining devices presented on the table had a negative total profit in the past year with Obelisk's SC1 Immersion suffering an aggregate loss of -1,104.12$.

Table 5.4. *Total Profit of the Top 2 ASIC machines per algorithm*

Algorithm	Manufacturer	Model	Hash rate/s	Power	Profit ($)
SHA-256	Bitmain	Antminer S19 XP	140 Th	3010 W	848.94
	Bitmain	Antminer S19j Pro	104 Th	3068 W	-250.43
Scrypt	Bitmain	Antminer L7	9.05 Gh	3425 W	5,091.99
	Goldshell	LT Lite	1.62 Gh	1450 W	44.71
EtHash	iPollo	V1 Mini SE Plus	400 Mh	232 W	151.76
Equihash	Bitmain	Antminer Z9	42 ksol	970 W	-786.60
	Bitmain	Antminer Z9 Mini	10 ksol	300 W	-259.23
Blake2B-Sia	Goldshell	HS3-SE	930 Gh	930 W	-53.13
	Obelisk	SC1 Immersion	2.2 Th	1600 W	-1,102.94

Chapter 6

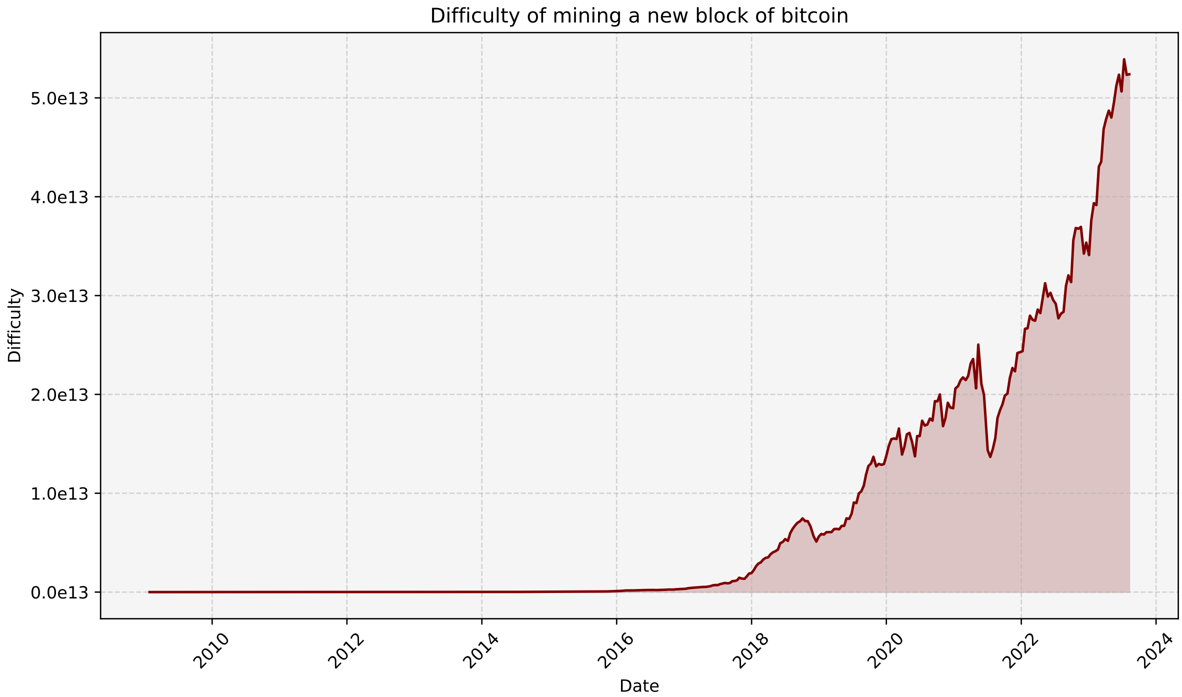
Conclusions

6.1 Conclusions

The most important thing when dealing with a problem is knowledge. Over the past two decades and with the advance of the technology, knowledge and information has become widely available to everyone that has access to the internet, but when addressing the issue of cryptocurrency electrical energy consumption that has troubled the world in the last decade there is a lack of information available. This thesis focuses on one of the most discussed issues of the past years, which is inadequacy of data available, in order to better understand the impact of the continuously increasing amount of electrical energy that miners are utilizing for the purpose of mining cryptocurrencies. Another research question that needed answering was if mining is still profitable in 2023. After explaining the cryptocurrency mining process, how the rewards are distributed, what devices are used in the process and important aspects of cryptocurrencies, we established how important it is to address the problem of substantial amounts of electrical energy used by exhibiting the magnitude of the cryptocurrency mining networks that are now compared and in many cases surpass entire countries in terms of power consumption and also emission of huge amounts of carbon. Moreover, we discussed about the ways that someone could start mining cryptocurrencies, his main sources of income and when the process stops being profitable. With selecting the top cryptocurrencies by market cap and the algorithms they utilize, we managed to showcase the top mining devices of each of the top 5 algorithms available. We concluded that, most of the ASIC machines in the past year (5 out of 9) suffered losses ranging from -50.86$ to -1,104.12$. On the other hand, the most profitable device appeared to be Antminer L7 which uses the Scrypt algorithm to mine Dogecoin, Litecoin and Syscoin among others and had a total profit of 5,117.75$. While this dissertation provides valuable information about the issues that are cryptocurrency energy consumption and the profitability of miners, further research should be applied in order to better understand these matters in question by using the databases that are being produced in the academic community and find solutions to regulate and reduce power consumption used by mining networks and also establish if it is profitable to continue or start to mine cryptocurrencies at the current period.

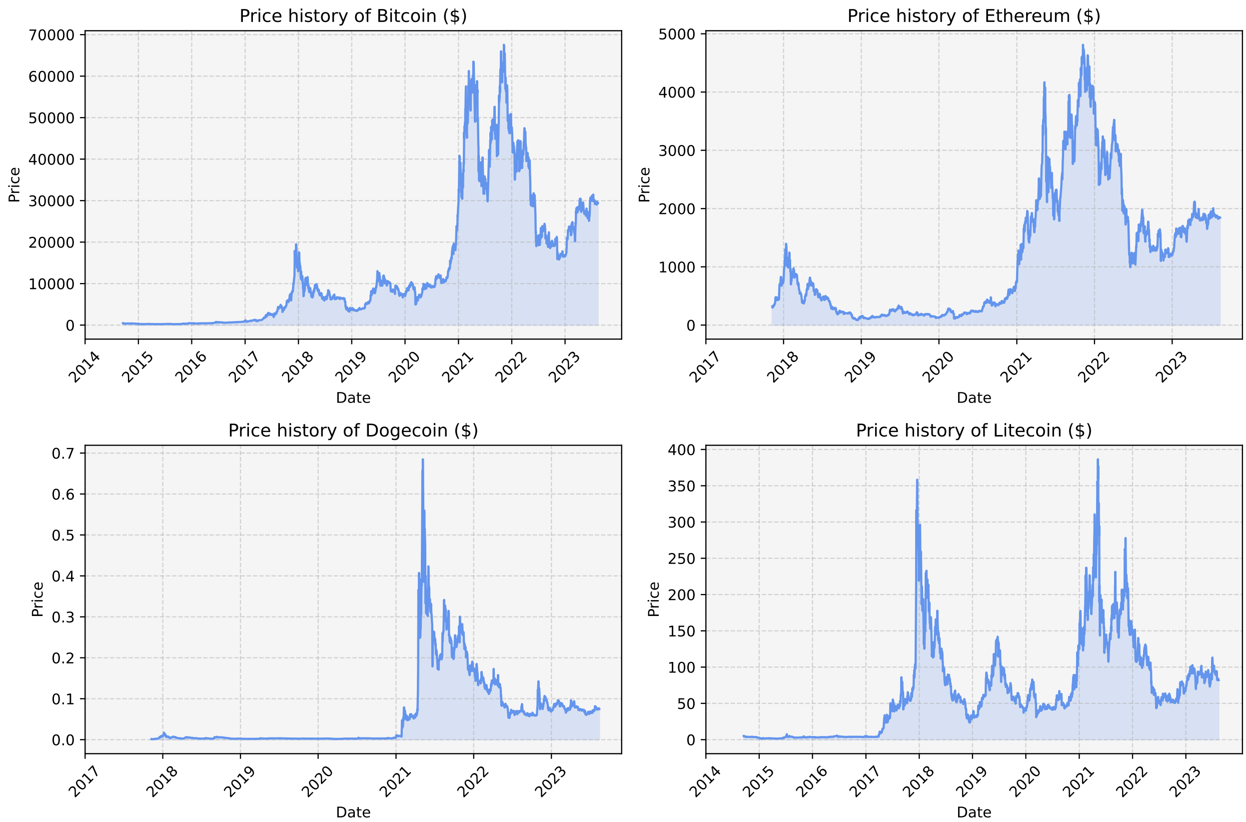
Appendix A

Figure A.1: Bitcoin difficulty chart



source: btc.com

Figure A.2: Price history of popular cryptocurrencies (USD $)



source: finance.yahoo.com

Table A.1. *Data list of variables*

Variable	Type
algorithm	character
date	date
electricity per day	float
graphdata	float
income per day	float
manufacturer	character
model	character
power	character
profit	float
release date	character
url	character

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