Bitcoin mining, the clean energy accelerator

A Degree Thesis

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by

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Abstract

The increase in the production of electricity from renewable sources, basically wind and solar, produces strong imbalances between instant production and demand. Currently we do not have systems for large-scale storage of energy in the moments when supply exceeds demand. This can cause problems of stability in the electrical grid, and worsens the return on investment made in production facilities. This project aims to study the proposal to use surplus energy to mine Bitcoin, thus reducing the problems of overloading the electricity grid, and improving the economic return of renewable energy installations.

Resum

L'increment del la producció d'energia elèctrica a partir de fonts renovables, bàsicamet eòlica i solar, produeix forts desajustos entre la producció i la demanda instantànies. Actualment no disposem de sistemes per a l'emagatzematge a gran escala d'energia ens els moments on la oferta supera la demanda. Això pot produeix problemes d'estabilitat els la xarxa elèctrica, i empitjora el retorn de la inversió feta en les instal.lacions de producció. En aquest projecte es vol estudiar la proposta d'utilitzar els excedent d'energia per a minar Bitcoin, reduïnt així els problemes de sobrecàrrega de la xarxa elèctrica, i millorant el retorn econòmic de les instal.lacions d'energies renovables.

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Resumen

El incremento de la producción de energía eléctrica a partir de fuentes renovables, básicamente eólica y solar, produce fuertes desajustes entre la producción y la demanda instantáneas. Actualmente no disponemos de sistemas para el almacenamiento a gran escala de energía en los momentos donde la oferta supera la demanda. Esto puede producir problemas de estabilidad en la red eléctrica, y empeora el retorno de la inversión hecha en las instalaciones de producción. En este proyecto se quiere estudiar la propuesta de utilizar los excedentes de energía para minar Bitcoin, reduciendo así los problemas de sobrecarga de la red eléctrica, y mejorando el retorno económico de las instalaciones de energías renovables.

Dedication

This project is first of all dedicated to the incredible work done by Satoshi Nakamoto. Thanks to your invention there is some light in a world getting darker as time goes by.

Moreover, during the months I've been carrying out this project, many people have accompanied me and I want to acknowledge them for the huge help and patience they've had.

From my family, specially my dad, who has let me run my ASIC miners in his own industrial complex and listened to my endless talks about Bitcoin, to my girlfriend and all my friends who are tired of listening to the Bitcoin fanatic.

Last but not least the people from PoW Containers, who appeared in an uncertain moment in my life and gave me a good path to follow.

Thank you to all and each one of you, the rabbit hole of information about Bitcoin never ends and without you I couldn't have got any further in it.

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Table of contents

List of Figures

1. Introduction

There is no doubt that 2021 has been a revolutionary year for Bitcoin mining. Many companies have been publicly listed in the NASDAQ [1] to be able to expand their operations in ways never imagined before. China banned mining in all the country, but the Bitcoin miners proved that they could move anywhere else and continue making the network even more secure. Renewable sources for mining has grown at an incredible pace. And many more things could be said about mining improvements during the last years.

However, we can still find many people talking about the "incredibly damaging" environmental carbon footprint of Bitcoin, how it will destroy our planet, and dismiss it's potential just because their font of information is biased [2].

This study aims to provide an easy to understand explanation of how Bitcoin mining works and we will try to disregard the false information spread about the "Bitcoin mining pollutes the world" narrative, and bring a clear frame to understand why Bitcoin could be the technology that finally brings humanity an incentive to adopt clean energy, and help our world in transitioning into a more sustainable future.

To do so, we'll make a close study of the current state of the profitability of Bitcoin mining, and then focus on our electrical grid, the problems we are facing nowadays driven by renewable energy production, and how mining Bitcoin could be a possible approach to this problem.

Before getting more in depth into the study, let's present the current problems we are facing nowadays.

The increase in the production of electricity from renewable sources, basically wind and solar, produces strong imbalances between instant production and demand. Currently we do not have systems for large-scale storage of energy in the moments when supply exceeds demand. This can cause problems of stability in the electrical grid, and worsens the return on investment made in production facilities. This project aims to study the proposal to use surplus energy to mine Bitcoin, thus reducing the problems of overloading the electricity grid, and improving the economic return of renewable energy installations.

While 2021 and the start of 2022 have brought many interesting insights into the Bitcoin mining ecosystem, there's no doubt that in the coming years the space will keep evolving at an incredible pace, and we should be able to identify the best paths to go through.

When we are in the verge of creating this new clean-energy based future, reliant on new technologies, we should ask ourselves, could Bitcoin be a key part of it?

2. State of the art of the technology used or applied in this thesis:

In this chapter we will describe the current state of the art of the two basic components of this thesis. Bitcoin mining, and why it could be a key part on the development of renewable energies.

Once we know that, we can estimate the amount of electricity which is not properly consumed organically, and so forth, we can refer to it as “wasted”, as it does not produce any type of useful activity, nor economic incentive.

Finally, with the amount of wasted energy found, we will determine the profitability of mining Bitcoin with it, and the economic returns it would cause on the whole facility, during the following years.

2.1. Bitcoin mining in 2022

Before diving into the study of energy production, let’s explain what is Bitcoin mining, and the current state of the art.

As described in the Bitcoin whitepaper [3], Bitcoin mining uses *Proof-of-Work*, to implement its distributed timestamp server, instead of relying on a trusted third party. Proof of work was chosen due to its ability to not be faked, only the ones who spend computational resources into the Bitcoin network would be the ones who would verify transactions, and so forth, add them to the public ledger.

The main incentive of spending computational resources to verify transactions, is that the Bitcoin network itself rewards the miner who has found a valid block (also understood as: anyone who completes the mathematical function known as hashing, which gives a certain number of zeros in result of combining the block header, with a specific random nonce) with a certain amount of Bitcoin, directly into their Bitcoin wallet.

Anyone could choose to participate in the Proof-of-Work algorithm, however, not just by participating would mean being the one who would earn the reward. As more people joined the network, the more difficult it became to find a valid block, as intended with the genius invention of Satoshi, the *Difficulty Adjustment*.

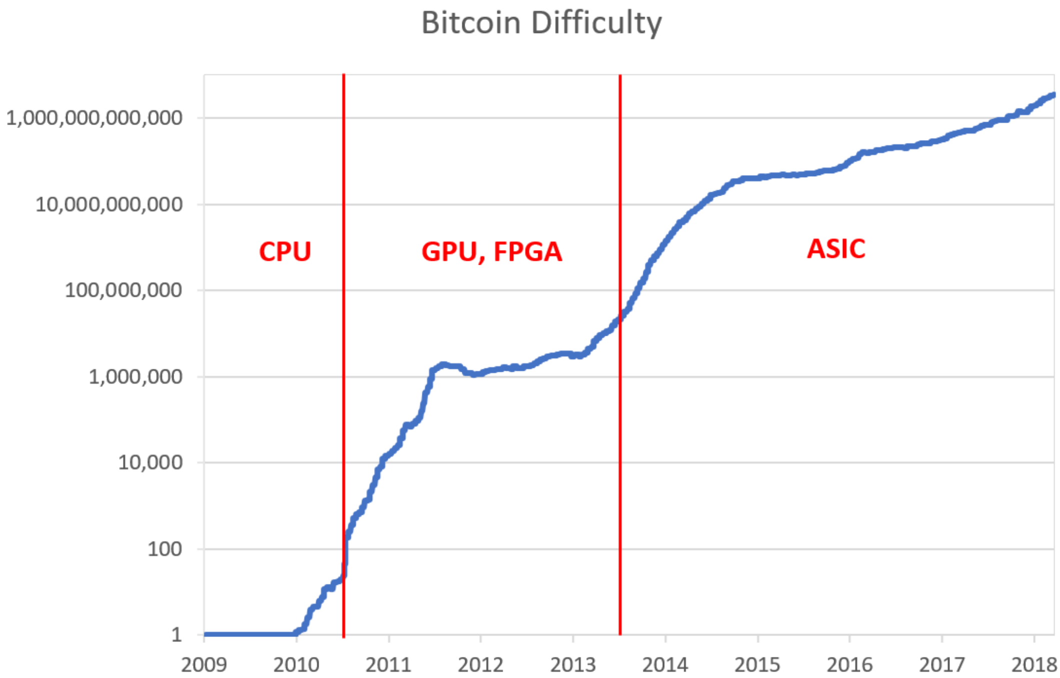

Figure 1: Bitcoin difficulty growth 2009-2018 [https://tokeneconomy.co/is-the-war-against-asics-worth-fighting-b12c6a714bed]

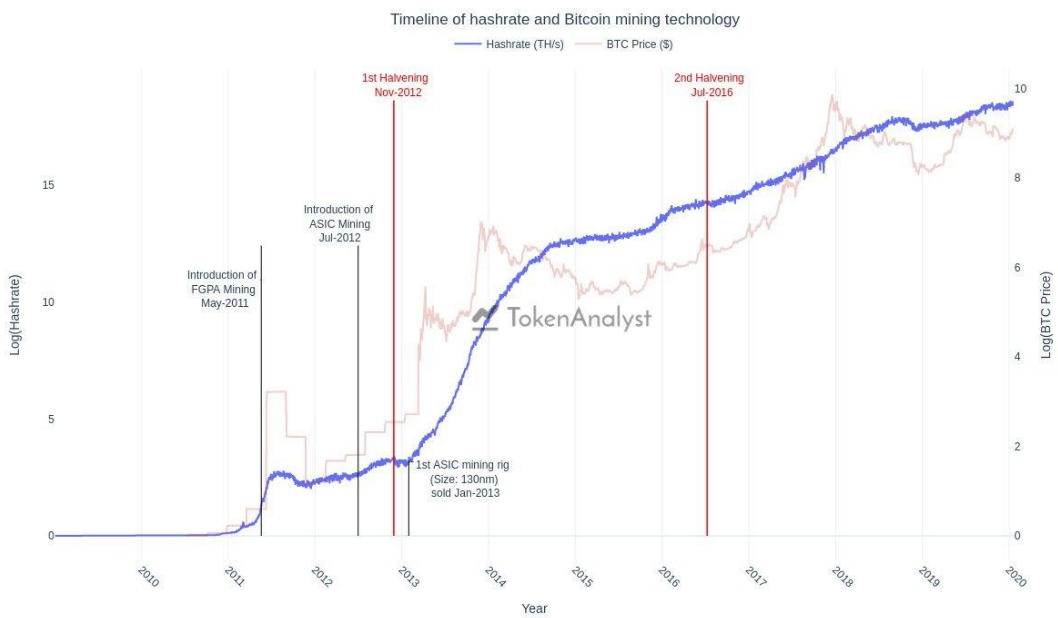

Figure 2: Bitcoin difficulty growth compared to price increase 2009-2020 (https://docs.tokenanalyst.io)

People soon realized that the one who was able to calculate hashes faster, let's say, the more computational power they had, the faster the blocks could be found, and so bigger gains would be made, and if they kept mining with the same resources while more people joined the network, they would end up without being profitable.

Originally, Satoshi Nakamoto described the Proof-of-Work as “One *CPU* one vote”, however, soon it became clear that CPUs were not the fastest hardware hashers, so miners began exploring new ways of faster computation, and *GPU mining* came into play.

Ordinary CPUs were no longer able to run at the speed needed to meet the increased difficulty of the mining algorithm. So in 2010, there was a release of the first software design specifically for mining with a computer graphics card.

The computing power of a GPU in one graphics card is equivalent to dozens of CPUs in parallel computing. So the mining efficiency will be greatly improved. Therefore, many people switched to GPU mining and assembled one or more advanced graphics cards to build their own mining appliance.

GPU mining had its glorious years, and it is still alive in many altcoin mining algorithms, as their difficulty is not as high as the Bitcoin one. However, as happened with CPUs, more and more people got into mining due to its good incentives and high ROI, which caused the difficulty to continue going up.

This brought the industry to advanced mining equipment, field-programmable gate arrays (FPGA), emerged. The first FPGA miner in China appeared in 2011. Manufactured by Nangeng Zhang. However, due to the high power consumption of *FPGA mining*, it took only six months for it to be phased out of the market.

In 2012, there was the first release of an *ASIC miner* (Application Specific Integrated Circuit, which means cards that only do one thing, but do it really well). Initially, the computing power of ASIC miners was about 200 times that of graphics card mining, and the power consumption rate was not much different, so it soon became popular in the market. ASIC miners have finally established themselves (or at least seems so) as the main Bitcoin miners, and a huge industry is devoted to making them more efficient each year that goes by. [4]

During 2022, either Intel and Samsung have announced their plans to release chips to make ASIC miners even more efficient.

This leads us to the power consumption part of the whole Bitcoin mining infrastructure, as the more efficient the miners are, the less electricity they’ll consume for the same amount of work they’ll be doing. However, this doesn’t mean that the total consumption will be lower. Actually quite the opposite. The more hashrate the network has, the more secure it will be, but the more electricity it will consume. So with these tremendous consumption levels, we need to ask:

Where will this electricity come from?

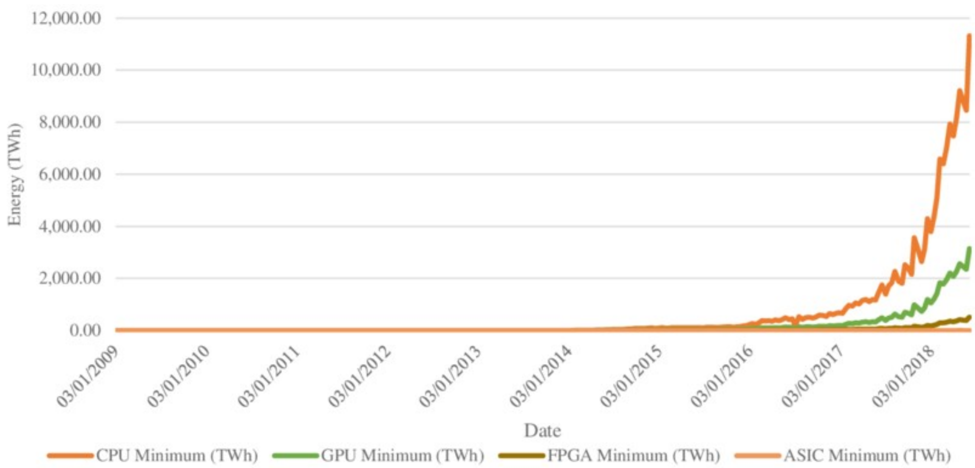

Figure 3: CPU, GPU, FPGA, and ASIC minimum energy consumption between difficulty recalculation

2.2. Electricity generation state of the art

Once we've understood the way mining works, it's easy to see that the most profitable miners will be the ones who can access the cheapest energy possible.

And given the situation we are facing in the world nowadays, it seems pretty obvious that in the long run there will not be many miners who will be plugged to the electrical grid, as the residential electricity rates tend to increase in the following years.

Instead, they'll be looking for places where energy is lost, stranded, or easy to produce, and no one else wants to consume it (p.e. hydroelectric plants that had to be shut down due to not being profitable enough), or current energy production installations that produce more energy than the one that can be consumed at the moment of production.

Additionally, miners can be placed anywhere in the world, reducing the localization-dependence many industries have nowadays.

The obvious conclusion to the previous statements, is thinking about renewable fonts of energy, which are indeed endless, and can provide profitability to miners longer than other fonts of energy production.

Nevertheless, fossil fuels have some advantages against clean energies, like stability and they are easier to transport, which makes them suitable for energy-dependent businesses, and that's why currently many miners are still using fossil fuels for their operations.

This could be seen as a climate problem, as miners could be a good incentive for fossil fuels instead of cleaner energies. But nothing is less far than the truth, for two reasons.

First, it is evident that Bitcoin mining is most profitable when it is running 24/7 non-stop. However, this does not mean that it needs to be running 24/7. It just makes the return on investment faster if you run it non-stop, but it is not at all crucial for its operations.

Actually, as already mentioned, one of the big advantages of mining is it can be turned on & off whenever it is needed, making it much more flexible than other businesses which depend on a stable and continuous flux of energy, which is typically powered by fossil-fuels, as they provide the most reliable font of electricity production. This also means bitcoin mining will not “steal” the electricity which is crucial for other businesses, as it does not need the most stable font, but rather the cheapest one. Miners can be turned off when there is an excessive demand of electricity, without affecting its operations, and this way provides electrical stabilisation in areas where energy shortages are abundant.

Second, Bitcoin mining is not meant to be a neutral carbon footprint business, but a negative carbon footprint one. Many of the biggest mining operations nowadays are already using flared gas to power their operations, which was previously expelled to the atmosphere, thus reducing the pollution that fossil fuel installations were producing prior to mining bitcoin.

Once it has become clear that mining will inevitably transition to a clean energy backed business, we shall take a look at how it could improve the stability of electrical grids, and thus become a crucial part of our interconnected world. Concretely, this study will be focused on the real profitability of Bitcoin mining, how miners are incentivized to look after the cheapest font of energy, and how they can help with the imbalances produced by solar and wind energy production. How mining could be the first-resort consumers to this excess electricity produced, providing an economic return on otherwise wasted electricity, and this way improve the return on investment of the mentioned energy production facilities.

3. Methodology / project development:

We will divide the methodology part in 2 sections.

The first one is focused on the data I've been gathering with a real Bitcoin mining machine, as well as the configurations made to control it remotely, and the ROI I've had with it, with my specific conditions.

Then, once we understand how Bitcoin mining works, we will proceed with the research of renewable energy production in Spain, and if it could profit from Bitcoin mining, while at the same time improving the efficiency of renewable facilities, and producing a better balanced electricity grid.

3.1. Bitcoin mining at home. Configuration and results

Once this project was started, one of the things that needed to be done was extensive research on how Bitcoin mining works nowadays, to get our hands dirty to really understand the profitability, and to see the real ups and downs mining Bitcoin has.

To do so, I managed to have 3 Bitcoin miners, specifically Antminer S9, with 14TH/s each one, and around 1350W of consumption each one of them. However I initially only managed to get one, and after 4 months the other 2 arrived.

The price of each one of them was around 300€ as they were already used for 2 years when I bought them. The intention was to see if they could keep running for at least the time until I could recover my initial investment.

During the first 4 months I did only have one of the machines, and I did only mine with it. We will later see the results of the mining rewards during the time I had the first machine, and then the results of the two latest machines mining together.

3.1.1. Configuring the miners

Before you start mining there are some aspects you need to have in mind:

The first one is the elevated consumption of these computers, as they will be running 24 hours a day and 7 days a week ideally.

In my case I decided to plug them in an industrial complex which already had a certain amount of electricity paid each month, but it was not fully consumed. That way I could plug the machines without any problem of over consumption, and the price of electricity has been almost 0, as otherwise it would have been paid but not consumed.

The second thing you need to consider is the heat they produce. It is impossible to have them in a closed room, especially if you live in a country with hot temperatures.

The last thing to mitigate is the sound, as these computers are really loud machines, and produce noise during 24h a day, so they are not suitable in a residential area.

These machines need to be connected to the Internet, as they need to send their calculation results (usually called **shares**) to the mining pool. To connect them you need a Modem/Router and plug them into it with an Ethernet cable. For bigger mining farms, Switches are also needed to separate the different Virtual LANs, not only for a better efficiency but also for a higher grade of security.

The following figure describes better a typical **Mining Farm network diagram**:

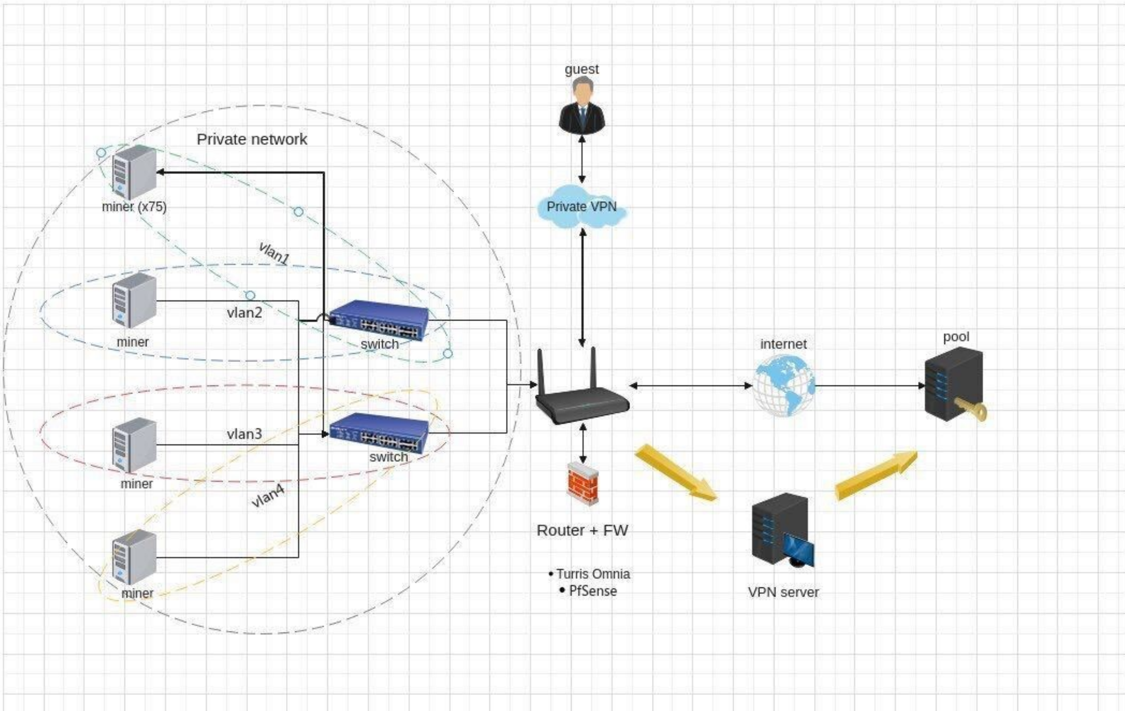

Figure 4: Mining farm network schematic

In our case we will just focus on the part of the mining machines connecting to the internet, and also how we have managed to connect our local computer to the router which is directly connected to our mining machines, to be able to monitor them in real time.

Once the devices are connected to the Internet, the next step is sending the shares they produce to your desired pool.

Pools are simply groups of miners who mine together, and once one of them submits a share that has the expected difficulty and is validated, it creates a block to add it to the blockchain and receive the reward. This reward is then distributed through all the miners who have been submitting valid shares at the time the block was found.

This way you can ensure continuous rewards when mining Bitcoin.

In my case, I registered into **Slush Pool**. I created an account and then they give you a specific URL, which you need to copy and paste into your machine's desired pool field, and it will automatically submit your shares to your desired pool.

Each pool has a dashboard where you will be able to see in real time the number of shares submitted by your miners, the Hashrate they have in real time, and the rewards you are earning.

For Slush pool you will see something like this:

Figure 5: Slush Pool mining dashboard

In the upper part you can see the number of workers (miners) which are currently working, and if there is one of them that has gone offline, or is suffering any type of problem.

The first one of my machines stopped working properly after 4 months, and so I decided to unplug it to repair it before mining again.

The other two machines, at the time of the screenshot, were producing around 27.69 TH/s, with an average 28.77TH/s during the last 24h.

In the same dashboard, you can configure your wallet address to receive your funds.

Even if I could have left the machines like that as I was already receiving my rewards in my wallet, I decided to do some tweaking to the network they were connected to, and take some security measures, as it is really common for hackers to **Hijack your hashrate**.

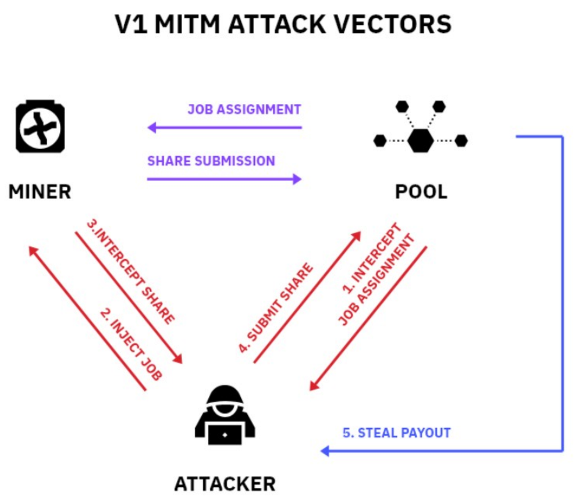

Figure 6: BraiinsOS: MITM hashrate hijacking representation

To do so I decided to install a VPN, a firewall and segregate the networks directly in my Turris router.

This VPN would allow me to connect to the router from outside the network (as I could not spend the whole project next to my machines), and the firewall would prevent possible attacks.

The process to connect my personal computer with Tailscale was done through the following steps:

We start by downloading the specific **tarballs** of tailscale for our hardware in our local computer

```
curl -O https://pkgs.tailscale.com/stable/tailscale_1.0.5_arm.tgz
```

Then we do send it to our router to the /tmp directory

```
scp tailscale_1.0.5_arm.tgz root@192.168.1.1:/tmp
```

We enter to the router through ssh and unpack the tarball

```
cd /tmp
```

```
tar x -zvf tailscale_1.0.5_arm.tgz
```

Install the missing packets

```
opkg update
```

```
opkg install ca-bundle kmod-tun
```

Copy it in /usr/bin/

```
cp tailscale tailscaled /usr/sbin
```

From our local pc we download the initial **procd** configuration from will angley, and we send it to the router

```
curl -LO https://willangley.org/tailscale-procd
less tailscale-procd
scp tailscale-procd root@192.168.1.1:/tmp
```

We log in to the router again and copy the files to /etc/init.d/tailscale, and give them execution permissions to execute them

```
cp /tmp/tailscale-procd /etc/init.d/tailscale
chmod +x /etc/init.d/tailscale
/etc/init.d/tailscale start
```

Once tailscale is started we need to log in to our tailscale account (created previously)

`tailscale up` → it gives us a link to log in to our account. Once logged in we will see a dashboard where we will need to verify the new device connected to the internal network, which is the router in this case, and we also disable **key expiry** to avoid needing to log in again in the future.

Once we have managed to connect our machines between them, the only thing missing is make sure tailscale runs each time there is a reboot in our router.

```
/etc/init.d/tailscale enable
```

We check it

```
ls /etc/rc.d/*tailscale
```

And we should be seeing the following line

```
/etc/rc.d/S80tailscale
```

Finally we reboot the router to check if it's working correctly and we connect again through ssh, but this time using the new IP provided by the tailscale network. In case we can log in correctly to the service, the previous steps have been successful.

This way we've managed to connect to our router from any part of the world and we can monitor what's happening in our network in real time.

3.1.2. Analysing the mining conditions

Once my machines were configured and I could access them remotely to solve any potential issue, I just needed to let them do what they are meant to do, and analyse the results after a certain time.

The most interesting thing has been seeing that during the time I've been carrying out this project, there have been three things which made it each day less profitable to mine Bitcoin, and maybe it has been one of the least profitable times in the whole Bitcoin history to be a miner.

The first thing has been the price decrease from September 2021 (when I plugged my first machine), to June 2022 (the current moment of writing this results).

Obviously in dollar or euro terms, this price decrease has affected the profitability of an initial investment, as the Bitcoin I kept mining had less value as price kept decreasing.

The second factor has been the difficulty increase despite bad conditions for miners. During 2021 many big mining firms ordered big batches of machines, which could not be deployed until early 2022. So once these firms started plugging in their new machines, more Hashrate was added to the network, and so forth each one of the miners earned less Bitcoin each day, as the pools had to distribute the rewards between more people, and the Bitcoin algorithm itself made mining more difficult for each miner.

The two previous conditions do not usually happen together, as once price decreases there are some miners who stop being profitable and they need to unplug their machines to pay for the electricity. However this was not the case this time.

Finally, during the last year we've also seen a huge increase in electricity price. This affects directly to all the miners who have their machines connected to the grid, as they need to pay more for their operations, while earning less bitcoin due to the difficulty increase, and this bitcoin having less value due to the price decrease.

3.1.3. Mining Profitability

After finding myself in this situation during the time I've been mining, let's take a look at the profitability I've had.

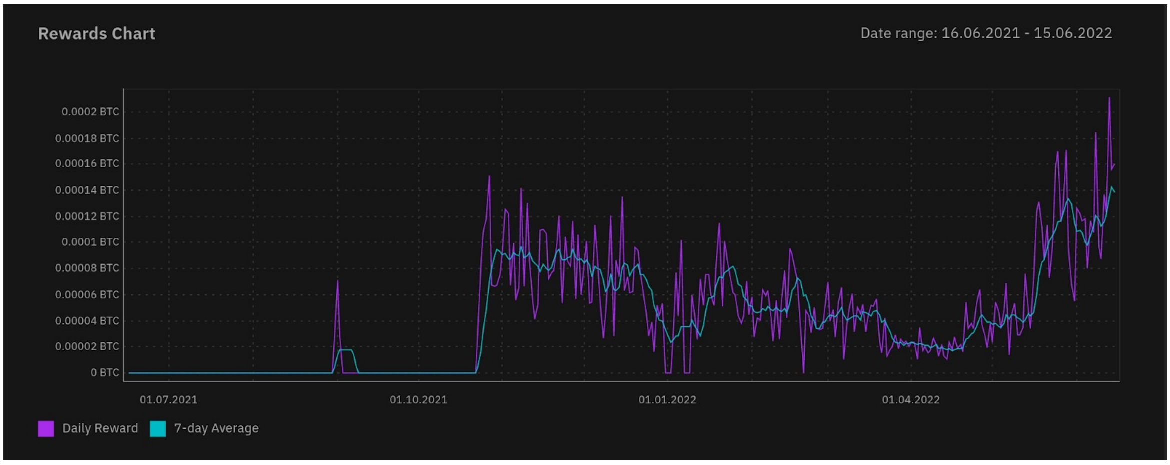

Figure 7: Rewards distribution between October 2021 and June 2022

The previous chart shows the rewards I've had during the whole last year.

It is interesting to keep in mind two aspects to analyse the results:

- From **September to April** I only mined with **1 miner**, which produced 14TH/s
- From the start of **May to mid June**, I've retired the old machine due to failures, and replaced them with **2 miners** with 14TH/s each one, so a combined hashrate of 28TH/s approximately.

Once I started mining, during the first 2 months, price kept stable as well as difficulty. This made my miner to earn an average reward of 0.000095 BTC per day.

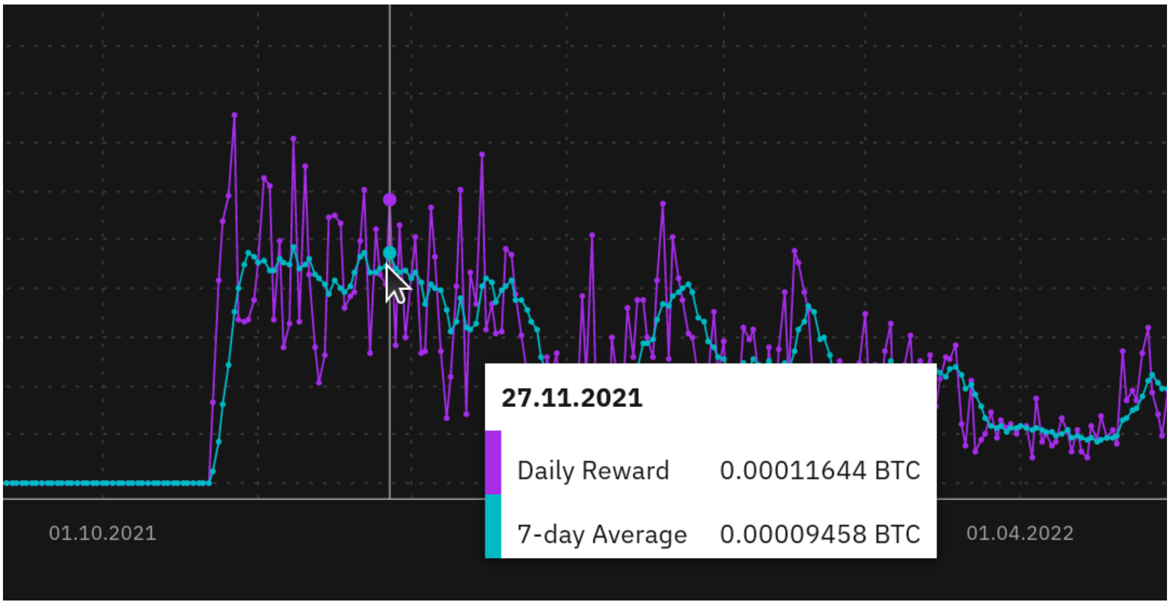

Figure 8: Zoom in - October to December rewards

As the difficulty started to increase due to new machines being plugged into the network, the profitability started going down in Bitcoin terms, however in Dollar terms I kept earning a similar amount of money, so that would be a scenario where miners can keep up their profitability even if difficulty increases, but price does also increase.

Then we do see a sudden drop in rewards, which is due to the first problems my miner was experiencing, and it suddenly stopped mining. After resuming the mining operations, we entered the moment where Bitcoin price started going down, so I also kept earning less and less rewards either in Bitcoin terms and Dollar terms.

Surprisingly, **after 4 months**, even if we had unfavourable conditions, **my miner had already paid its investment**! During that time I had collected around 0.01BTC. While the Bitcoin price kept above 30.000€ it meant I made 300€ or more, so I could consider my machine was already paid.

That was also the moment where my first miner started facing serious problems, some of its chips stopped producing hashes, and so it's when we can clearly see in the rewards chart that the rewards went to the lowest part, as I just kept 1 of the miner's hashboards mining.

After that, I managed to get 2 more miners (this time for free thanks to my company), to test with them and continue analysing data.

We can see a sharp increase in rewards from the start of May to mid June. However if we take a look closely, we will see the real effects of the bad situation we found ourselves in, explained previously.

Even if I plugged in 2 miners instead of 1, the mining average daily reward is around 0.00012BTC per day:

Figure 9: Zoom in - May to June rewards

There has been an increase in the reward, however the 7 day average shows us that it is not the double of the reward I received with just 1 miner, as one could have thought. Even if I had the double amount of hashrate, and I was spending the double amount of electricity, the rewards with two miners were just 1.33x from the ones received with just one miner. Not 2x.

And the worst part comes now, with this last update of the research as of 16 of June of 2022. Bitcoin price has fallen down to 20.000$ while mining difficulty has kept going slightly up.

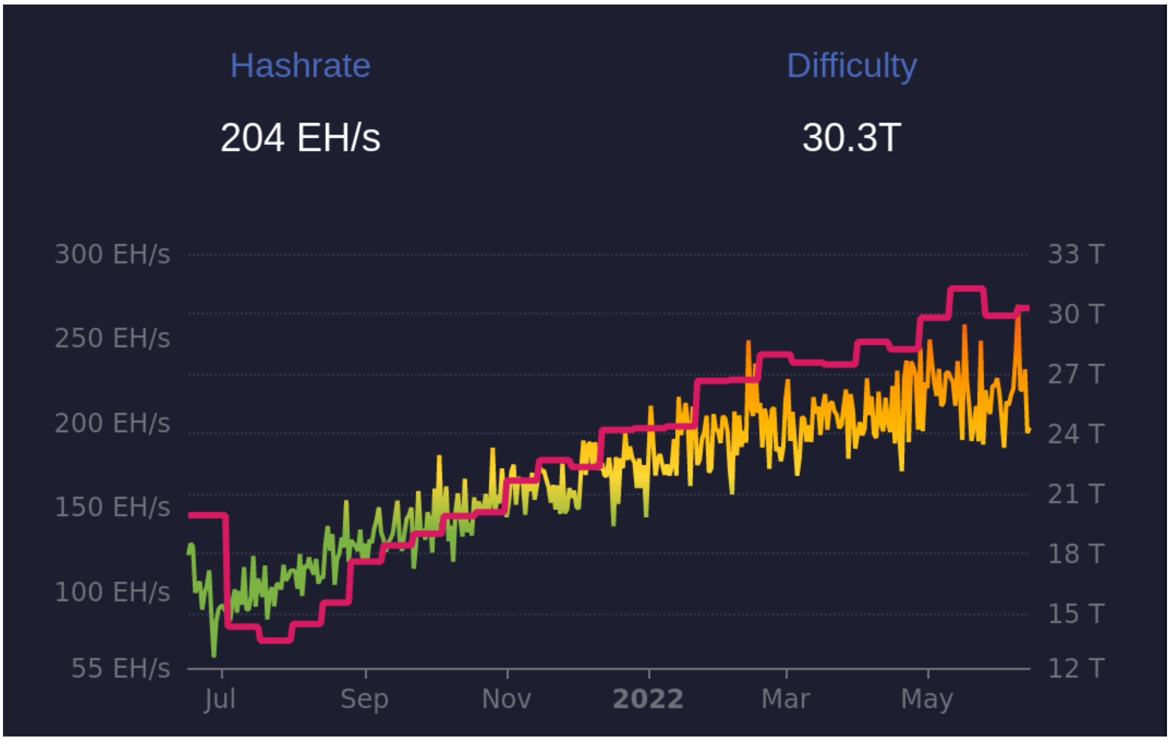

Figure 10: Mining difficulty during May 2022

It is worth noticing the current amount of Bitcoin earned during the whole time I've been mining, either during the first months with one miner and the last ones with two:

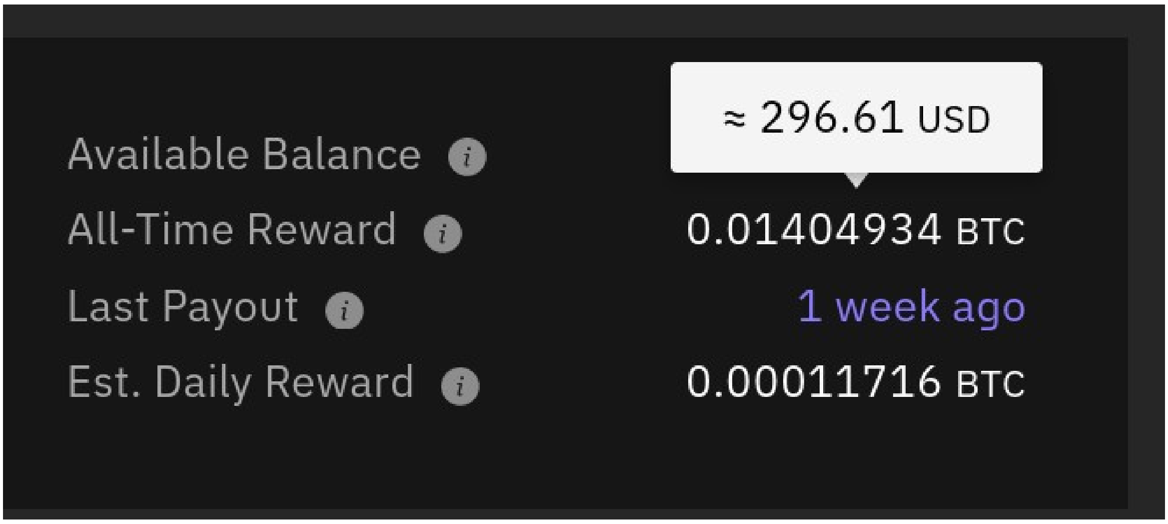

Figure 11: Mining rewards as of June 2022

We see that the All-Time reward is at 0.014BTC, which in dollar terms is around $296.61.

Less than the value of my Bitcoin after I stopped mining with the first miner, even if my Bitcoin stack is bigger.

3.1.4. Mining conclusions

After all this month's mining, I've realised that not by having more machines you are just going to be more profitable.

An important thing has been not needing to pay for extra electricity used, as the electricity I consumed was already paid for other uses, so in my case I did not need to pay a monthly fee for that consumption. But that's a theoretical situation only, as the huge majority of miners will need to pay for their electricity usage each month, and deduct it from the profits they've made with their Bitcoin.

If this electricity comes from the grid, and we keep with last year's trend, the price will keep rising, or at least at higher prices than 2 years ago.

Otherwise when using renewable energy, due to it's infinite nature, the price of electricity will keep going down once the investment on the installation of energy producers such as solar panels has been recovered.

Of course this research has been done just during a period of 9 months, and cannot be taken as the definitive guide on Bitcoin profitability, but the points extracted from real data have been helpful in realising how the Bitcoin's network hashrate and it's price affects the profitability of Bitcoin mining.

This study led me to a higher interest in the current state of renewable energy production, and how it could be used as the main electricity producer for Bitcoin miners.

In the next sections we will be focusing on that, and how mining Bitcoin in renewable facilities could also help in the investment recovery time.

3.2. Expected growth in renewable energy

We will focus on the Spanish market of renewable energies, and its expected growth during the next 8 years, until 2030.

Apart, we will also look at the expected growth in electric consumption in the exact same area, to see if renewable production will be enough to power it completely, or if we will still need to depend on fossil fuels to power our grids.

Finally, we will try to determine if the difference in growth between production and consumption (supply & demand) could be used to mine Bitcoin, and if this mining activity could indeed be an accelerator to push renewable energies development forward.

3.2.1. Spain renewable Energy Goals by 2030

According to the Plan Nacional integrado de Energía y clima 2021-2030 published during 2021, Spain needs to take into action some measures to accomplish the objectives proposed by the EU to reduce carbon emissions and evolve into a cleaner planet.

This objectives are the following ones [5]:

- 40% reduction in greenhouse gas (GHG) emissions compared to 1990
- 32% renewable on total gross final energy consumption
- 32.5% improvement in energy efficiency
- 15% electricity interconnection of the Member States

The data from the most recent years tells the following:

During 2020 only 21,21% of the energy consumed came from renewable sources [6]. This means that almost 80% of the electricity consumed comes from fossil fuels.

If Spain invests in more renewable energy facilities, the consumption of the population that comes from renewable sources should increase.

In the next pages we will see what would happen if we started consuming this extra amounts of energy produced with Bitcoin miners.

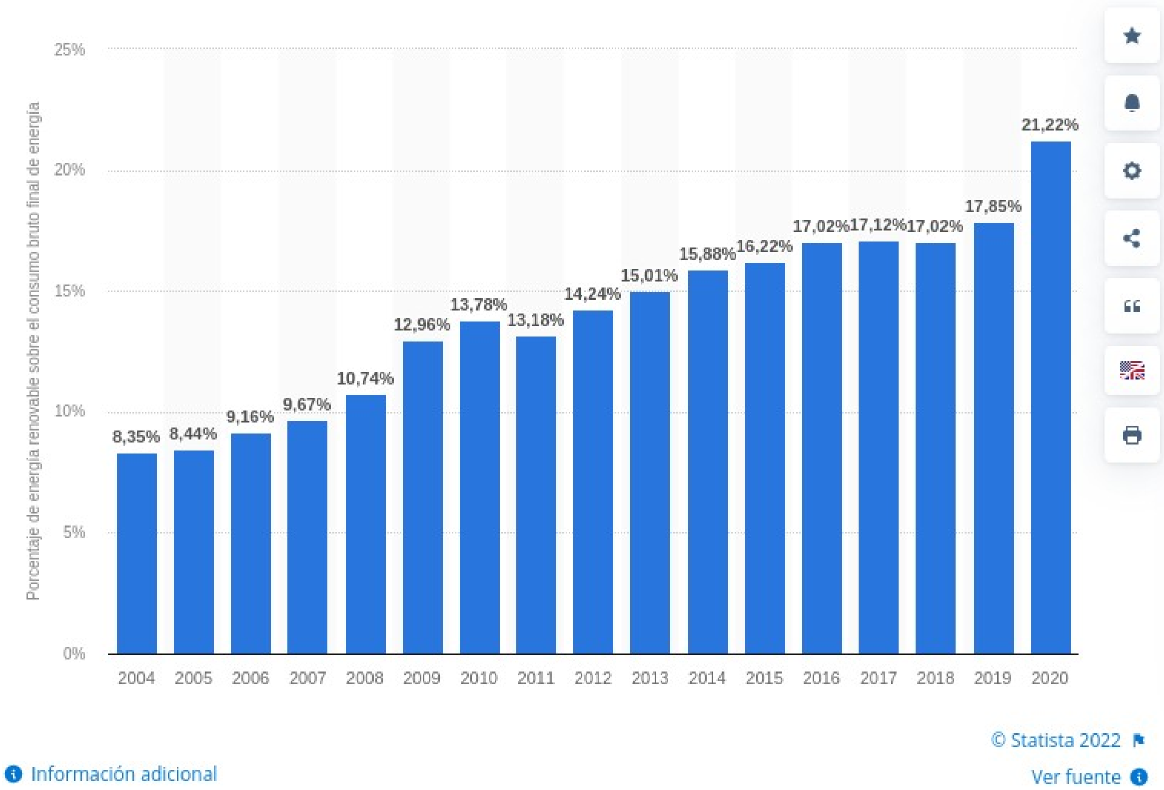

Figure 12: Renewable powered energy use in Spain 2004 - 2020

Even though that nowadays Spain is already one of the top 3 countries when talking about renewable energy production in Europe, according to a study made by an analytics company [7], only 43% of the total energy is produced by renewable sources in Spain.

To accomplish the goals proposed by the EU, Spain has set higher expectations than the general objectives, as it is one of the state members which has a bigger renewable energy production potential.

Concretely Spain aims to achieve a sustained 42% of renewable energy usage over the total use of energy by 2030, and specifically, a 74% of electricity to be produced from renewable sources [8].

To achieve that, Spain wouldn't need to invest more money into more renewable facilities, but instead it could directly start consuming from the energy that is nowadays wasted, ending up in a lower percentage of unused energy, and reduce the amount of fossil fuels used to produce the energy that is not properly consumed from renewable sources.

Nevertheless, Spain is investing in more renewable sources [9], which will bring more energy production to the country, and thus more electricity could be consumed from these sources, especially the amount that would be wasted otherwise. This investment aims to achieve an approximate renewable energy production of 122,7GW by the year 2030.

3.2.2. Spanish expected energy consumption growth

According to the official document published in the BOE [10], the Spanish population will have the following expected growth:

From 46.582 to 47.155 millions of inhabitants. This represents a population growth of around 1,20%.

Tabla A.2. Proyección de la población española

Proyección de la población española (miles de personas)				
Años	**2015**	**2020**	**2025**	**2030**
Población	46.450	46.582	46.803	47.155

Fuente: Comisión Europea

Figure 13: Spanish population projection (2030)

This same study also gives some expectations of a huge rise in prices of fossil fuels:

If this ends up being certain, the adoption of renewable energy sources will increase exponentially, and the possibility of increasing the consumption of energy from renewable sources seems reasonable.

Tabla A.5. Precios internacionales de los combustibles fósiles

Precios internacionales de los combustibles fósiles (€ a precios constantes de 2016/ barril equivalente de petróleo)				
Años	**2015**	**2020**	**2025**	**2030**
Petróleo	46,65	69,17	91,47	100,77
Gas	40,40	44,15	56,08	60,99
Carbón	11,71	16,58	18,36	22,04

Fuente: Comisión Europea

Figure 14: International fossil fuel prices (2030)

As we can see in the previous tables, there won't be a huge growth in population, but this population is set to consume a higher percentage of their daily electricity that comes from renewable sources, otherwise they'll have to pay much more for fossil fuels sourced electricity.

However we do still have a situation where a certain percentage of the energy produced by renewable sources is not used by 2030.

Let's imagine 3 different situations.

1. Energy consumption covers almost all the energy production made by renewable sources.
2. Energy consumption from renewable sources increases exponentially, and we reduce the amount that's not consumed to only 25% of the total energy produced by renewable sources.
3. Energy consumption from renewable sources does not increase that much, and we still have 50% of the production without being consumed.

In the first situation, almost all energy problems would be solved, as energy sources would be cheaper each year, and the facilities would also recover their investments faster, as they would earn money for almost all the energy they produce.

Obviously this situation is utopian without increasing the energy consumption made by the whole population, which would mean they are paying much more money, and the population does not have infinite amounts of money to spend.

In the second one, we do have a more realistic case, where we do reduce the consumption of fossil fuels, and thus the consumption of renewable sources increases. Covering the whole energy that's produced by renewable sources without a first-resort buyer (Bitcoin) is almost impossible as we've seen in the previous situation, so we would still have around 25% of the energy produced that's not consumed. Taking the 122GW expectations from the previous study, we would have around **30GW not consumed**.

Finally, in the third situation, fossil fuels still play an important role in our country, and we could not increase the renewable source energy consumption, so it still has around 50% of the energy produced not being consumed. This accounts for around **60GW**.

3.3. <u>Bitcoin miners as energy consumers</u>

In this last section we will try to determine what would happen in each of the situations that we've described before, and what role could Bitcoin mining play on them.

In the first one, as we've already seen, there would not be much stranded energy to be used by bitcoin miners, as the population and the industry would already consume the whole energy that is produced. As we know, this is almost impossible, and we consider that as an ideal situation, not even worth mentioning.

In the second situation, we can start analysing the benefits that mining Bitcoin could provide to the renewable energy facilities, just by consuming the 25% of stranded energy that would not be consumed for any productive means otherwise.

With this 25% we would have around **30GW of energy that's not directly consumed**. Here Bitcoin mining comes into play to consume this energy, but of course at a certain cost*.

On the last hypothesis, we would be in a similar situation than the second one but with 60GW of surplus energy.

**The following calculations are based on either Bitcoin prices and ASIC prices as of April 2022. Further development and increased efficiency is expected during the following years, which could modify the following results.*

Today's most efficient Bitcoin mining machines cost around $10.000 , and consume 3KW.

We will take these machines as an example, due to their expanded use and the round numbers we can use to make calculations with them.

3.3.1. Profitability of renewable facilities with Bitcoin mining vs public grid

For the previously exposed hypothesis, we will make an estimation of the return we would have if we mined Bitcoin with the excessive energy produced, versus if we sell it to the grid.

Eventually, the second option is not even viable, as if there is no demand for that electricity, electric companies will not be able to sell it to the grid. Anyway we will try to estimate the difference in profits between the two activities and extract conclusions from that.

For the sake of the study, as we don't know which will be Bitcoin's price in 2030, we will consider that we start mining this year, with a future projection of 5 years.

The results if we started mining in 2030 are impossible to calculate, however we will now try to make an estimation of the profitability we would have by mining Bitcoin to recover the initial investment made in renewable facilities instead of "wasting" it or selling it to the grid in the case the usage of electricity produced by renewable facilities increases exponentially.

3.3.1.1. Hypothesis nº2: 30GW of unused energy produced by renewable facilities

f we plan to use **all** the surplus energy for Bitcoin mining, we would need to deploy an enormous amount of machines, which is not a real option due to the current lack of semiconductors, and supply chain bottlenecks.

But let's say we plan to deploy a **30MW Bitcoin site** (to make the numbers more appealing and easy-going). *If it was possible to deploy the full 30GW site, the extrapolation on the results found for the 30MW would simply be a linear scale of x1000.*

With 30MW available (only 0.1% of the total available energy) we could power up to 10.000 Antminer S19j, with an effective hashrate of (100TH/s/miner) **1EH/s** (1 million TH/s).

At an average cost of $10k per miner, we would need a maximum initial **i**nvestment of $100M to deploy those machines.

Now let's see the returns we would have during the next 5 years, considering the following points:

- The **network difficulty grows around 50%** each year according to the last 4 years trend, starting at around 30T of difficulty [11].
- **Price increases** around **135% per year**, according to full Bitcoin's life trend [12].
- Even if we should consider the electricity used as "free" or without cost, as it would be produced anyway, we consider an **electricity price of 0.01** to be able to calculate the approximate CAPEX Break Even time.
- **We sell all the Bitcoins** we mine during the whole 5 years (HODL ratio = 0%)
- We consider fixed monthly expenses (e.g. labour, security, insurance, taxes), of **$10.000/month** (OPEX).

For the following calculations I've used BraiinsOS profitability calculator [13], and we can see the following results:

Initial conditions when we start mining:

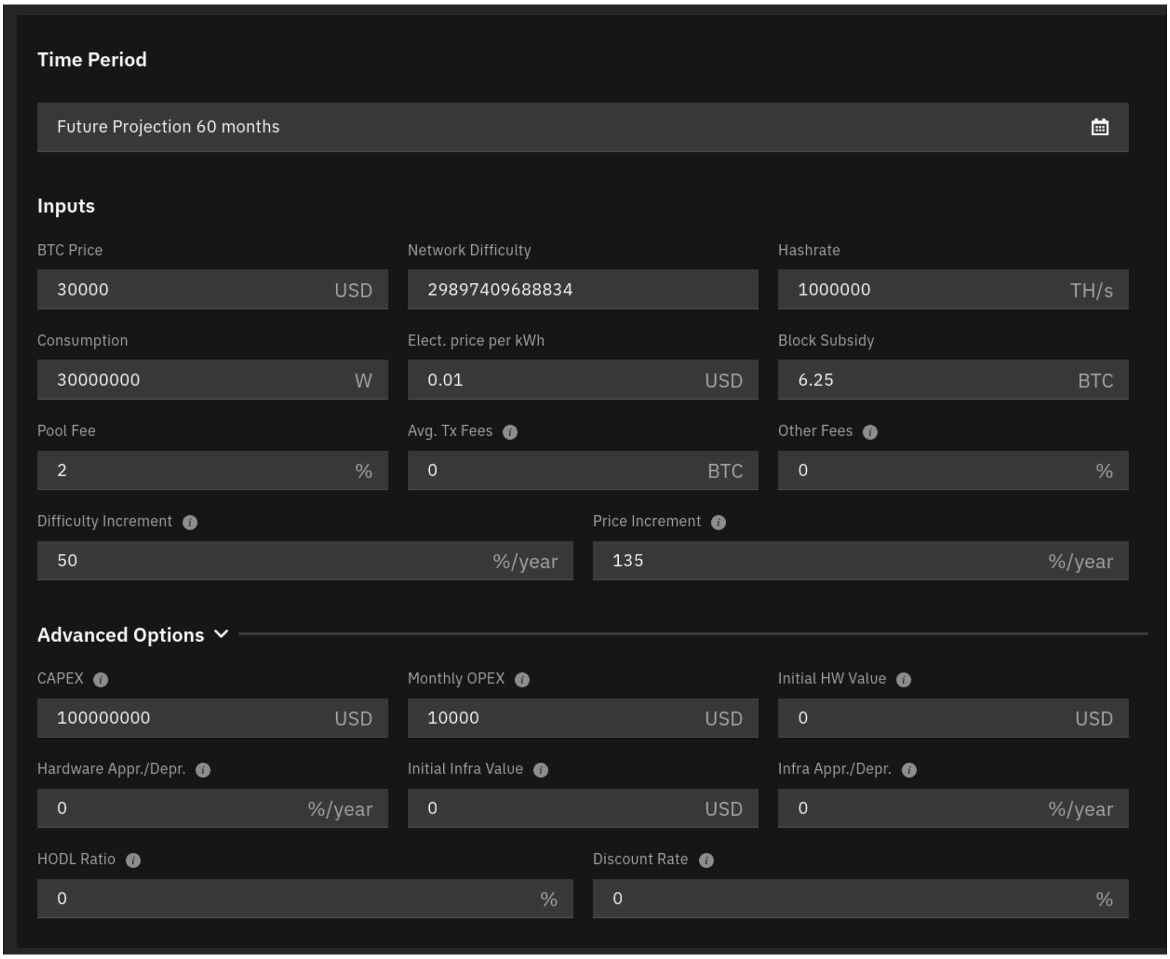

Figure 15: Mining conditions hypothesis 2

Economic returns:

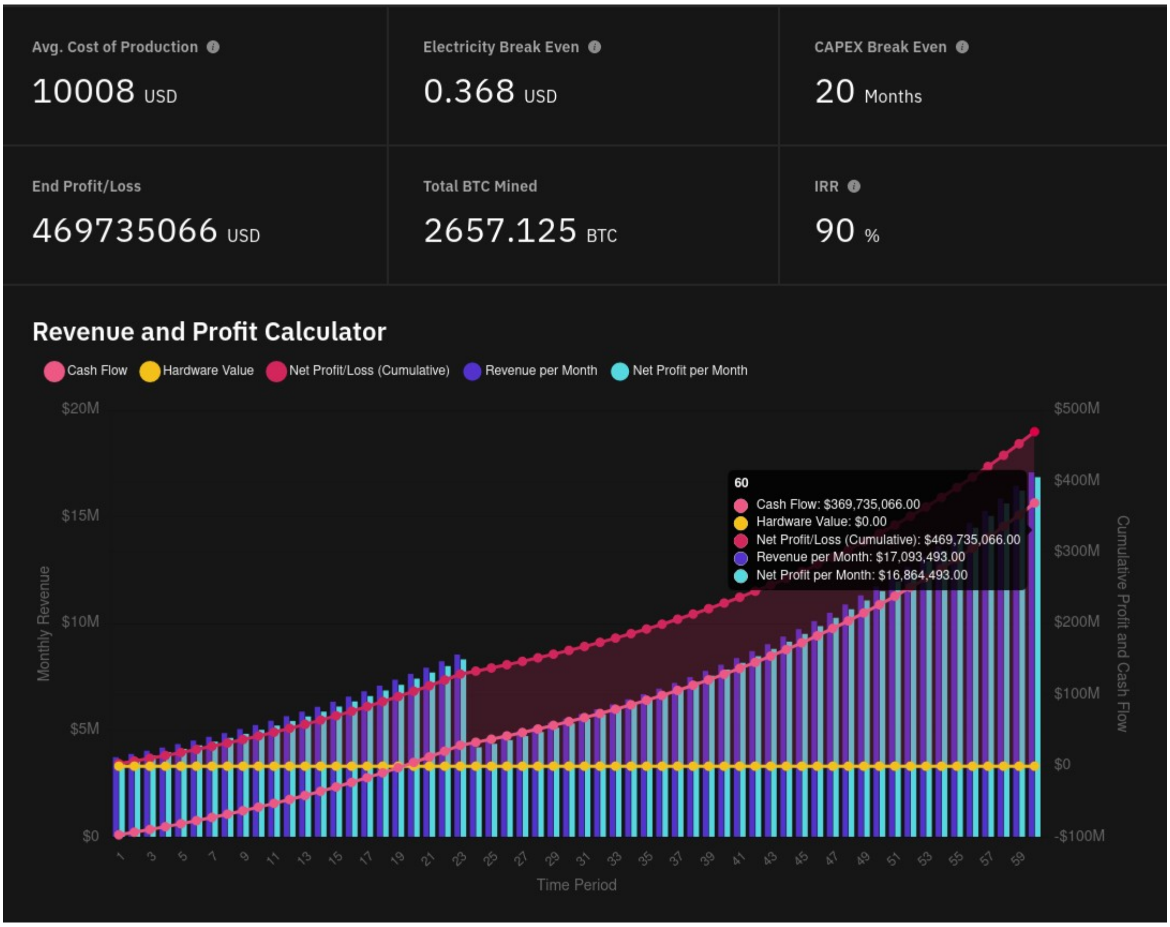

Figure 16: Mining expected returns hypothesis 2 – HODL 0%

Let’s break down the most important results we can extract from the previous calculations:

- CAPEX Break Even time: **20 Months**
- Total BTC mined during 5 years: **2657.125 BTC**
- End Profit: Approximately **$470M**
- Investment Profitability (IRR): **90%**

In simpler words, this just means that in 20 months we would already have recovered the $100M spent on the initial miners investment.

With the conditions previously described (conservative conditions), we would have a net profit of $470M, if we sold all the Bitcoins we mine during this period of time.

For the sake of this project, **we will now consider that we don't sell any Bitcoin we mine during the 5 year period** (HODL ratio = 100%):

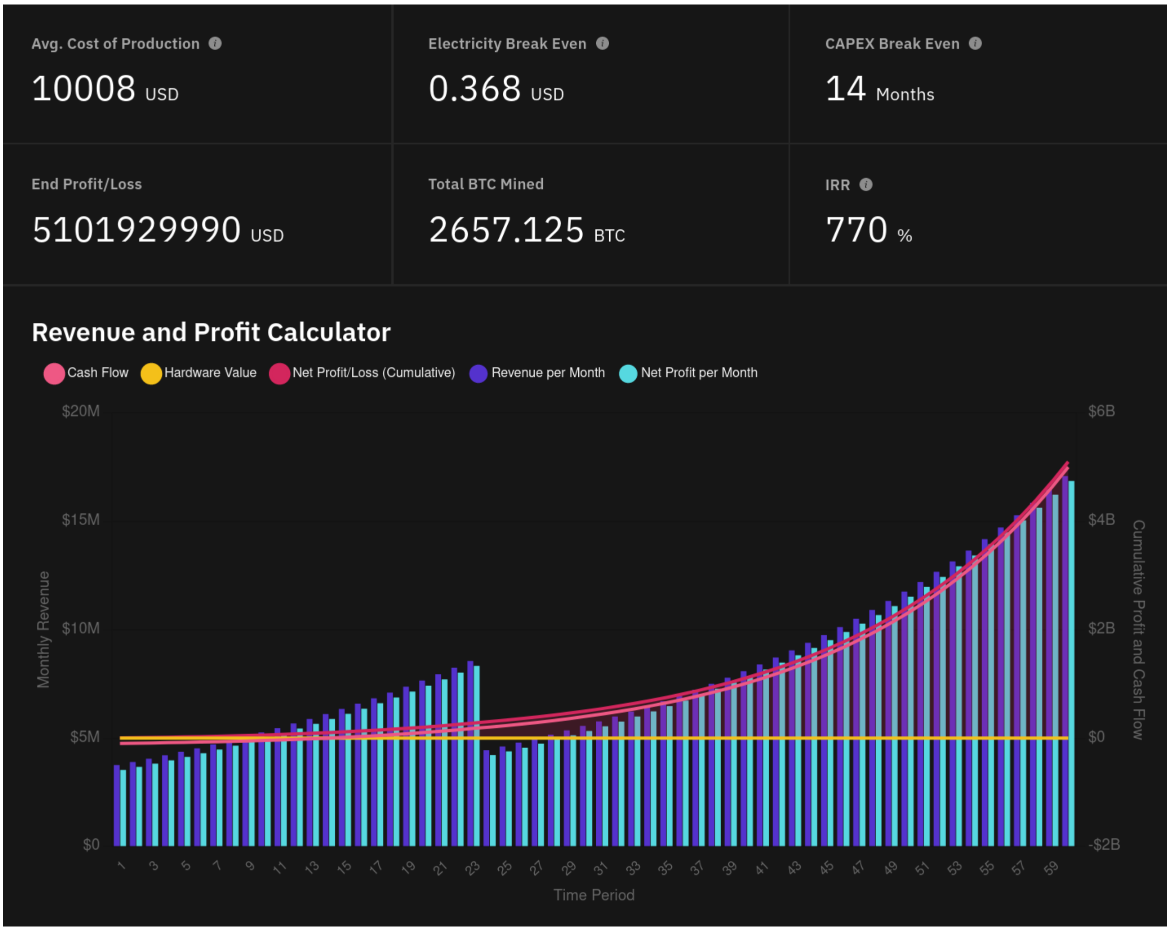

Figure 17: Mining expected returns hypothesis 2 - HODL 100%

In this conditions the results are even more favourable than before:

- CAPEX Break Even: **14 Months**
- Total BTC mined during 5 years: **2657.125 BTC**
- End Profit: Approximately **$5.1B**
- Investment profitability: **770%**

Needless to say, some Bitcoins should need to be sold during this period, to cover for the expenses.

The most interesting part is realising that Spain would not even need to invest more money in renewable facilities, as they already have more than 30MW of surplus energy currently.

Let's now see **how much money we would make if we sold those 30MW to the grid** (in case the energy was used and sold to the grid) during 5 years:

We'll take the **retail electricity price during June the 7th 2022**: 185,45€/Mwh [14], even if that is also another variable that can suffer huge changes over time.

Figure 18: Retail electricity price June 7th 2022

Results are not completely accurate, and should be recalculated each time someone wants to estimate the money they would make selling the energy to the grid. This will depend on the most expensive energy in Spain during the next 5 years, and that is the price that should be used at the moment to make the following calculations.

We've got 30MW available, which accounts for **720MWh each day, at a current average price of 185,45€/MWh, during 365 days a year and for the following 5 years** (*considering electricity price does not decrease*):

185,45€/Mwh * 720MWh/day * 365 days/year * 5 years = €**243,68M**

3.3.1.2. Hypothesis nº3: 60GW of unused energy produced by renewable facilities

Due to the linear nature of the previous calculations, the results will be exactly double than in the previous hypothesis.

Let's take a look at them, assuming the **same conditions**, and just like before, using 0.1% of the total excessive energy, **60MW to mine Bitcoin during the following 5 years**.

20.000 Antminer S19j, with 100TH/s of effective hashrate per miner → 2000000TH/s

- $10.000 per miner → $200M of CAPEX
- Difficulty increment = 50% per year ; Price increment = 135% per year
- Monthly OPEX: $10.000 per month
- HODL RATIO = 0%

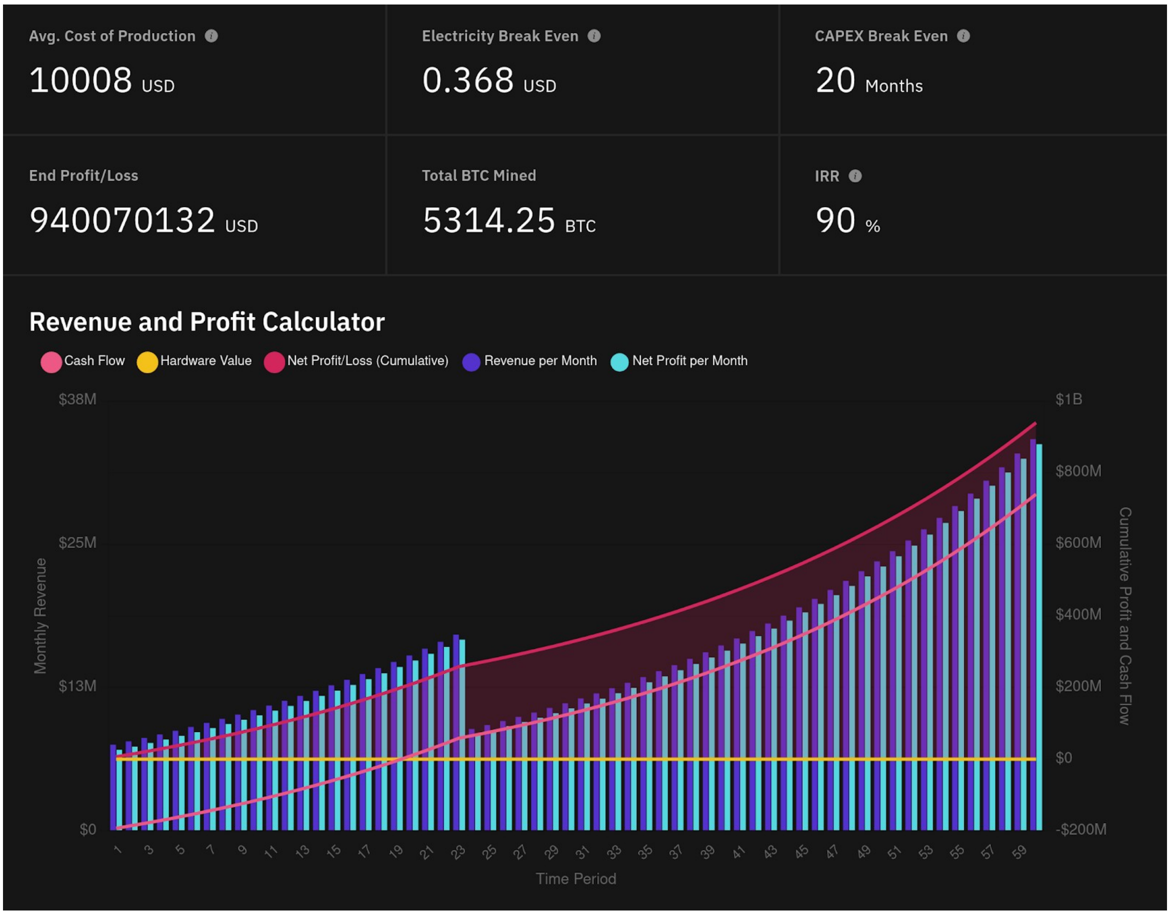

Figure 19: Expected mining rewards hypothesis 3 - HODL 0%

Obviously the Break Even continues at 20 months as we would need to invest the double amount of money, but we would be also mining the double amount of Bitcoin.

After 5 years we would have an End Profit of approximately **$940M**, with a HODL ratio of 0%.

If we would have kept the whole amount of Bitcoins mined, the sum raises to **$10.2B**.

If we now make the numbers in the case of selling that energy to the grid (60MW), we can see the following result;

185,45€/Mwh * 1440MWh/day * 365 days/year * 5 years = €**487,36M**

As we can rapidly see, with a HODL Ratio of 0% we would still be improving the ROI on a 2x basis, thus reducing the time to half of what it would normally take to make the same amount of money.

Either the 2nd situation and the 3rd one are favourable for Bitcoin mining, it all depends on the initial capital we've got available to deploy, as even if there was a supposedly bad situation as the 3rd one, with Bitcoin mining we could use all the excessive energy to produce economic activity and reduce the time it would take to recover the money invested in the energy production facility.

4. Results

During the first part of this project, the one focused in mining Bitcoin, we've been able to see that the profitability of mining operations depend on various factors:

- Bitcoin's price
- Bitcoin's network difficulty
- Electricity price

At the moment we carried out this study, the conditions have been extremely unfavourable for miners, as prices have fallen down, and the network's difficulty and electric prices have been going up.

This led our mining operations to be favourable during the first months as the price kept relatively stable, and **we recovered the initial investment of just 1 miner within 4 months**.

However, once the first machine broke down, and I had to plug in another 2 different ones, things had already changed, and the profitability has fallen down for bad conditions on the 3 factors that determine the profitability of mining operations.

In these new conditions, my 2 machines would take more than double the time it took for just the first one to recover my investment.

In case my electricity price could drop lower and lower over time, the profitability could go up again, and that's when renewable energy comes into play.

Regarding the second part, let's take a look at the comparison between the profits that we would make if we sold the excessive energy to the grid (and thus, created an artificial demand, which is not even feasible), versus if we consumed it with Bitcoin miners. We will take the Hypothesis nº2 as a reference, as the nº3 is just the same conclusion but with prices being doubled.

If we compare the two situations previously described (HODL ratio = 0% and HODL ratio = 100%) we can see there is a huge difference in the profits that could be made by selling that electricity to the grid, or mining Bitcoin:

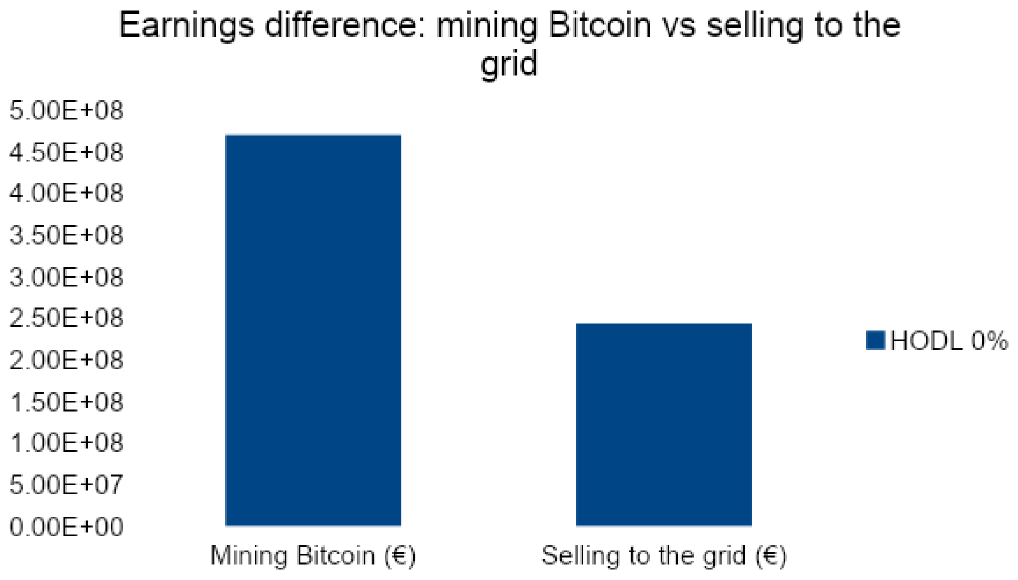

Figure 20: Earnings difference: Bitcoin mining vs selling to the grid – HODL 0%

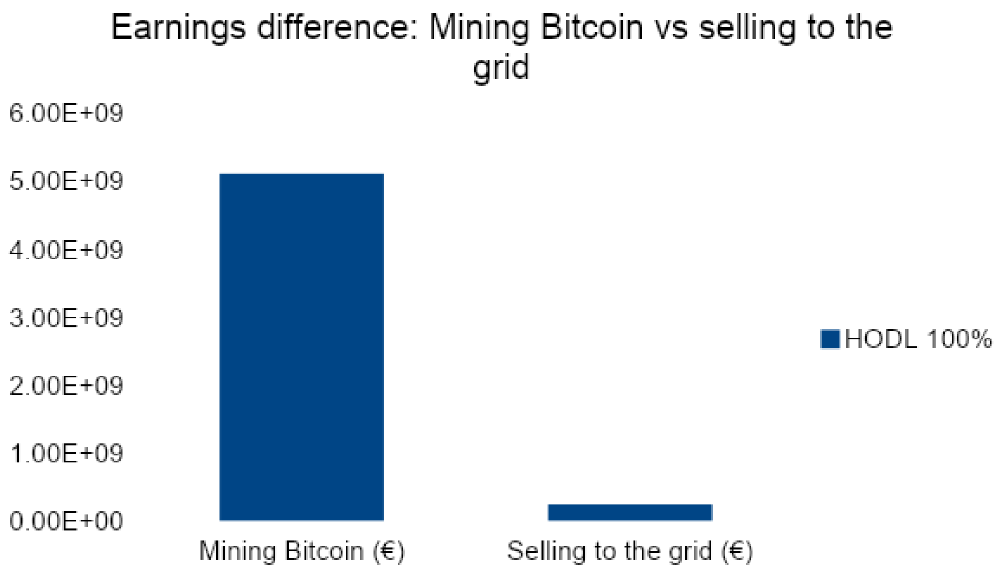

Figure 21: Earnings difference: Bitcoin mining vs selling to the grid - HODL 100%

With the previous results, it becomes obvious that mining Bitcoin results in an extremely higher ROI than just selling this energy to the grid. Apart of being more profitable, we would be increasing the overall renewable energy efficiency, as more energy would be consumed, and not simply thrown away due to inexisting demand.

By increasing the economic returns, renewable facilities could invest in other supplementary types of energy production facilities, to make sure there is no imbalances in the grid, and that during the whole day electricity can be provided without interruption to the whole population.

The following image describes how Solar (during the day) and Wind (during the night) can create a balance in the energy supplied to the population, while using the surpluses of energy produced to mine Bitcoin:

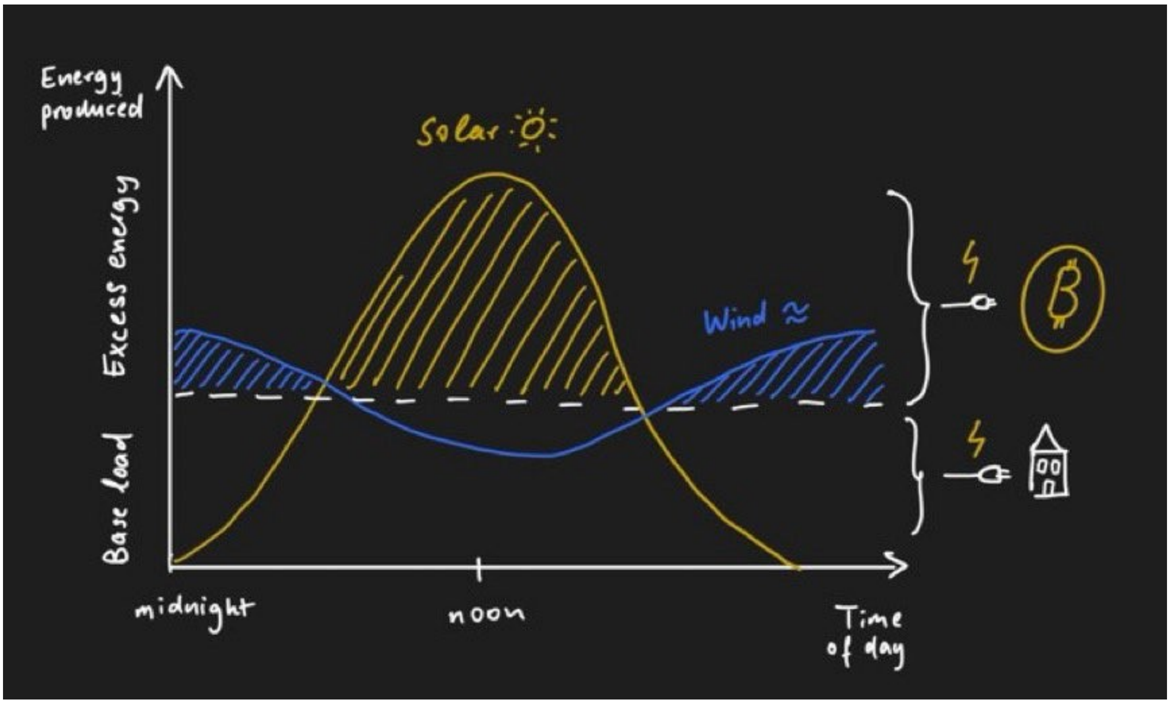

Figure 22: Solar and wind imbalances consumed by Bitcoin miners

Either with both hypotheses we have stated in this study, Bitcoin mining would be a huge advantage when applied with renewable facilities.

Even with a supposedly "bad situation" like the 3d one, where we Bitcoin miners could start consuming huge amounts of energy, this would help in a faster transition to a cleaner energy grid, and fossil fuels wouldn't need to be used for electricity production faster than expected.

This study focuses on renewable facilities which are already deployed, so CAPEX to build new infrastructure is not part of it.

To conclude with the results, they made it pretty clear that Bitcoin miners are looking for cheap energy to maintain their operations profitable.

Renewable energy fonts can be these electricity providers, while at the same time Bitcoin being the main buyer for all the excessive energy they produce, and helping in recovering the investment made in the renewable energy facility faster.

5. Budget

For this project we can easily estimate the costs, dividing them in two main points.

First, the cost of the machines I've used to carry out this study. This specialized computers are each one of them the model Antminer s9, from Bitmain.

Luckily only the first one had to be paid, for a price of approximately 300€. The good part of doing that investment was knowing that I could recover it in a few months, as I have demonstrated during the project.

Once this machine stopped working correctly, I could get 2 more of them thanks to PoW Containers, a mining company firm based In Spain who I started working with at the same time I was doing this thesis.

The second thing is the number of hours I've spent doing this research with PoW Containers, which can be evaluated at the cost of a Junior engineer, exactly at 9€ per hour. The work with them has been 360 hours, which ends up in a total sum of 3240€ without taxes.

Total cost of the project if we take into account the 3 machines and the evaluated cost of the junior engineer hours, exceeds the 4000€.

6. Environment Impact (Optional)

Since the beginning of this project, we wanted to prove if Bitcoin mining is indeed one of the most polluting activities in the world, as told by mainstream media, or if there was something else behind it.

According to studies made by professional consulting firms regarding the biggest Bitcoin mining firms as of June 2022, it has been seen that the majority of Bitcoin mining operations are powered by renewable energies.

After the conclusion found doing this project, it is evident that miners who are not still mining with renewable energies will tend to do so in the near future, as renewable facilities are the ones with a lower marginal cost, and that's the main impediment for big miners.

Bitcoin mining can definitely be the technology that accelerates the global adoption of renewable energies, and gives an extra incentive to do so.

Meanwhile, some of the miners who are still not mining within renewable facilities, are actually doing it by using the Flared Gas emitted from Natural Gas extraction.

For more information about the current state of Bitcoin mining, and it's effect on the world's energy consumption, and pollution, check the letter made by Bitcoin Mining Council in the USA, responding to false claims

https://bitcoinminingcouncil.com/wp-content/uploads/2022/05/Bitcoin_Letter_to_the_Environmental_Protection_Agency.pdf

To conclude, Bitcoin mining is not only one of the less polluting activities in today's world, but one of the biggest contributors to the **reduction of the pollution of our planet.**

7. Conclusions and future development:

When we started this project, many people were already talking about the benefits of mining Bitcoin in renewable energy facilities, but there weren't any numbers accompanying their claims.

That's why we decided to study the real profitability of Bitcoin mining, it's ups and downs, and the expected renewable energy infrastructure deployment plan of Spain until 2030, and make some calculations to see if the claims were indeed certain.

After seeing the expected growth in energy infrastructure planned, the real (poor) usage of renewable-powered electricity for the past years, and the small percentage of expected growth of energy consumption, we decided to investigate whether it would be more profitable for the energy companies to create energy demand (either artificial or real), and sell that energy to the grid, or just mine Bitcoin with the amount of energy that would not be consumed otherwise.

The initial feeling was already that Bitcoin mining would be a better option, but the results did indeed surprise us.

This study has led to the conclusion that using the already deployed infrastructure would result in a much better outcome than just building new one, as there is currently huge amounts of already produced energy that is not consumed, and finding a first resort consumer for that unused energy is crucial.

With the most conservative calculations, we have reached the conclusion that the return on investment on energy facilities would be at least double as if we sold that exact same amount of energy to the grid. Additionally we did only consider using 0.1% of the produced energy that is seen as "wasted" nowadays. With a higher percentage of consumption the results would be even better.

To sum up we made 2 types of calculations. The first one takes into account that we do not sell any of the Bitcoins we mine during a lifespan of 5 years (ASIC lifetime expectancy), and the second one we do hold all the Bitcoins we mine. In the second scenario, the results are extremely favourable for Bitcoin miners, however this assumes that the company behind does not need to pay anything in the meantime, which is not a real scenario, and would involve the company to be a real Bitcoin believer, which is indeed another story.

To conclude this thesis, we just want to discard the current idea of Bitcoin polluting the world, as it's huge energy consumption, if treated correctly, can be the first technology ever that helps our society achieve a cleaner grid, and accelerate the adoption of renewable energies as the main electricity producers in the whole world, by reducing the

ROI of renewable facilities, and being the main consumer when imbalances in the grids are produced.

Further investigation is needed in the topic and will be duly conducted, to help either the Bitcoin network, and energy producers around the world, as well as the mining profitability and life cycle of mining machines research will keep going until either the miners die, or they stop being profitable enough to cover the electricity expenses.

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Glossary

Bitcoin: A Peer-to-Peer Electronic Cash System.

Difficulty Adjustment: Bitcoin difficulty adjustment is an event that occurs after every 2016 blocks mined based on the mining difficulty of the previous difficulty. The increase suggests that the previous difficulty was too low. Bitcoin difficulty is the number of hashes required to find a solution below a given threshold.

Proof-of-work mining: The blockchain technology behind Bitcoin is essentially a database, but it's decentralized and powered by peer-operated nodes distributed around the world. To ensure that everyone agrees on the contents of the ledger, Bitcoin miners compete between them creating hashes from the block headers that include the latest transactions, and once one of the miners finds a hash that meets the expected difficulty adjustment, that block is added to the ledger and transmitted to the rest of the participants who instantly start working in the next block hashes. This procedure is called proof-of-work, and it is the way Bitcoin reaches consensus without a single intermediary.

Block: Blocks are the data structures of the blockchain. Data is stored inside a block and encrypted.

CPU: Central processing Unit.

GPU: Graphics Processing Unit.

FPGA: Field-programmable gate array.

ASIC: Application specific integrated circuit.

ROI: Return on Investment.

Mining pools: Miners working together to find a valid block and distribute the reward between all the participants.

BOE: Boletín Oficial del Estado.