COMS4507, 2021 Project Report

Economics of Cryptocurrency Mining Visualisation Tool (CryptoVis)

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1. Abstract

The aim of the project was to develop a visualisation tool to better understand the economic viability of cryptocurrency mining. Given the most significant limitation on the project was time, we narrowed the scope of the project to focus on the three most popular cryptocurrencies for each type of hardware's optimal hashing algorithm. For SHA-256 optimised ASICs we used Bitcoin, for Ethash optimised GPUs we used Ethereum and for RandomX optimised CPUs we used Monero.

After completing background research and a literature review, we determined the three most important factors to consider in our product were: hardware performance, electricity price and coin price.

An Agile methodology was followed as part of our team's development process due to its adaptability and flexibility. Tools such as GitHub, Flutter SDK, Google Drive, and Zoom were used to contribute to the success of the project.

Critically evaluating our project, given the limitations and constraints of the project, we were able to achieve our set goal of developing a tool to assist cryptocurrency miners to better understand the economics behind mining.

Future areas of work identified are (not limited to): system UI improvements, support for Scrypt cryptocurrencies (such as Dogecoin or Litecoin), multiple cryptocurrency options for each hashing algorithm, and the introduction of Machine Learning models for more accurate predictions.

2. Introduction

2.1 Overview

This report will provide a detailed description of the general processes our team took to develop our proposed product. In Section 2, Introduction, the project goals, scope, desired outcomes, and contributions are stated. Following this, in Sections 3 and 4, background research conducted into the problem space of the project is presented. This includes looking into how cryptocurrency mining works on a high level and its driving economic factors. Additionally, relevant papers in this domain were reviewed along with similar existing solutions in this space. Following this research, Section 5 details the agile methodology our team took throughout the project to ensure a smooth process. Finally, we discuss the critical evaluation of our completed product in Section 6 before concluding the report.

2.2 Goals

The overarching goal of this project was to develop a visualisation tool that makes interpreting the economics of cryptocurrency mining more accessible and understandable for different mining user demographics.

The visualisation tool developed for this project was in the format of a web-hosted application where users could input their relevant metrics and resulting graphs, numeric summaries and other visualisations would be produced. To produce these results, the web app used custom numeric methods to calculate the economic viability of cryptocurrency mining for major coins such as Bitcoin, Ethereum and Monero.

2.3 Scope

For this project, our scope was limited to what we could achieve given the time constraint of about 7 weeks for the final deliverables of the project. As a result, we split our project timeline into three main stages: background research, development, and product reviewing.

For the project to be effectively carried out in the given time frame, it was decided that our product would take the sole format of a responsive web app. This decision meant that the product would be easy to build with the team's existing skill sets and could be accessible across a wide range of devices.

The data and related statistics we used in the calculations performed by our web app were limited to the data and information resources freely available on the internet. Furthermore, it was decided that we would narrow our scope of determining economic viability to only a few major cryptocurrencies such as Bitcoin, Ethereum and Monero.

2.4 Achievements and Contributions

With cryptocurrency mining becoming more and more prominent in our society, the success of this project had numerous potential benefits and applications. Building a comprehensive visualisation tool meant that we were able to significantly help cryptocurrency miners of various levels of experience and understanding.

Since determining whether cryptocurrency mining is economically viable for different individuals requires numerous factors and non-trivial calculations to be considered, the major achievement and contribution of our project was being able to alleviate the stress and burden for individuals to manually perform these calculations themselves.

Whether the user of our web app is an experienced miner or someone who is new to cryptocurrency, they could simply input some basic information about their current circumstances into the app, and various informative visuals were produced for the user to inform them about how they would perform if they were to mine cryptocurrency from that moment. The information produced by our web app allowed users to be well-informed about whether it was economically viable and profitable for them to participate in cryptocurrency mining.

3. Background

3.1 Fundamentals of Cryptocurrency Mining

Cryptocurrency is a type of digital money created from code to function outside of traditional banking and government systems. Currently there are over 1500 different cryptocurrencies available online. One of the popular cryptocurrencies to date is Bitcoin, this cryptocurrency will be the primary focus in terms of research and implementation for this project. Bitcoin is the original and arguably the most well-known cryptocurrency; it was created in 2009 by a person or group under the name of Satoshi Nakamoto. As it stands, currently there are approximately 16.7 million bitcoins in circulation [1].

A prominent feature of cryptocurrency is that it is designed to be limited in supply, and as such that limited supply equates to a higher value for the currency. This is evident where the number of Bitcoins available is not expected to exceed 21 million. Ethereum, on the other hand, has issuance capped at 18 million tokens per year [1].

Cryptocurrencies such as Bitcoin are built on the foundation of the following concepts:

- **Blockchain** – all transactions are stored in a public ledger called the Blockchain which is decentralised, such that it is maintained by a Peer-to-Peer (P2P) network.
- **Hash Functions** – one-way Hash Function that takes any size input and returns a fixed size output, e.g. SHA-256.
- **Hash Pointers** – building blocks of the Blockchain, points to a hashed block of data via an address like a normal pointer in data structures.
- **Merkle Trees** – Binary Tree with Hash Pointers, the fundamental data structure used in Bitcoin to store Transactions in a Block where integrity of a large number of data blocks, e.g. transactions in Bitcoin is protected.
- **Digital Signatures** – transactions use digital signatures such that the owner of the source funds (Bitcoin to be transferred) is 'signed' to prove ownership of funds and prevents forgery of coins or transactions.
- **Proof of Work (PoW)** - consensus mechanism where it is easy to verify a solution, easy to generate new puzzles of adjustable and predictable difficulty.

Mining of new coins in the process of adding new transaction blocks to the Blockchain. In this process, new bitcoins are attributed to the miner, adding to the total number of coins in circulation. Mining requires mathematical puzzles of various difficulty to be solved via some sort of software or code script and this validates the legitimate transactions which make up blocks. These blocks then get added to the Blockchain at regular intervals. When a miner is the first person to find the solution, it is validated using the Proof of Work method and the miner is rewarded with a set amount of Bitcoins. Generally, the faster a miner's hardware can process the mathematical problem, the more likely they are to find the solution and subsequently gain the Bitcoin reward [2].

In the process of Bitcoin mining, miners are also paid as 'auditors' verifying the legitimacy of transactions. By verifying transactions, miners are helping to prevent the "double-spending problem" where someone illicitly spends the same Bitcoin twice. The rewards for Bitcoin mining are reduced by half every four years as seen in Figure 1 below, currently mining one block would earn you just over 6 Bitcoins. Bitcoin is designed to evaluate and adjust the difficulty of mining every 2016 blocks, or roughly every two weeks. When there is more computing power collectively working to mine for Bitcoin, the difficulty level of mining increases in order to keep block production at a stable rate; less computing power means the difficulty level decreases [2].

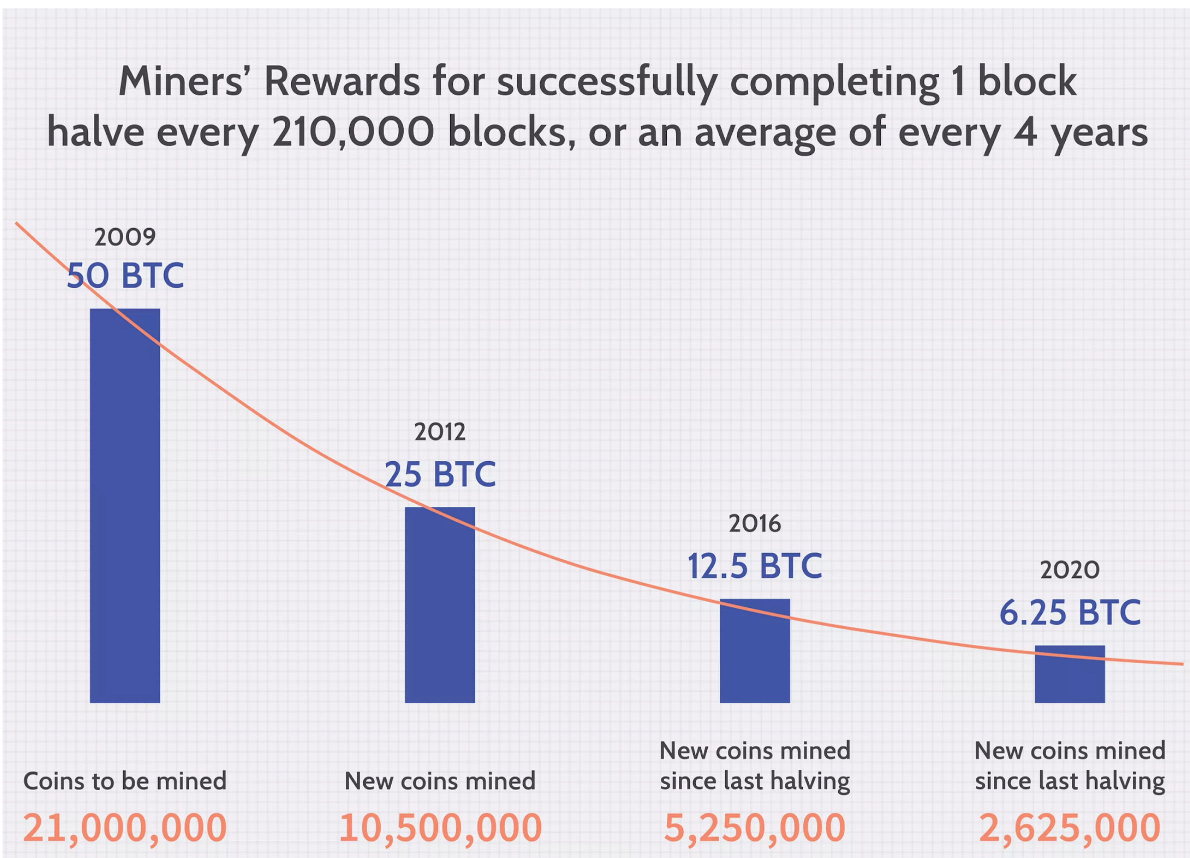

Figure 1. Trend of reward for mining a block of Bitcoin over time [2].

As stated previously, due to the limitation of the total number of Bitcoins available, the general trend is that the value of Bitcoin has been increasing with time (as seen in Figures 2, 3 below). Currently, as of April 2021, one Bitcoin is worth about just over $75,000 AUD and one Ether (top unit of Ethereum) is worth about just over $2500 AUD.

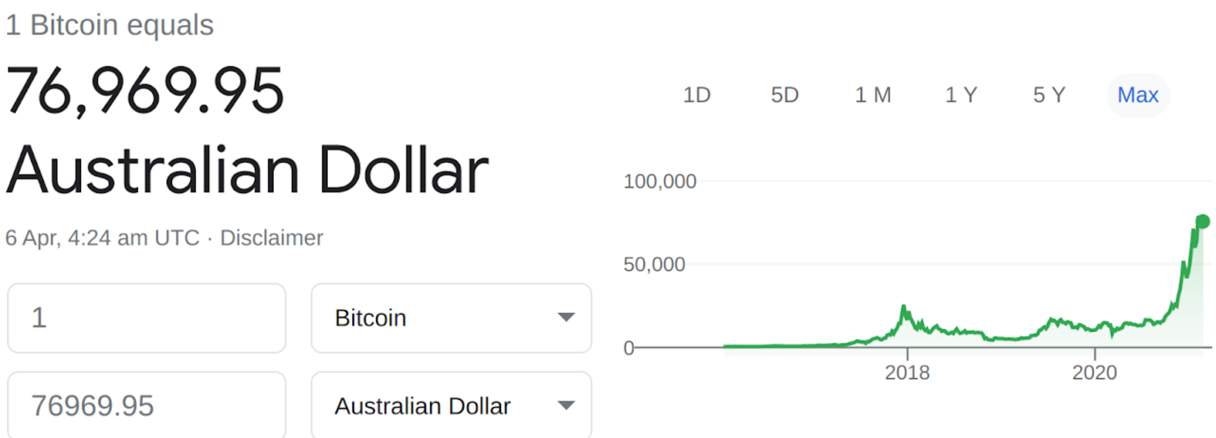

Figure 2. Historical Trend of Bitcoin's value over time [3].

Figure 3. Historical Trend of Ethereum's value over time [3].

3.2 Hardware Platforms

As stated in Section 3.1 mining cryptocurrencies such as Bitcoin requires the miner to solve some sort of puzzle using their available platform. Diving into the specifics of these mining challenges, miners are essentially using their computing power to make guesses at a target hash.

Miners make these guesses by randomly generating a nonce, hashing that nonce with some other static information, and then checking if the resulting hash is a valid answer to the puzzle. The primary objective of a miner is to complete as many of these guesses as they can as fast as they possibly can, so they have the best chance of finding a valid solution to the puzzle before anyone else. In Bitcoin mining, a nonce is 32 bits in size; the first miner whose nonce generates a hash that is less than or equal to the target hash is awarded credit for completing that block [2].

All target hashes generally begin with zeros with at least 8 zeros and up to 63 zeros. There is a maximum target set by the Bitcoin Protocol with no minimum target [2]. See Figure 4 below for an example of randomised hashes and the criteria for whether a miner has successfully reached a solution.

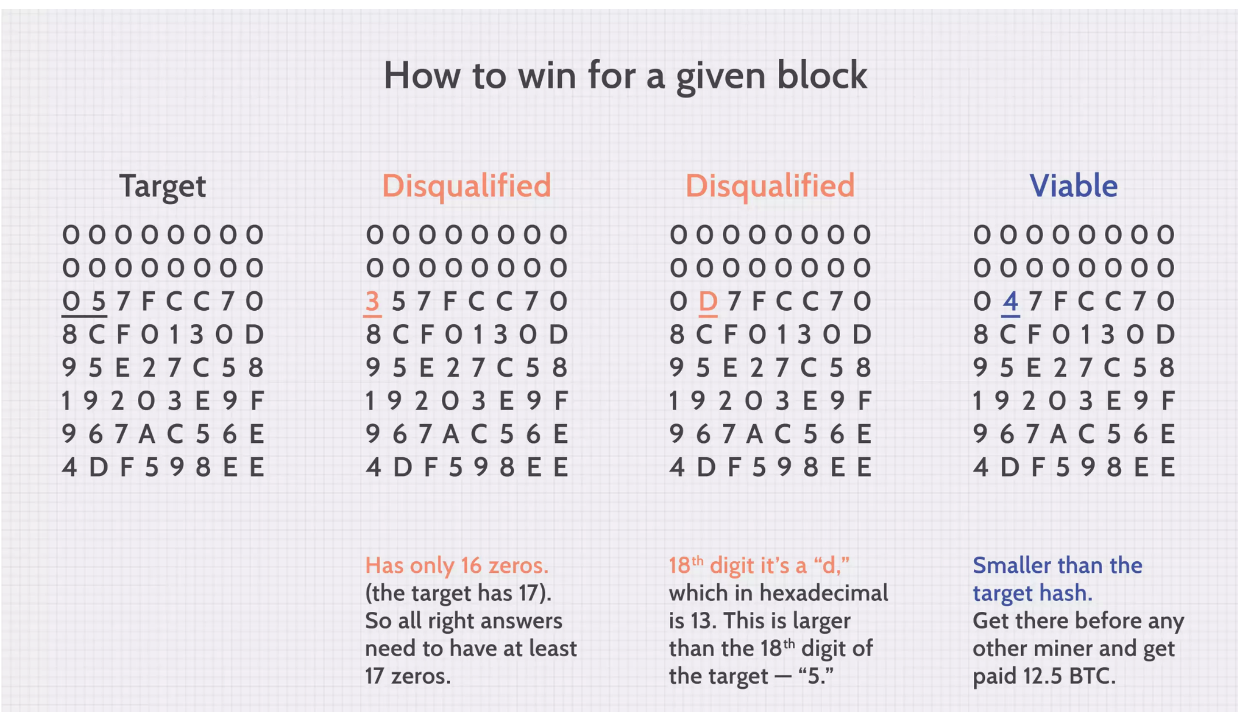

Figure 4. Example of how a miner would successfully gain a solution to a puzzle [2].

Since the output for new inputs in hash functions are chosen randomly, reaching a solution to a block is probabilistic and can take anywhere between a few hours to a few weeks. With miners essentially throwing whatever computing power they have to run software to solve these puzzles, this warrants the investigation into different hardware platforms. More specifically, with the mining puzzles requiring mass computation of hash values, the most important factor to consider for the hardware used for mining is its hash rate. Hash rate refers to the total combined computational power that is being used to mine and process transactions on the Blockchain [4].

There are three main hardware platforms to consider when one wants to dive into cryptocurrency mining: CPU (Central Processing Unit), GPU (Graphics Processing Unit) and ASIC (Application Specific Integrated Circuit) [5].

When Bitcoin first began, the only way to mine was via a CPU on a Personal Computer (PC). Intel and AMD were the famous names in CPU production. When Bitcoin was released one could mine about 100 coins a day using a CPU. CPUs were designed to switch between different tasks, since the hashes in Bitcoin required proof of work in mathematical calculation and CPUs have less arithmetic logical units; therefore, when it comes to performance in the large scale, CPU is relatively slow [5].

GPUs are often used in gaming computers for smooth flow of 3D animation and videos. GPUs can mine much faster than CPUs. GPUs are very good at mathematical computation, can be easily sourced as standard hardware and can be easily upgraded. However, GPUs have high power usages, require large equipment and have a limit on the type of cryptocurrencies it can mine [5].

ASICs are microchips purpose-built for a single hashing algorithm and designed to compute that hashing algorithm as fast as possible. Some ASICs have the ability to calculate hashes 100,000,000 times faster than modern CPUs. Currently, the most popular ASICs are designed by Bitmain and MicroBT. ASICs generally have low power use and provide better performance with a smaller physical size. However, ASICs are designed to be application specific, that is to only mine one specific hashing algorithm efficiently, and they are often also non-upgradable with a short lifespan [5].

In general, for miners it is desirable to have hardware that produces the best hash rate. CPUs, GPUs and ASICs have hash rates in the Kilo-hash/second, Mega-hash/second, and Tera-hash/second respectively. Due to the difficult nature in order to mine competitively, miners now usually invest in GPUs and ASICs which are more powerful than standard CPUs [6]. Generally speaking, the more powerful the hardware type, the more expensive the price is for that piece of hardware. The prices from a standard CPU to a powerful ASIC can range from a few hundred dollars up to tens of thousands of dollars. See Figure 5 below for a general summary of the tradeoffs for these hardwares. Also see Figures 6, 7, 8 below for table summaries of some of the most common CPUs, GPUs and ASICS.

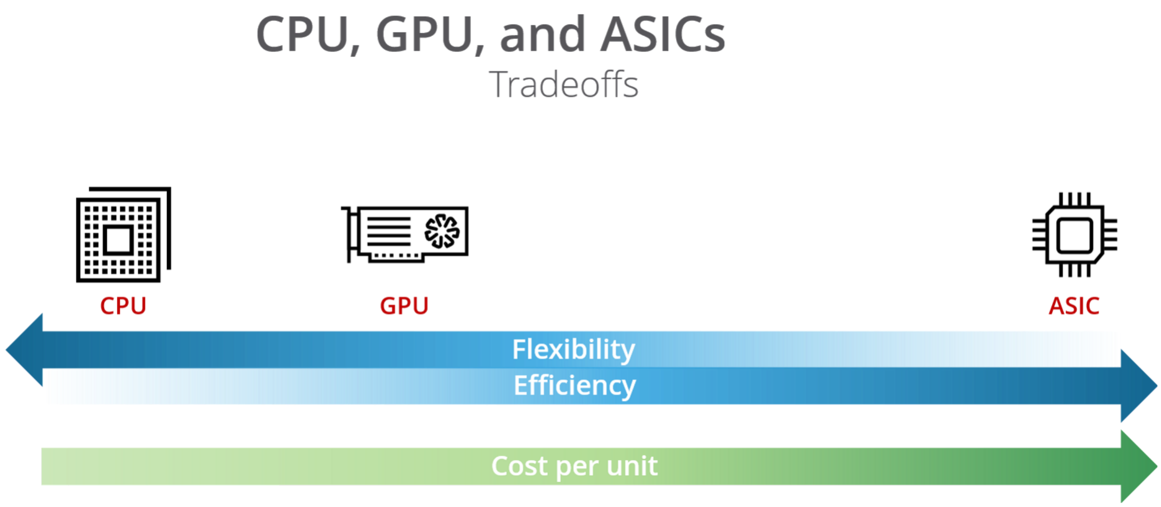

Figure 5. Summary of CPU vs GPU vs ASIC [6].

CPU	Mining speed (KH/s)	Power used (Watts)
Athlon 64 X2 5600+	6.07	89
Athlon II X3 425	9.5	125
Phenom II X4 955	22	125
FX-8120	46	125
FX-8350	65	125
Core 2 Quad Q6600	9.68	100
Core 2 Quad Q9550	32.2	125
Core i3-2130	23	65
Core i5-2500K	48	90
Core i5-3570K	55	90
Core i7-3930K	98	200

Figure 6. Popular CPUs with their associated Hash rate and Power consumption [5].

GPU	Mining speed (MH/s)	Power used (Watts)
AMD 4870	90	150
AMD 5770	240	100
AMD 5830	300	125
AMD 5850	400	180
AMD 5870	480	200
AMD 5970	800	350
AMD 6990	800	400
NVIDIA GT-210	4	30
NVIDIA GTX-280	60	230
NVIDIA GTX-480	140	250
NVIDIA Tesla S1070	155	800
NVIDIA Tesla S2070	750	900

Figure 7. Popular GPUs with their associated Hash rate and Power consumption [5].

ASIC	Mining speed GH/s	Power used watts
AntMiner S2	1000	1100
AntMiner S4	2000	1400
AntMiner S5	1155	590
ASICMiner BE Prisma	1400	1100
BFL Monarch	700	490
Black Arrow Prospero X-3	2000	2000
CoinTera TerraMiner IV	1600	2100
HashCoins Apollo V3	1100	1000
HashCoins Zeus v3	4500	3000
KnC Neptune	3000	2100
Spondooliestech SP10	1400	1250
Spondooliestech SP35	5500	3650

Figure 8. Popular ASICs with their associated Hash rate and Power consumption [5].

3.3 Economic Drivers

Following discussion of hardware options in the previous section, it is also important to consider the main economic costs associated with mining cryptocurrency. Since mining means having one's hardware turned on to continuously compute hashes to find potential solutions to the puzzle, cryptocurrency mining is a power intensive activity. Due to this, an essential factor when mining cryptocurrency is the price of electricity.

The price of electricity varies across countries (see Figure 9 below for a summary of average usage rates in major countries), specifically in Australia, it can vary depending on the state and suburb that the miner is located in along with which company is chosen as the energy provider. In Australia, there are two main contributing factors to one's electricity bill: usage rate and daily supply rate. Usage rates on average can range from 20 cents to 35 cents per kilowatt-hour (kWh); whereas, daily supply rates can range from 80 cents to 110 cents per day [7].

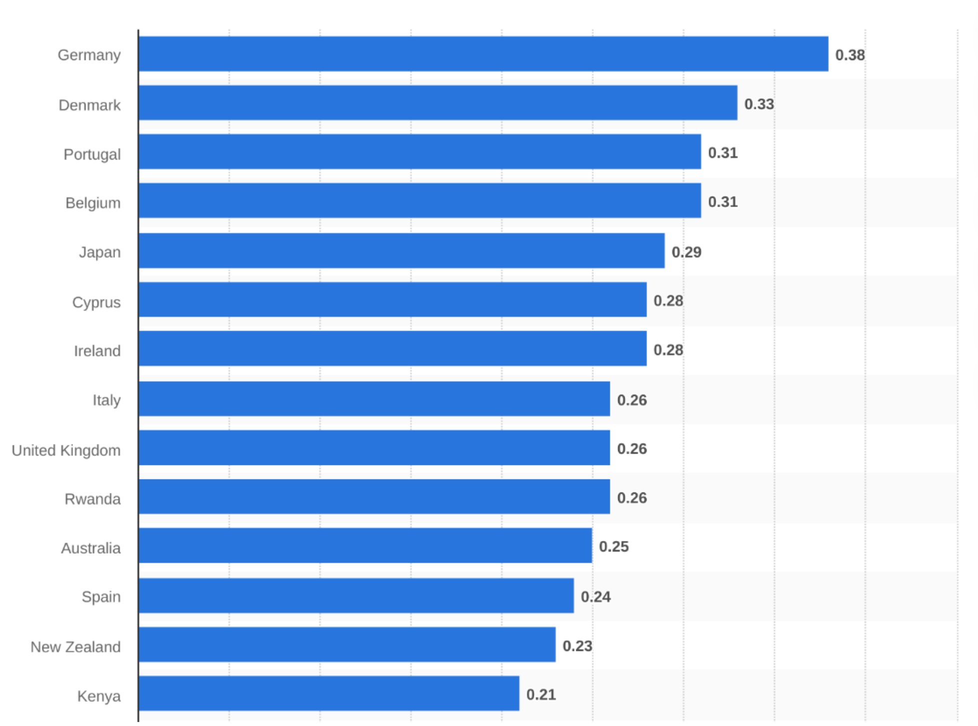

Figure 9. Average electricity usage prices for selected countries as of 2020 (in USD/kWh) [8].

Therefore, in order for cryptocurrency mining to be profitable, the miner must consider that the total amount of reward they gain from mining must be higher than the initial cost of their mining hardware summed with the ongoing cost of electricity due to power usage from the hardware. Furthermore, it is also important to consider that in some countries of Africa, the Middle East and South America, cryptocurrency mining is illegal as it is considered a threat to the dominance of fiat currencies and government control over the financial markets [2].

With mining rewards paid to the miner who discovers a solution to the puzzle first with the probability of a miner being the one to discover the solution equal to the portion of the total mining power on the network. Hence, a person with a small amount of computing power stands a very small chance of discovering the next block on their own.

One way for miners to ease their workload and have a higher chance to reap the rewards of mining is to join a Mining Pool. In a Mining Pool, a group of miners join their computing power together to mine the cryptocurrency. Mining pools are operated by third parties and coordinate groups of miners. By working together in a pool and sharing the payouts among all participants, miners can get a steady flow of income every day they activate their miner. Usually the rewards are split according to the amount of work the miner in the group contributed to the probability of finding a block [2]. Miners who have a large amount of funds and interest have warehouses full of hardware dedicated towards mining cryptocurrency.

In the following sections, a comprehensive literature review and relevant work into the economic viability of mining cryptocurrency will be investigated to further determine how to properly calculate the profit margin given various input factors, which will lead into the design and functionality components of the visualisation tool being developed for this project.

4. Literature Review

4.1 Relevant Work

In the paper by Islam, Marinakis, Olson, White, Walsh, titled “Is BlockChain Mining Profitable in the Long Run?”; the authors investigated the long term economic viability of cryptocurrency mining in Ethereum [9]. The paper developed an Ordinary Differential Equation (ODE) model using performance and cost for mining with GPUs, electricity prices, block price and reward as variables. This model was easily adaptable for other mineable cryptocurrencies such as Bitcoin; and could be used to investigate specific forms of cryptocurrency investment, such as miner-friendly cryptocurrency or novel forms of compensation for users. Although numerous limitations for the paper’s proposed ODE model exist (such as forecast price and hash rate, limited expense model, etc.); in general, the ex-post and financial analysis from the model suggested that mining for Ethereum has been historically profitable. Furthermore, the paper stated that organic growth from mining operations can be profitable, but are subject to two opposing caveats: the weekly growth in the network hash rate must approach 1%; the appreciation of cryptocurrency prices must be high enough to compensate for both power consumption and capital investment [9]. Alternatively, the paper points out the importance of joining mining pools for users to increase the viability of their ventures and generate consistent profits. This paper directly relates to our project, where although not as complex, our proposed visualisation tool could take a simplified version of the variables and techniques used in the paper’s model to inspire the way we approach for calculating and presenting economic viability for the user.

As mentioned in the Background, running hardware non-stop for mining cryptocurrency such as Bitcoin uses a large amount of electrical energy. In fact it was estimated that 73.1 TWh of electricity would be required for Bitcoin mining annually [10]. The paper by Malfuzia, Mehr, Rosenc, Alharthid, Kurilovae titled “Economic viability of bitcoin mining using a renewable-based SOFC power system to supply the electrical power demand” looked into using alternative more sustainable energy sources for Bitcoin mining. The paper found that, using grid electricity, Iran, Russia, and China are the best countries to mine Bitcoin due to their low energy prices. On the other hand, using the natural gas-fed SOFC (Solid Oxide Fuel Cell) system, Iran, Canada, and Russia are the best countries for mining Bitcoin. While the profitability of SOFC based mining is lower than grid-based mining, the latter method compensates with better sustainability and lower environmental costs.

The paper by Fadeyi, Krejcar, Maresova, Kuca, Brida, Selamat, titled "Opinions on Sustainability of Smart Cities in the Context of Energy Challenges Posed by Cryptocurrency Mining" [11] further supports the work by Malfuzia, Mehr, Rosenc, Alharthid, Kurilovae [10]. This paper further highlighted the environmental challenge of climate change and the impacts of cryptocurrency mining. The paper suggested that a possible way of reducing energy use and all activities involving mining would be by seeking to replace PoW methods with improved alternatives. With the environment being an important issue in our current society, the concepts discussed in these papers could be important to consider when building our proposed tool, where users are also informed about the impact on the environment as a result of their mining process along with their projected profit.

Overall, specifically focusing on the economic viability of mining cryptocurrency for individuals; the costs of hardware equipment with electricity as well as the difficulty associated with mining and how the price of the cryptocurrency will impact potential rewards [12]. Hence, for the context of this project: the need for a good visualisation tool that incorporates all these variables and efficiently outputs understandable information.

4.2 Existing Solutions

When researching existing solutions in this problem space, there were a number of Bitcoin mining profit calculators available for free online. For this project, 4 calculators have been evaluated and reviewed for inspiration for our project implementation.

The first calculator reviewed is from nicehash.com [13]. As seen in Figure 10 below, the inputs for this calculator includes a country, electricity price and a list of hardware devices. The output for the given inputs shows a generalised table of profit, income (revenue), costs and profit over a timeline say if the user started 1 day or 1 week or 1 month ago. Along with numbers, a graph also visualises these values over the given timeline (see Figures 11, 12 below). This calculator also allows for comparison on profits between different configurations of hardware. In terms of calculation methods, this calculator uses an average live price for Bitcoin, lab tested hardware performance (with manual performance value inputs allowed for non-listed hardware); the output is based on past profitability and can not be directly used as a prediction for future profitability.

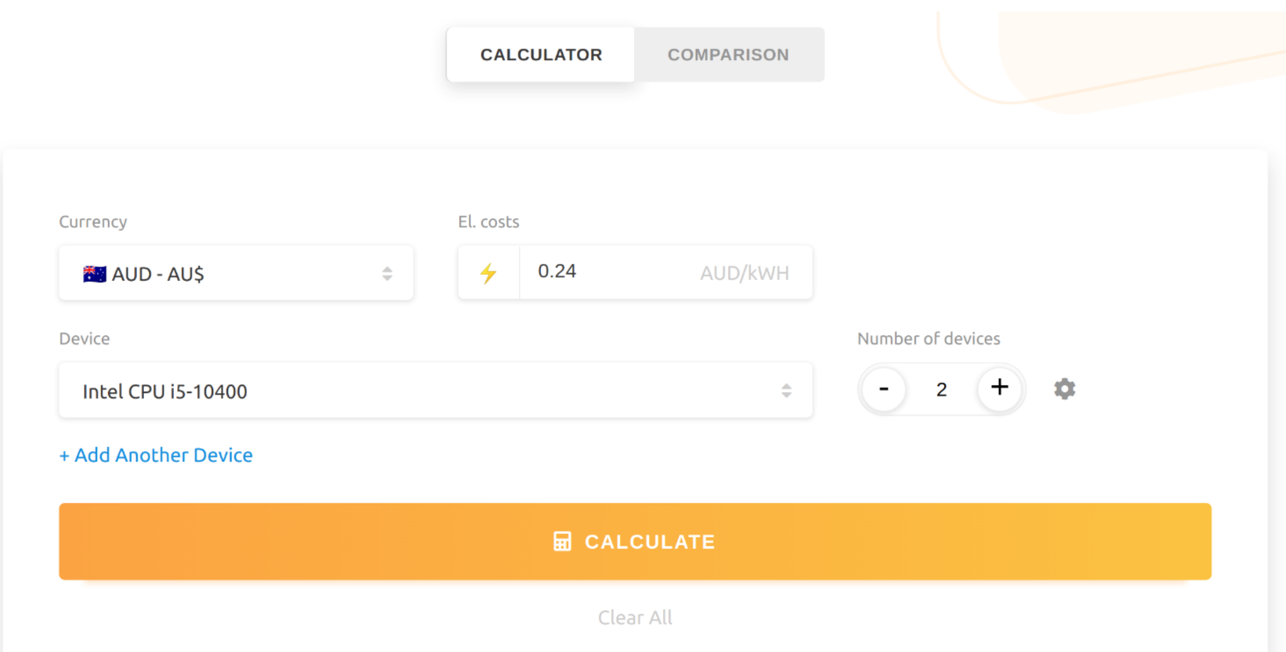

Figure 10. Input interface of nicehash.com's calculator [13].

Intel CPU i5-10400

Your approx. income with NiceHash

0.24 AUD / Day

START MINING WITH NICEHASH

*Please note that values are only estimations based on past performance - real values can be lower or higher. Exchange rate of 1 BTC = 65140.07 AUD was used.

Past earnings of **your setup** on NiceHash

	1 DAY	1 WEEK	1 MONTH
Income	0.00001511 BTC 0.98 AUD	0.00009615 BTC 6.26 AUD	0.00037102 BTC 24.17 AUD
El. costs	0.00001138 BTC 0.74 AUD	0.00008035 BTC 5.23 AUD	0.00035623 BTC 23.20 AUD
Profit	0.00000373 BTC 0.24 AUD	0.00001581 BTC 1.03 AUD	0.00001478 BTC 0.96 AUD

See how values are calculated

Figure 11. Output table of nicehash.com's calculator [13].

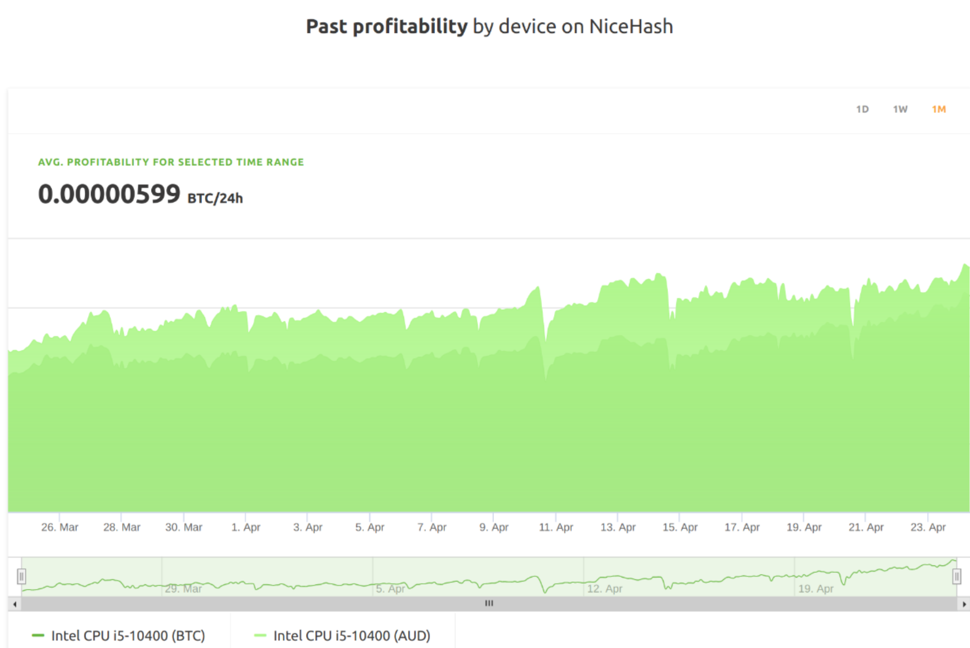

Figure 12. Output graph of nicehash.com's calculator [13].

The second calculator reviewed is from cryptocompare.com [14]. As seen in Figure 13 below, the inputs for this calculator includes performance factors about the user's hardware (hash rate, power consumption), electricity price and pool fee (if the user joined a mining pool). The output shows a table of estimated cost and profit values over generalised day, week, month and year long periods given the live Bitcoin price and block reward and user inputs.

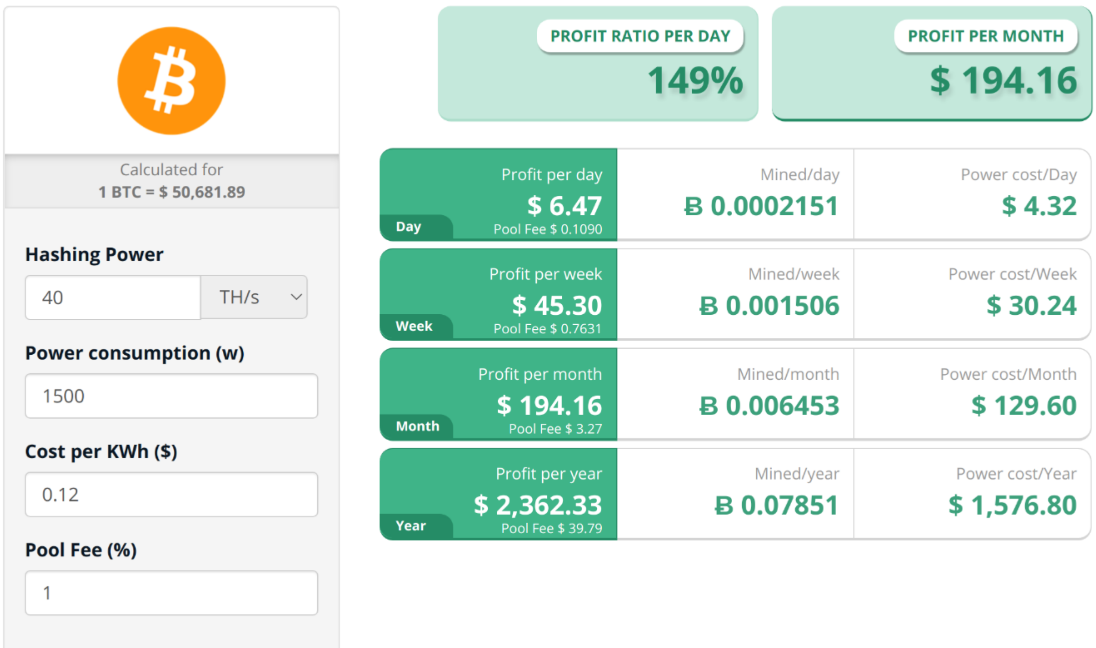

Figure 13. Interface of cryptocompare.com's calculator [14].

The third calculator reviewed is from buybitcoinworldwide.com [15]. As seen in Figure 14 below, the input layout of this calculator is very similar to the one from cryptocompare.com; where the hardware's hash rate, power consumption along with the electricity price is present as inputs. Additionally, this calculator has a pre-filled value for the current Bitcoin price which is adjustable by the users. The output is again very similar to cryptocompare.com, where a table is presented with projected profits and cost over day/ month/ year periods. The two of the main factors influence profitability considered for this calculator are: the Bitcoin price and the total network hash rate. This calculator assumes the Bitcoin network hash rate is growing at a rate of 0.45% per day with the block reward to be 6.25. It states that "Without factoring in this growth, most Bitcoin mining calculators show results that appear much more profitable than reality."; hence, potentially making the output values of this calculator more realistic.

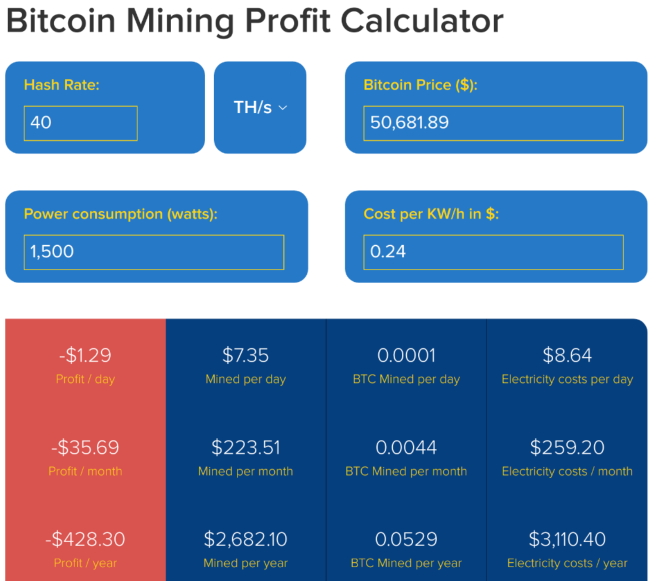

Figure 14. Interface of buybitcoinworldwide.com's calculator [15].

The final calculator reviewed is from btc.com [16]. This calculator includes a more extensive list of input factors compared to the other 3 calculators reviewed previously. As seen in Figure 15 below, along with the standard electricity price and hardware performance inputs, this calculator also includes Bitcoin specifics along with the user anticipated mining timeline. The output shows a detailed table of cost, revenue and costs over the timeline inputted by the users. Furthermore, a simplified version of the calculator is available, where users can see what requirements are needed if they want a specific profit (seen in Figure 16 below).

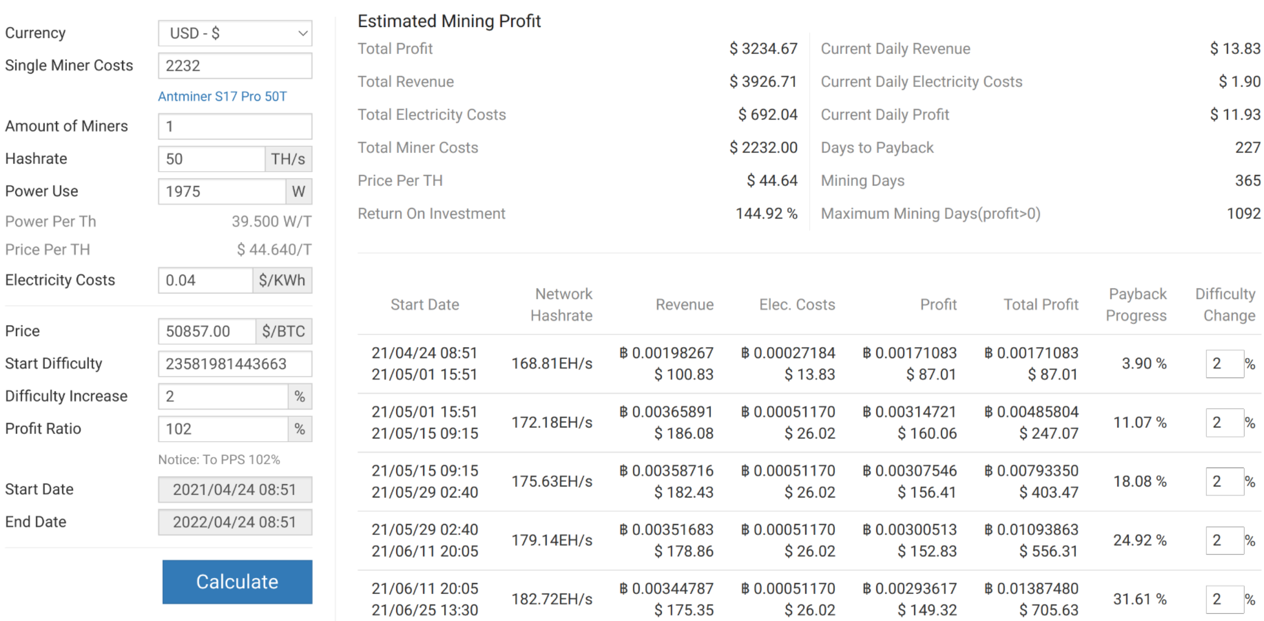

Figure 15. Advanced interface of btc.com's calculator [15].

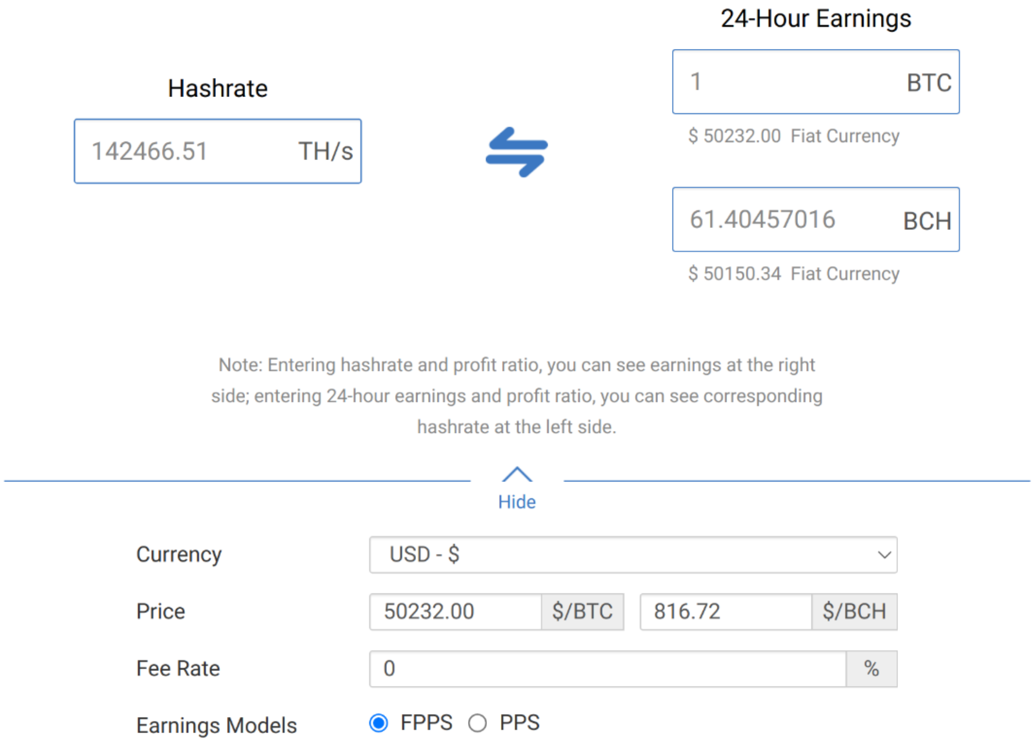

Figure 16. Simplified interface of btc.com's calculator [15].

After reviewing the four existing Bitcoin mining profitability calculators, it can be summarised that the major user inputs are hardware performance and electricity prices. These values can be pre-populated from open-source APIs (Application Programming Interface) found online. Furthermore, having information about Bitcoin performance (i.e. price) is also important for forecasting predictions. This information does not have to be user input, rather an average price once again taken from an API. To add value to a calculator (as most reviews only have text outputs), it would seem that graph visualisations (similar to the one presented from nicehash.com) along with numbers would be useful, as "a picture is worth a thousand words". The following section of Methodology explains in detail our design and implementation process for our proposed visualiser inspired by the research and literature review completed. Following this, a discussion and evaluation is presented of our completed product with potential future directions.

5. Methodology

5.1 Iterative Design

An Agile philosophy was used to develop this project. This allowed the developers to start work on the project as early as possible, and allowed the iterative design process to run concurrently with the build. As a result there were a number of design iterations which are pictured below. These started as extremely low fidelity designs drawn on paper, through to computer generated designs with labels. Figures 17, 18, 19 below are some examples showing the increase in design and implementation fidelity over time. Furthermore, our team conducted some basic user testing during development (detailed in Section 6.1.2) which helped to refine and improve our User Interface design.

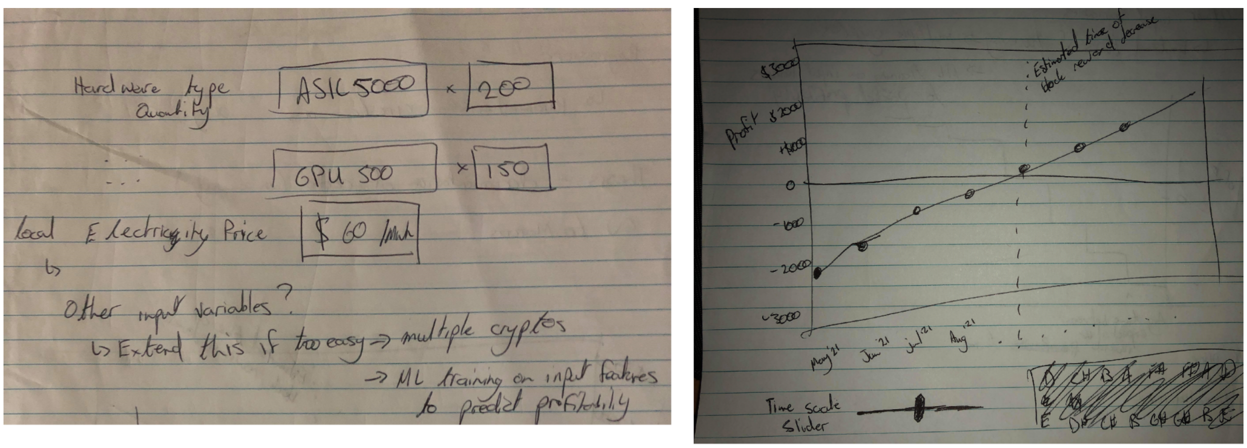

Figure 17. Design Iteration #1: Low fidelity design for user data capture and visualisation pages.

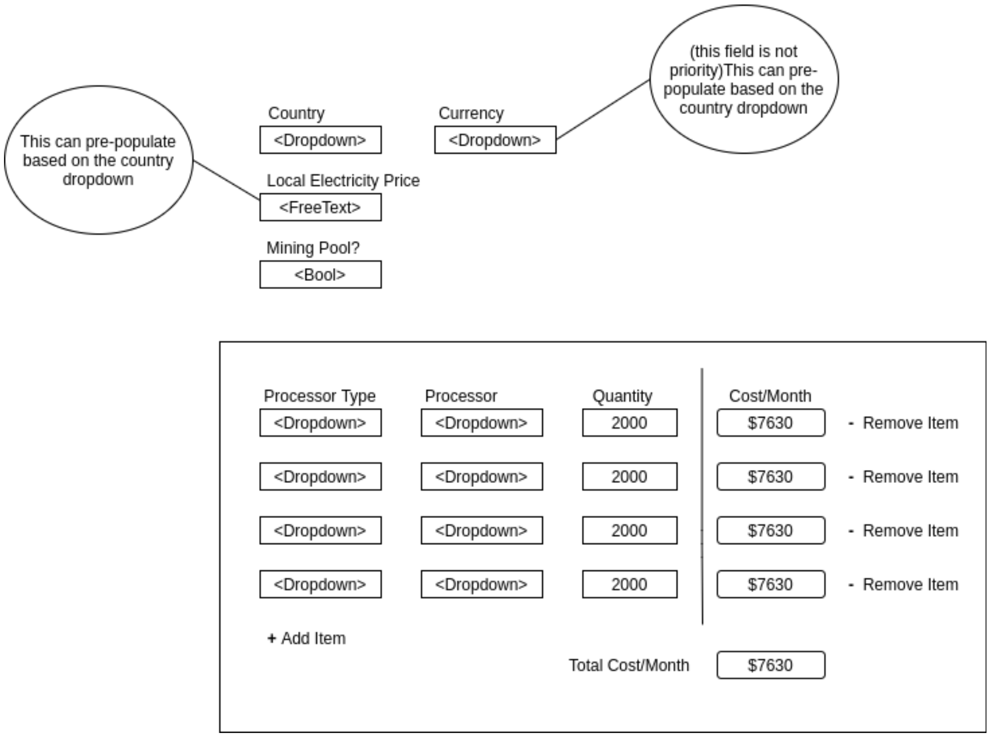

Figure 18. Design Iteration #2: Medium fidelity design for user data capture page.

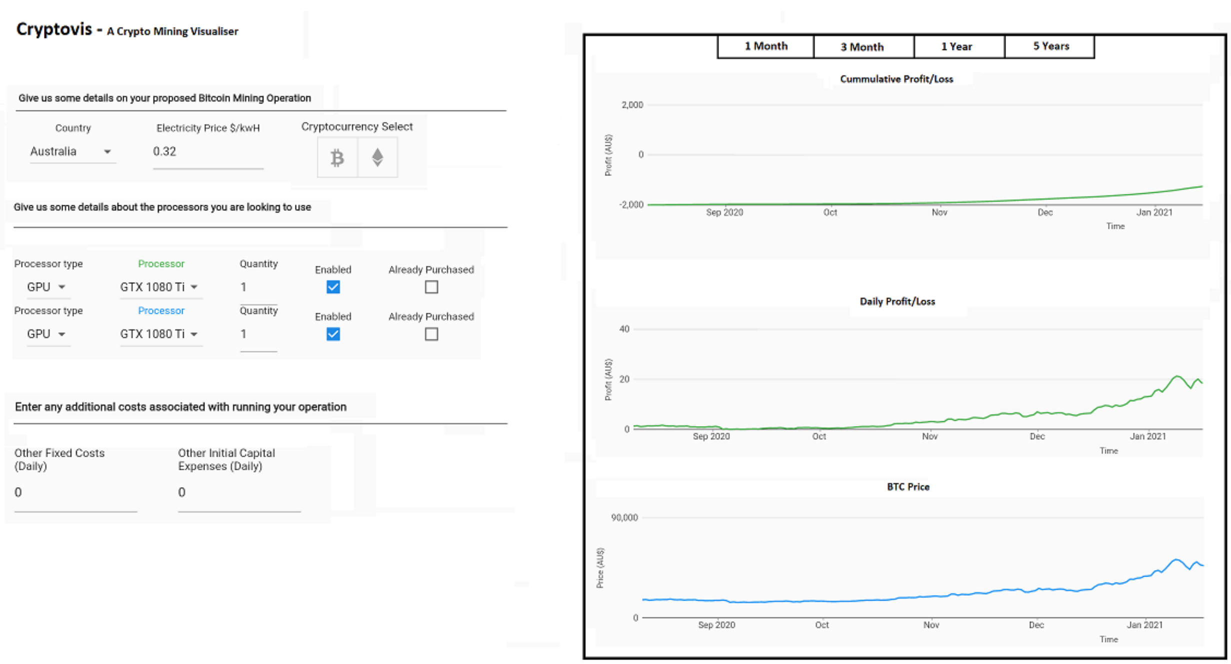

Figure 19. Design Iteration #3: High fidelity design for user data capture page and visualiser.

5.2 Input Factors

Table 1 below shows the key input factor decisions considered for building our visualisation tool. The ability to input multiple processors types and quantities is an important input factor for the user to control. This allows them to investigate the impact of using legacy hardware at a higher operating cost and lower hash rate, rather than investing in new hardware that operates more efficiently and could yield more profit. All values considered were retrieved or calculated at a per day value.

Input Factor	**Retrieval**	**Usage**	**Context**
External Fixed Costs	User Input	Calculate fixed costs	External costs like staffing costs and infrastructure expense to house new equipment
External Capital Expense	User Input	Calculate fixed costs	
Processors: {Type, Quantity}	User Input	Calculate fixed costs	In any large scale mining operation there is likely to be a number of different processors in use, in a mixture of quantities
Electricity Price AUD	Web Scrape/ User Input	Calculate fixed costs	This will change with the country, and is an important value to consider when mining
Block Reward	Approximation	Calculate variable revenue	The block reward of the selected currency is required for calculations of profit
Crypto Value AUD	API	Calculate variable revenue	The currency's value is volatile; hence, it has a significant impact on the miner's current potential profit

Table 1. Key input factor decisions.

5.3 Output Model

The Output Model and its User Interface was carefully designed with the user in mind. This was done by conducting interviews with potential user demographics and stakeholders to investigate the various potential use cases of the product, and shape the design requirements around these user expectations. From these informal interviews, a number of decisions were made about the Output Model and its User Interface.

It was decided that a retrospective model would be implemented. This decision was made due to the high volatility of Cryptocurrency value, and its strong impact on the profitability of a mining operation. Because it is nearly impossible to accurately speculate the value of cryptocurrency, it follows that it would be nearly impossible to accurately speculate the future profitability of a mining operation based on speculative pricing.

In terms of the output visualisation, the user is able to toggle different input factor graphs that are scaled correctly to the variable in question, and time-aligned with the profit/ loss graphs. This allows the user to compare different input factors at a point in time to give them an indication of how the different input factors contribute to their bottom line. As to the UI design of these graphs, we were inspired by the graphs presented by Google (examples in Figures 2, 3) due to its simplicity and user friendly style. Hence, our system will aim to replicate this design.

The user is able to adjust the time scale of the retrospective result, this allows them to easily look at periods of time with different input factor values, and compare this against the profitability of the scenario. As an example, the user may want to look at a time when the value of BTC was extremely high, and see how this might have affected their mining operation compared to a time when the value of BTC was relatively low. The output visualisation UI was developed with this use case in mind.

The user is able to see both cumulative profit/ loss as well as the daily profit/loss graphs. In conjunction with the ability to adjust time-scale, this functionality allows the user an ability to see both the granular day-by-day impacts of input factors on profit/loss, as well as look at the long term big-picture of whether a mining operation could be profitable in the long run.

The daily profitability was calculated using the following formula:

$$Profit = \left(blockReward \times \frac{1440}{blockTime} \times \frac{userHashRate}{networkHashRate} \times coinPrice\right) - (fixedCosts + electricityPrice \times 24 \times processorPowerConsumption)$$

Where:

- *blockReward* is the amount of coins/tokens given by the network per block mined.
- 1440 is the number of minutes in a day.
- *blockTime* is the average number of minutes it takes for a block to be mined.
- *userHashRate* is the sum of the hash rates of all of the users' processors in MH/s.
- *networkHashRate* is the average hashrate of the network on the day the profit is calculated in MH/s.
- *coinPrice* is the price of the given cryptocurrency at the end of the day in AUD.
- *fixedCosts* is the sum of all of the ongoing daily fixed costs in AUD.
- *electricityPrice* is the cost of electricity per Watt/hour in AUD.
- *24* is the number of hours in a day.
- *processorPowerConsumption* is the sum of the average electricity consumed by all of the users processors in Watt/hours.

5.4 Tools and Technologies

Table 2 shows a list of tools and technologies used in our project to ensure a smooth process from start to finish.

Tools and Technologies	**Description**
GitHub	Used for code version control for best team collaboration during development. Also ensured effective back-up of code in case of disasters. GitHub's built in features also allowed for easy project progress tracking and display of important documentation.
Flutter	Open-source Software Development Kit (SDK) used for developing the product with code written in the Dart language. This SDK is made by Google and is quite new and innovative. It allows for seamless integration between front and back end along with simple adaptations to multiple platforms.
Android Studio	Integrated Development Environment (IDE) used for development. This IDE had built in Flutter support and was excellent in organising project files.
Google Drive	Used for documentation collaboration to ensure best collaboration and everyone is on the same page at all times.
Facebook Messenger	Communication tool for text messages for daily progress updates.
Zoom	Communication tool for weekly virtual team meetings.
Firebase	Website hosting tool for making our product available on the internet.

Table 2. Summary of the tools and technologies used for the project.

6. Evaluation and Discussion

6.1 Critical Evaluation

6.1.1 Team Reflection

Figures 20, 21, 22, 23 below are screenshots of the current iteration of our completed product before user evaluations with Figure 24 showing the refined version post evaluations. Our product is currently in the form of a web-hosted application and can be accessed via the following URL: https://cryptovis.xyz/. Additionally, our source code can be accessed with this URL: https://github.com/will33/crytovis2. The points below further list out a high level summary of how our system currently works.

- Users choose the country in which they are mining. On country change, the average electricity price will be pre-filled, with this value being able to be changed for a more accurate representation.
- Additional user inputs include:
    - Date range of mining for a period summary.
    - Costs and expenses to be considered when calculating profit.
- Users are able to choose from a list of hardware devices to compare for their mining operation with the hardware's performance pre-computed in the system's back-end.
- The application automatically chooses the optimal coin to mine between Bitcoin, Ethereum and Monero. If the user attempts to change the coin mined to a coin that is not profitable with their hardware, the app informs them why their hardware is not suitable to mine using that coins hashing algorithm.
- The application then generates an overall profit chart, a daily profit chart and a historical price chart of the mined coins market price. The date range for the charts can be easily manipulated using buttons with various date ranges located above the charts.
- The graphs will automatically update given changes to user inputs.

When reflecting on the work completed on the current iteration of our product, as a team, we can proudly say that we have achieved the major goals we stated at the beginning of the project. Overall, our product has been able to show excellent quality of project outcomes and contributions with a high degree of initiative and creativity. This was done where we took inspiration from reviewed background and literature and made a tool that takes important user inputs and outputs clear visuals to demonstrate the economic viability for mining cryptocurrency given a user's circumstance. Although the problem space of our project is not a new concept, we have shown innovation in our solution in terms of UI design and functionality. Our profit graphs along with cryptocurrency prices sets us apart as these visualisations would further assist the understanding of our users. Additionally, we have considered feedback from our brief user testing and made relevant changes showing our continuous striving efforts for improvements.

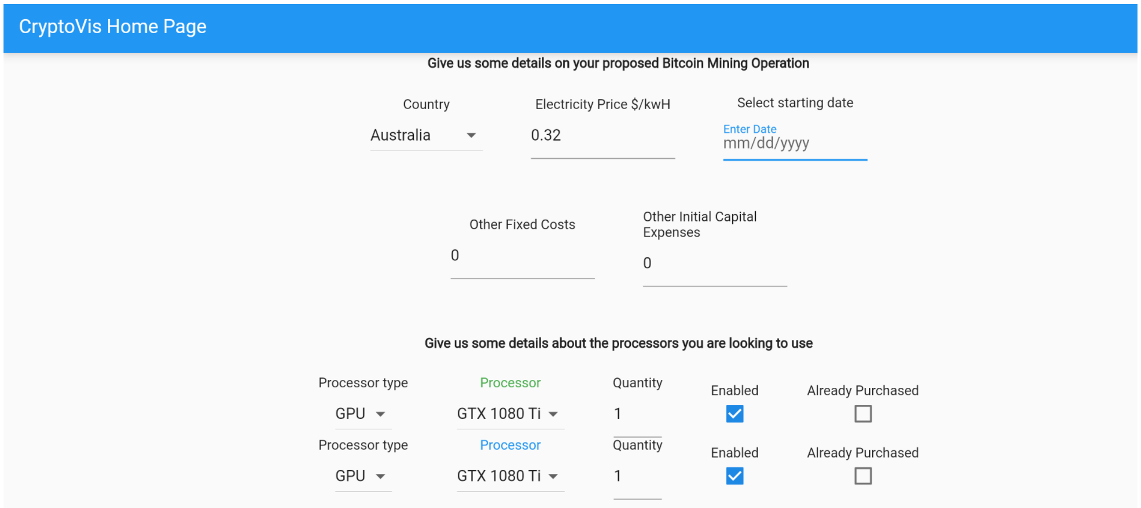

Figure 20. User input sections of product (pre user evaluations).

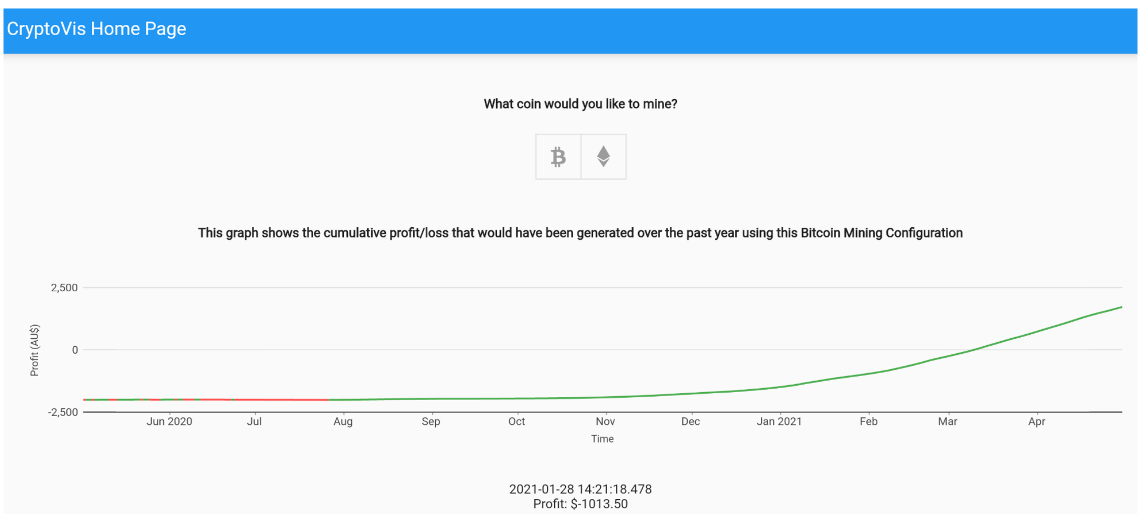

Figure 21. Cumulative profit output section of product (pre user evaluations).

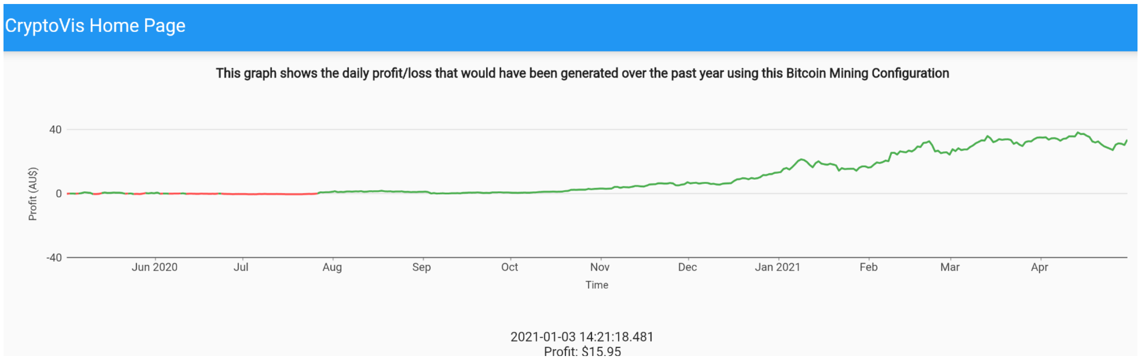

Figure 22. Daily profit output section of product (pre user evaluations).

Figure 23. Historic coin price section of product (pre user evaluations).

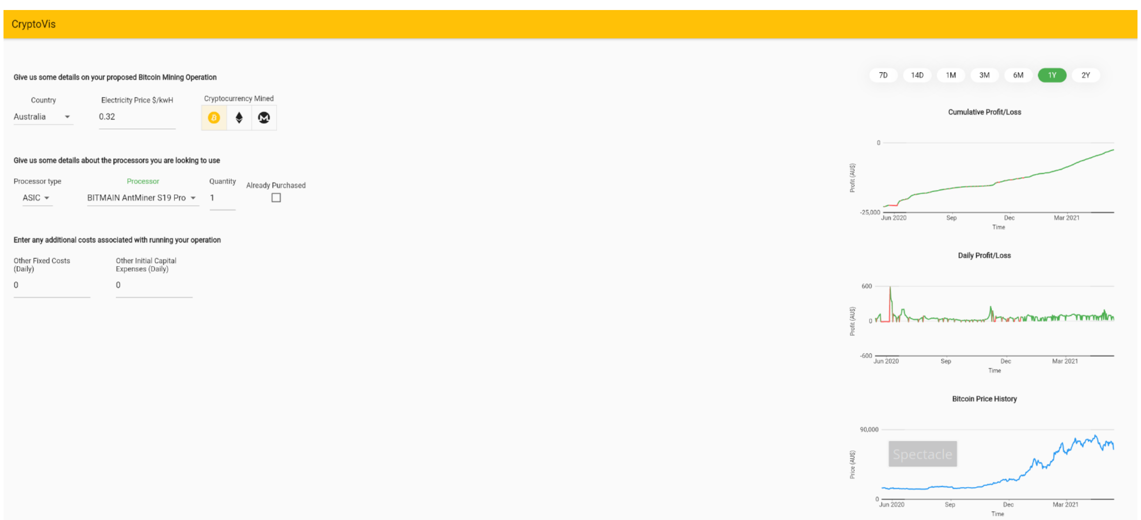

Figure 24. Screenshot of entire product post evaluations.

6.1.2 User Evaluations

6.1.2.1 Evaluation Protocol

Upon completion of the main functionality of our product development, our team completed some user evaluations with fellow university students to gain insight into the quality of our product and how it could be potentially improved. With knowledge in Human Computer Interaction (HCI) methods, we decided to utilise these evaluation techniques to further gain insight into user thoughts about the User Interface and main functionality of our website application.

The first activity completed was a Design Walkthrough. With this, the user completed specific tasks assigned by the evaluator. The evaluator recorded details including how long each task took to complete. This activity was useful for gathering observations from a user who hasn't interacted with this prototype before. The second task was Co-design. In this task, the user recorded their expectations of an app of this nature. This allowed us to gain insight into potential user expectations of how the system UI should be displayed and function.

The points below detail the protocol we followed as part of our user evaluation, with the following section discussing the main points of user feedback as a result of our evaluation.

1. Explain to the user an overview of our product in terms of its goal and relevance.
2. Design Walk-through: Get the user to complete the following tasks and record the time taken, how the tasks were completed and their thoughts as they were completing the tasks.
    a. Set the start mining date to 6 months ago.
    b. Enter your country of choice and fill in the associated costs.
    c. Compare a CPU and GPU of your choice.
    d. Examine your daily and cumulative profits given the chosen mining configurations for Bitcoin.
3. Co-design: Ask the user to state the aspects of the UI and functionality that they found surprising or confusing. Following this, ask the user to write down/ draw out how they would have envisioned that aspect in their mental model.

6.1.2.2 Evaluation Results

Table 3 below is a summary of the feedback received as a result of the user evaluations completed in the previous section. Following these evaluations, our team reviewed the results along with a critical evaluation amongst the team to refine the system and incorporate user feedback to further improve the appearance and functionality of our product; this can be seen from the iterative refinement visible above going from Figures 20-23 to Figure 24.

<table>
<tr><td colspan="3">Number of evaluations: n = 5.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Design Walk-through</td></tr>
<tr><td>Average time taken to complete tasks:</td><td>Summary of how users completed the tasks:</td><td>Summary of user thoughts while completing tasks:</td></tr>
<tr><td>30 seconds.</td><td>● Figures out the date 6 months ago and enters it.
● Sees Australia as a pre-filled country and selects dropdown to see the list of countries, but leaves the country as it is.
● Clicks on ‘Processor type’ and ‘Processor’ dropdowns and selected random CPU and GPU.
● Views output graphs, toggles the ‘Enabled’ buttons.</td><td>● Better if the date entry was on a slider or pre-formatted time buttons for easy and quicker access.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Co-design</td></tr>
<tr><td colspan="2">Surprising/ confusing element of system</td><td>User’s mental model</td></tr>
<tr><td colspan="2">1. Complaints about the scrolling and not being able to see all the content at once, especially when you update a field but then have to scroll down and see the change.
2. Complaints about the “Show crypto price” button, it’s better off just always showing.</td><td>1. The input boxes and graphs should be visible at once on the entire page.
2. Remove the “Show crypto price” button, the graph should always be showing.</td></tr>
</table>

Table 3. Summary of user feedback from completed user evaluations.

6.2 Future Work

As stated in Section 6.1 detailing the Critical Evaluation of our product, our major initial project goals set out have been achieved. However, like any project, especially this one with a time constraint, there presents room for improvement. Presented in Table 4 below, is a justified list of areas of improvement as future work if the project was to be carried into another iteration. Inspired from our team's product evaluation along with user feedback; these points would significantly improve our product and help to realise the major goals in understanding the economic viability of cryptocurrency mining and present it as an impeccable solution in this chosen problem space.

Area of Improvement	**Justification**
Further improved User Interface from additional round of user testing	Allows for a more usable system, which means it is more likely to reach our target audience.
Content distributed over multiple pages	Reduces cognitive load on our users meaning they can learn how the system works faster and are more likely to make repeated visits in using our system.
Integration of Machine Learning techniques	This was listed as an extension goal at the start of the project; however, it was not completed due to time constraints. With the use of ML models, our system would be much better at predicting future performance based on past data which provides another layer of abstraction for our users.
Inclusion of other major cryptocurrencies alongside Bitcoin, Ethereum and Monero	With the cryptocurrency market constantly growing, including a system that supports multiple currencies is important as users can visualise their mining currency of choice without being limited to the three major coins.
User inputs for unlisted hardware	Currently the user is limited by the list of hardware provided by the system. In the case of the user's hardware not listed in our provided list, it would be important to provide manual inputs (e.g. hashrate, power consumption) such that that user isn't discriminated against based on their hardware and can still use our system to visualise their potential mining operations.
More extensive use of APIs	This allows for data (e.g electric prices, hardware performance) to be more dynamic and accurate; hence, the output is more reflective of the real-world.

Table 4. Justified list of areas for future work of the project.

7. Conclusion

The main goal of the project was to assist users to increase understanding of the economic viability of cryptocurrency mining with the solution being a visualisation tool. We narrowed the scope of the project to focus on the popular cryptocurrencies of Bitcoin, Ethereum and Monero as a result of the time limitations of the project.

After completing the background research and literature review, we were able to gain a deeper understanding into the project's main problem space. Hence, we were able to identify the major factors of hardware performance, electricity price and coin price as imperative to integrate into our system.

Our team took an Agile development approach as it was flexible given the project's time constraint. We would hold weekly team meetings to discuss areas of work and set weekly milestones for a smooth push toward final project deliverables.

After the completion of our project our team did a critical analysis along with some user evaluations. Given the limitations and constraints of the project, we were able to produce a system we were proud of. Overall, it can be said that our team has achieved the major outcome and contribution of developing a tool that can assist cryptocurrency miners in better understanding the economics behind mining. Moreover, on a personal level, our team was able to gain a deeper understanding of using new and innovative technologies like the Flutter SDK in the context of web development.

As for directions of future work, we have identified areas where further work can be completed given another iteration to further boost the usefulness of our project. These areas of work include (not limited to): improvements to the system's UI, inclusion of more cryptocurrency options, integration of ML techniques for better predictions.

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