Bitcoin's electric consumption

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FOREWORD

Some time ago I discovered crypto currencies and their advantages: data ownership, decentralization, transparency,... I quickly got interested in the technology and to be honest in the possible profit promised by some "online crypto gurus". Given the controversial nature of cryptocurrencies I couldn’t stop hearing that they were only useless ponzi scheme with a disastrous impact on our beloved planet.

Ecology and sustainability have always been an important subjects to me so I couldn’t ignore those criticisms any longer.

Unfortunately I soon realized that finding unbiased answers was hard. Bitcoin’s maximalists claim that it uses mostly green energy, wasted otherwise [1], and Bitcoin’s detractors warn that Bitcoin alone could push global warming above 2°C [2].

This is the reason I choose to study the subject deeper on myself. In the following pages you will find facts, graphs and my humble opinion on the matter, all supported by data.

INTRODUCTION

WHAT I DID

Nowadays, it is difficult to accurately determine the true ecological impact of Bitcoin. In this work, I have chosen to focus on the electricity consumption required for Bitcoin mining, regardless of the source of this electricity and assuming that more electricity consumption leads to a greater negative impact on the environment

Some may argue that this is an unfair trial of the network. You will find bellow some arguments coming from those detractors:

Bitcoin is as clean as the energy you feed it [3].

Bitcoin requires a lot of hardware. This could by itself be considered as an ecological disaster.

Bitcoin can use electricity that would have been wasted otherwise . For example: wind turbine's production when there is no energy demand. This balance the energy grid. Or methane flaring [3], which reduces the greenhouse effect of the gas and would not be worth it without Bitcoin.

Bitcoin makes worth it producing energy when it is not needed, uses energy that could have been used by others servrices (data centers have the same flexibility as Bitoin) and increases the profitability of some oil fields(methan flaring is already compulsory in US [4], Bitcoin mining only make it economically viable).

Bitcoin has limited supply(no inflation). Inflation leads to overconsumption as it punishes the savers [1].

All these arguments are valid, but they also have equally valid counterarguments. This is precisely why I chose to focus on the electricity consumption only. I believe that it is a fair approach to understand the ecologocal impact of the network.

HOW I DID IT

All the data I used to achieve this work can be found online and is in free access.
You can find the sources of the collected data in the 'reference' section.

HOW THE WORK IS DIVIDED

The work is divided in 4 majors parts:

In the first section, we will see how the bitcoin network operates and why it requires energy to function properly. Additionally, we will compare the consumption of the network over one year to others values to provides a clearer understanding of its significance.

In the second section, we will focus on developing a model to estimate the network's electricity consumption over time. As you will learn in the first part, this consumption varies over time. We will then compare our model to exiting ones.

The third part will provide a prediction of the of electricity consumption trends for the following decades.

In the last part I will have a word about an alternative to the bitcoin network which , by definition, is less energy-intensive than bitcoin but still share same values of decentralization.

BITCOIN AND ELECTRICITY

This section will be dedicated to understand how the Bitcoin network works and what is its link with energy. The last part will be used to compare its electricity consumption over one year to others values.

WHAT IS BITCOIN

Bitcoin is a decentralized digital currency that allows peer-to-peer transactions without the need for intermediaries like banks or governments [5]. It was created in 2009 by an anonymous person or group using the pseudonym Satoshi Nakamoto. Bitcoin operates as a blockchain, which is a distributed ledger that records all transactions in a transparent and immutable way.

One of the key features of Bitcoin is its security. The network uses complex cryptography to secure transactions and prevent fraud. Each transaction is verified by multiple actors of the network, and once confirmed, it is added to the blockchain, which is stored on thousands of nodes around the world. This makes it virtually impossible to alter the transaction history or double-spend coins. Unfortunately, this security comes at a cost: electricity consumption

WHY DOES BITCOIN NEEDS ELECTRICITY

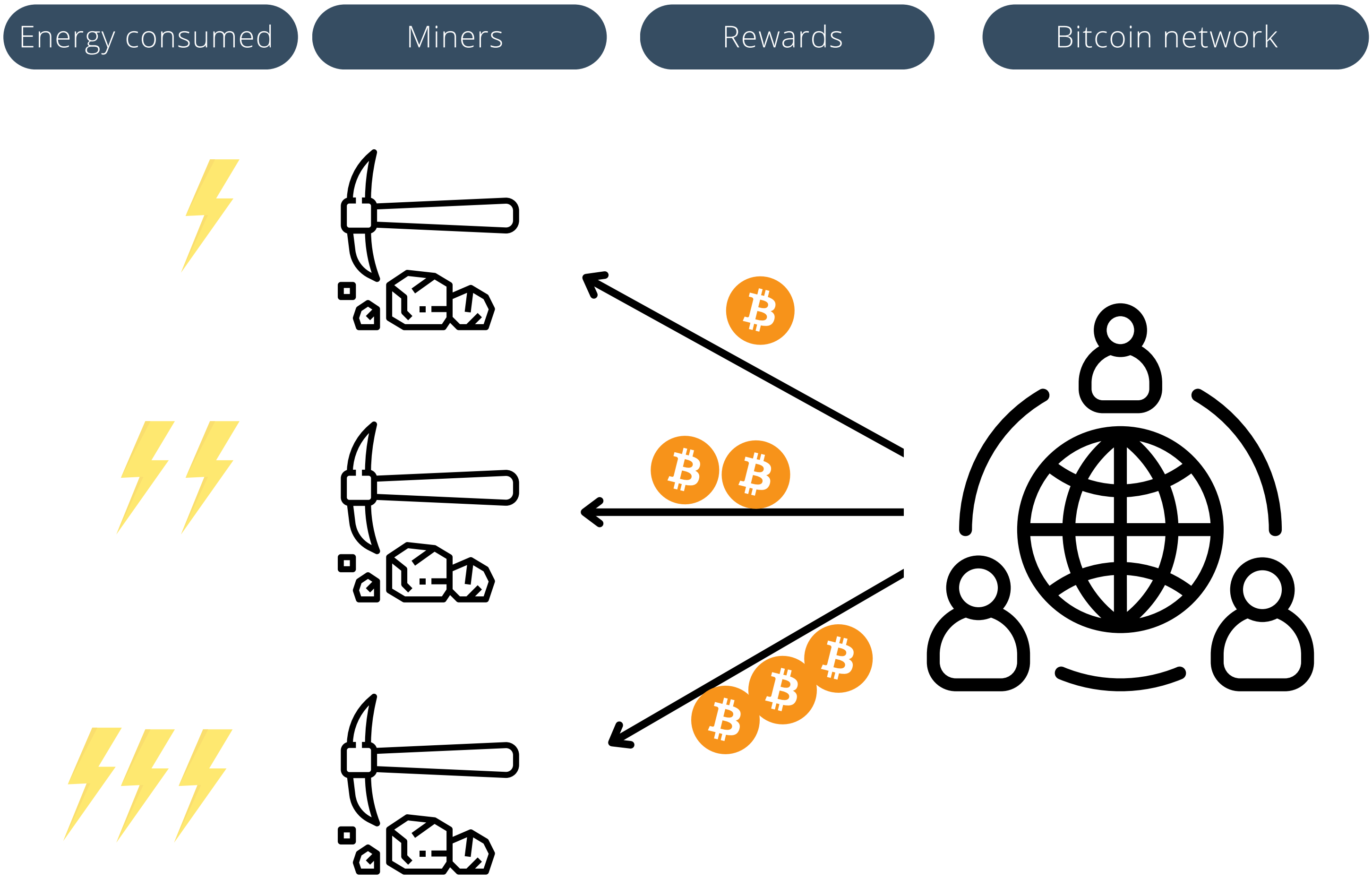
Those responsible for verifying transactions and adding them to the blockchain are called miners. They compete in a ‘game’ called Proof of Work. The rules of this game are simple: if you are the first to find a solution to a complex mathematical problem, then you get rewarded for it (in Bitcoin obviously). This incentivizes them, first, to continue to participate in the network’s security, but also, to add computational power to increase their chance of solving this problem first. This computational power can come in the form of more efficient computers or higher energy consumption. It is important to note that more efficient computers does not mean lower energy consumption [6], miners will still use the same amount of electricity, but more efficiently.

Of course, this is a simplified explanation of how Bitcoin works. In practice, a full understanding of the technology requires to master complex concepts in cryptography that are beyond the scope of this work. As a result, we will stick with this simplified explanation.

1) Bitcoin network's security is ensured by miners.

2) Those miners get rewarded only if they find a solution the a complex mathematical problem first.

3) To increase their chances of being first, miners increase their energy consumption.



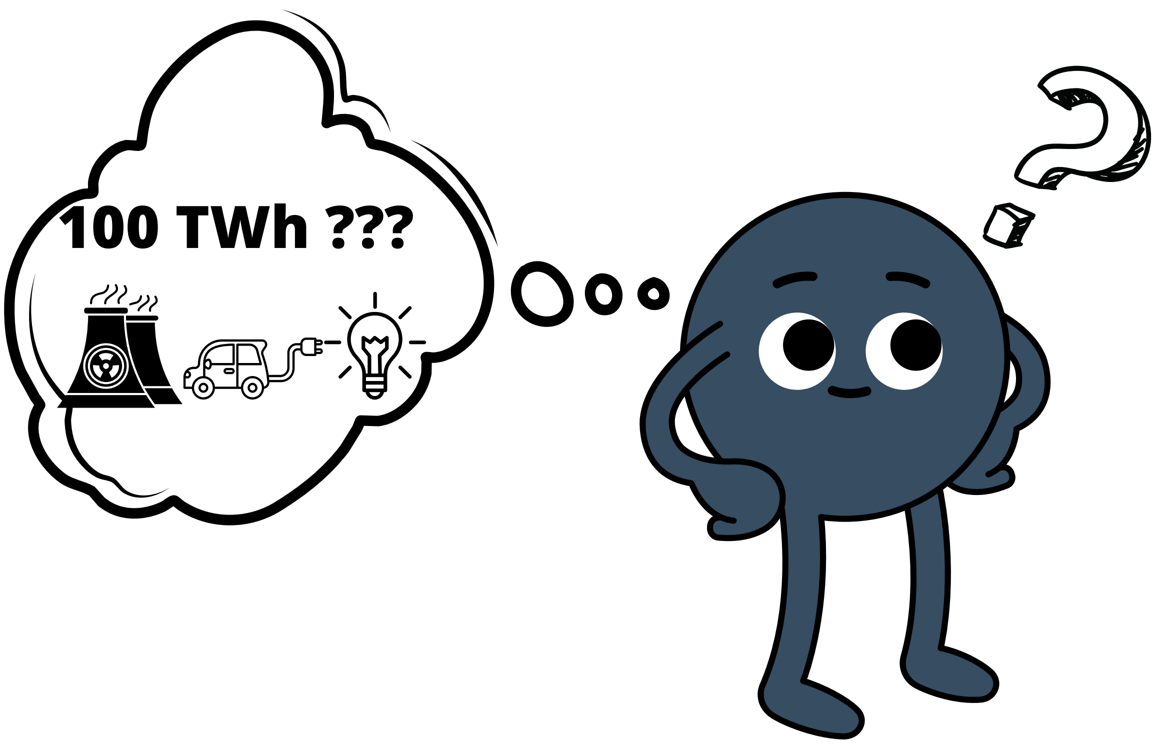
HOW MUCH DOES IT CONSUME

In the previous subsection we learned that the security of the network came with a cost, its high energy consumption. In fact, it is this high energy consumption that secures the network. If a malicious entity wants to bypass the network's security, it has to buy as much electricity as half of the miners, which makes the benefits/rewards balance not worth it.

1) Bitcoin is designed to have a high energy consumption, decreasing it would decrease its security and is therefore unwanted by its users. [7]
Security = f(Electricity used)

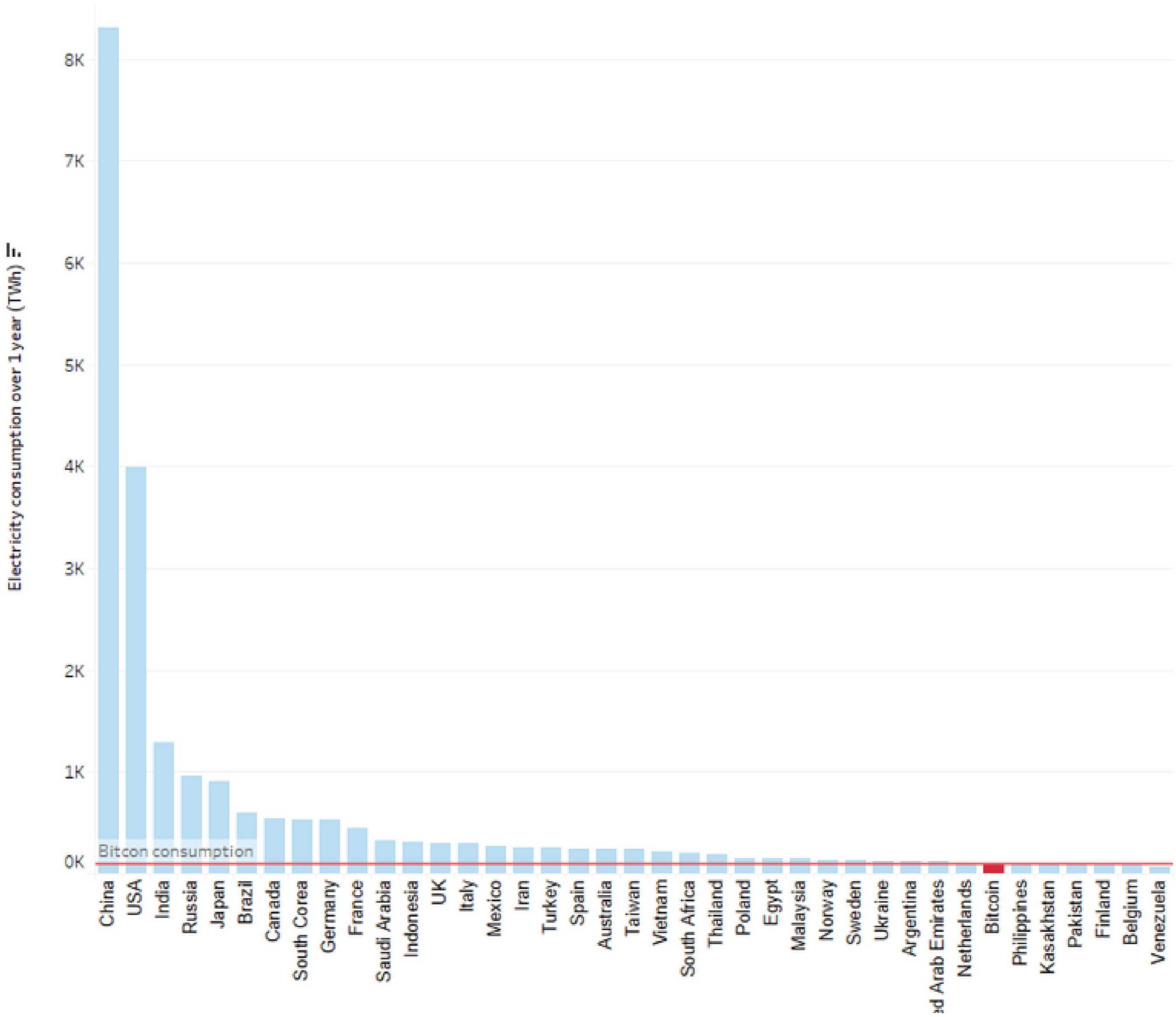
2) As miners are rewarded in Bitcoins, the amount of electricity they are able to purchase is directly correlated to the cryptocurrency price.
Electricity used = f(Price)

This being said, you understand that the estimation I will give you won't be true if Bitcon's price changes drastically. Today (May 2019), we can estimate that the Bitcoin network uses about **100 TWh** of electricity to ensure its security. Is that a lot? It depends on what you are comparing it to.



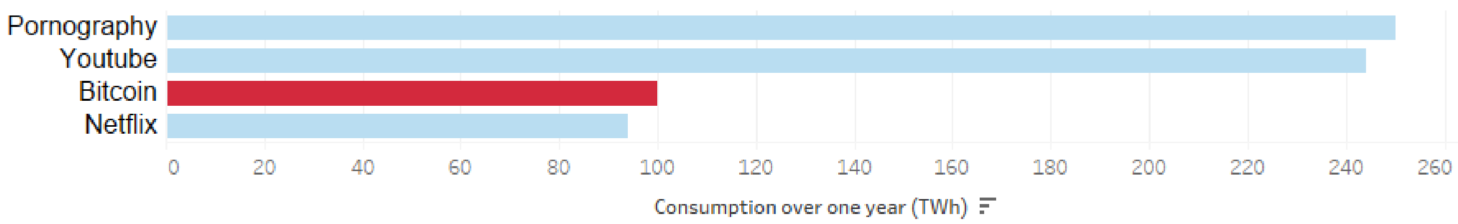
First, let’s compare this consumption to that of countries [8].As Figure 1 shows below, if Bitcoin were a country, it would be ranked at the 33rd position in terms of electricity usage. This is a lot, certainly, but if we compare it to China or USA it looks negligible. In fact, this consumption represents oly about 0.5% [9] of the world's total electricity consumption. (Note: you may find in some papers that it represents only 0.05% of the world's energy consumption,keep in mind that electricity is not equivalent to energy. In fact energy also includes heating, cars’ fuel,...)

Figure 1: Countries electricity consumptions over 1 year



We just compared Bitcoin's consumption to that of countries, but does this really make sense? Lets now compare it to some "entertainment" services [10]. The figure 2 shows the electricity consumption of some services commonly used worldwide. Even though these are not targeted for their ecological impact, we see that their consumptions are on the same order of magnitude as Bitcoin's.
Note that the Netflix consumption comes from an idependent study (from the shift project), they published an estimation of their consumption which is 200 times lower

Figure 2: Entertainment electricity consumptions over 1 year



I believe that this graph is a solid counterargument against people who say "I like Bitcoin's values, but yet I'm concerned about its ecological impact." I doubt that those people will answer "I like pornorgaphy's values and I'm also concerned by its ecological impact.".

Let's now have a word about the energy consumption of our current payment system. The entire banking system also has an electricity consumption of about 100 TWh [11], which includes electricity used in banks, ATMs, and other related operations. However, due to its architecture, Bitcoin does not require all those, so comparing the two doesn't really make sense.

We could try comparing the energy consumption of Bitcoin to that of centralized systems like Visa or Mastercard. Bitcoin's consumption is several orders of magnitude higher than that of centralized systems (*>10^(6)) [9]. However, this comparison isn't fair to the Bitcoin network since these centralized systems cannot function without the banking system, whereas Bitcoin can [11].

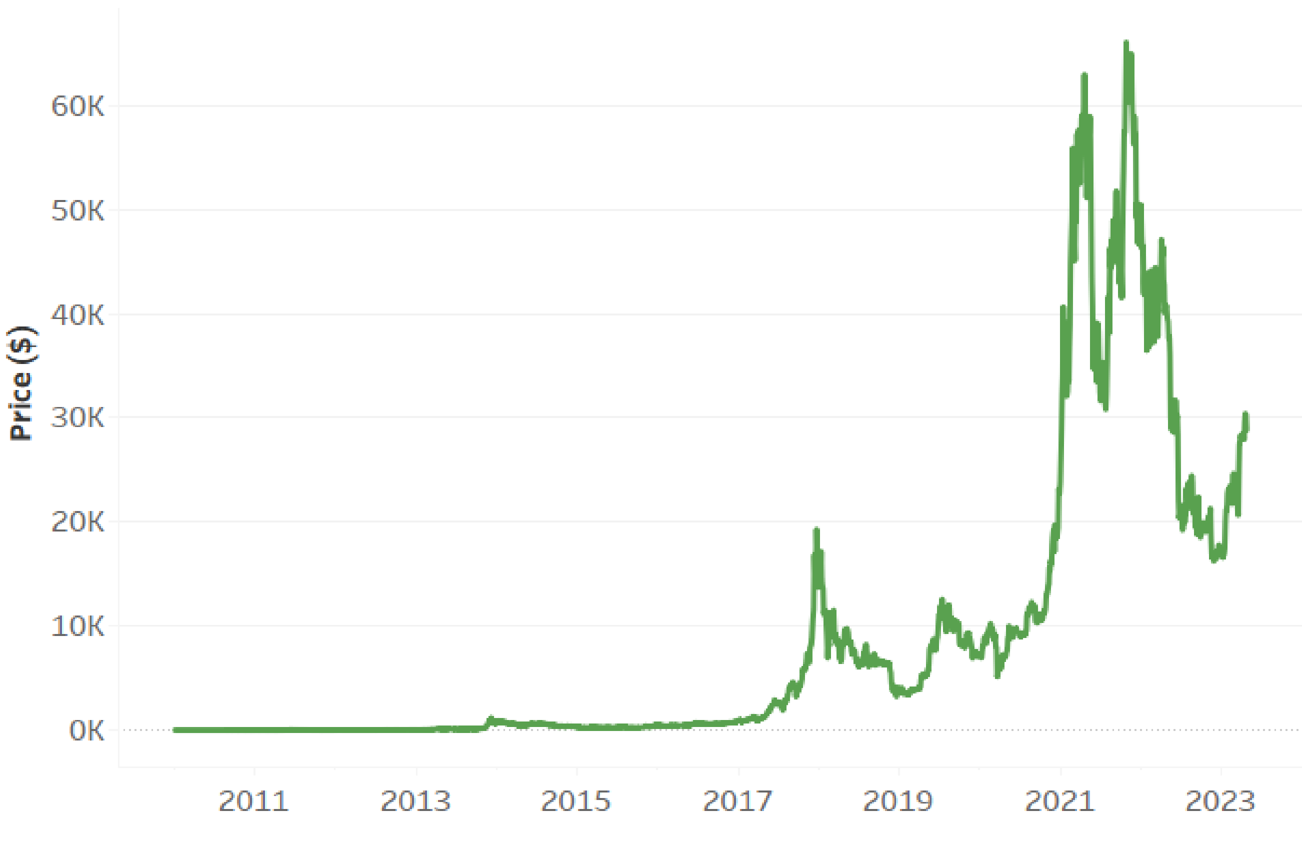
In conclusion, it is difficult to compare the electricity consumption of Bitcoin with that of our current payment system since they have completely different architectures. However, one thing is certain: Bitcoin will always consume much more energy than a centralized system, due to its decentralization and especially due to its security system.

MODELING

In this section I will explain how I build my model to estimate the energy consumption of the Bitcoin network. Each choices will be justified to make sure that the limits of this model is clearly understood and then the results will be compared with the one of 2 models executing the same task.

The analysis will only be done from 2016. You can see on the following figure that Bitcoin price before this date was nothing comparable to today's [12]. At this time Miners and more generally Bitcoin's users were only Bitcoin optimists.

Figure 3: Bitcoin Price



THE HYPOTHESIS

In the previous section I stated : "*As miners are rewarded in Bitcoins, the amount of electricity they are able to purchase is directly correlated to the cryptocurrency price.*" . This is the core of my model, which assumes that miners are rational and logical agents that will continue mining if and only if their activity is profitable.

In other words, to be able to have an estimation of the electricity used, we will consider:

- Miners continue mining if their rewards are greater than their cost.
- Their electricity consumption is a constant part of their cost.
- Electricity has a constant price

Knowing the rewards of the miners we can estimate their electricity consumption with the following formula:

$$\text{Electricity used} = \frac{\text{Rewards}}{\text{Electricity cost}}$$

THE COSTS

From comparing various sources we will now estimate that:

- Electricity represent a 60% share of the Miners cost(= 60% of minings rewards). [13]
- The cost of a kWh is 0.05 $. [13]

Which gives the updated formulas: (with 1 TWh = 10^(9) kWh)

$$\text{Electricity used (kWh)} = \frac{(\ 0.6 \times \text{Rewards})}{0.05}$$

THE REWARDS

Each time a miner solves the diffucult "*mathematical problem*", it can add what we call a block to the blockchain. With that block comes the rewards of the miner composed of the **block rewards** and the **transaction fees** (both in Bitcoin).

The network is design to change the difficulty of the "*mathematical problem*" in order to have an average of one block being added every 10 minutes, resulting in an average of (6 x 24 x 365) = 52562 blocks per year.

With those informations we can create the final formula of our model:

$$\text{Electricity used (kWh/year)} = \frac{52562 \times 0.6 \times (\text{Block rewards} + \text{fees}) \times \text{Bitcoin Price}}{0.05}$$

Let's now have a closer look to those 2 types of incomes

The **blocks rewards** are the way new Bitcoins are created. Each time a block is created '*n*' new Bitcoin will be given to the Miners which added this new block. This is what we call mining new Bitcoins.

The blockchain has, by definition, a limited supply so these rewards can't remain to '*n*' eternally. It is why there is a phenomenon called the **halving**. Every 210 000 blocks (+- 4 years), the block rewards are divided by 2. When the blockchain was created miners got 50 BTC for each block added, today they get 6.25 BTC and after the next halving,which is supposed to happen in 2024, they will get 3.125 BTC.

On the figure next page, you can see the amount received by the miners for each block added. In yellow and on the left axis in Bitcoin. In green and on the right axis in USD. [12]

Figure 4: Block rewards

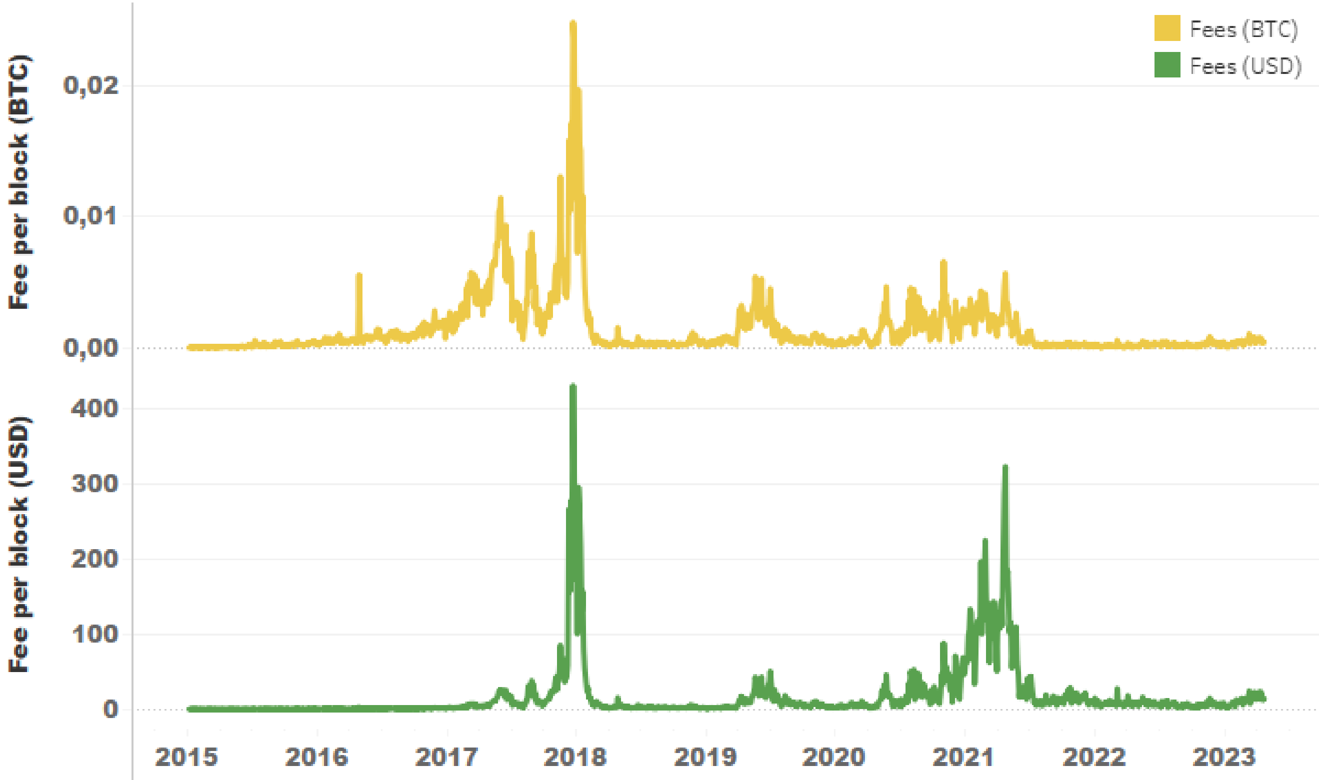
We notice that the profitability of mining is increasing. This is due to the fact that the price of Bitcoin is increasing faster than the speed with which the block rewards are decreasing. At least for now. If Bitcoin's price does not double every 4 years this profitability will decrease.

Anyway, at one point (predicted around 2140), all 21 000 000 Bitcoins will be considered as mined, and block rewards will stop. At this moment only the second type of rewards will continue.

The **transaction fees** are the amount people who use the network are willing to pay to execute their transactions. Each time you want to do a transaction, you have to allocate an amount for the fees. At that point, the nodes will choose which transactions will be added to the new block (blocks have a limited amount of transactions). Miners being completely rational economic agents, they choose the transactions with the highest fees.

On the following figure, you can see the amount received by the miners from transaction fees for each block. In yellow and above in Bitcoin. In green and under in USD. [12]

Figure 5: Transactions Fees



On this figure we notice 2 things:

Rewards coming from transaction fees are lower, by a factor of 1000 at least, than block rewards. This means that only block rewards encourage Miners to secure the network.

The amount of transaction fees Miners receive is not a function of the price. Locally the correlation between these 2 variables can appear high but even though the price tripled between the ATH(All Time High) of 2017 and the one of 2021, the amount of transaction fees decreased.

I think it’s important to have a word about the lightning network. **Lightning network** is what we call a layer 2. It uses payment channels to increase the scalability of the Bitcoin blockchain, resulting in faster transactions,lower fees and more transactions per block. However,this comes with a trade-off in terms of security and decentralization. [14]

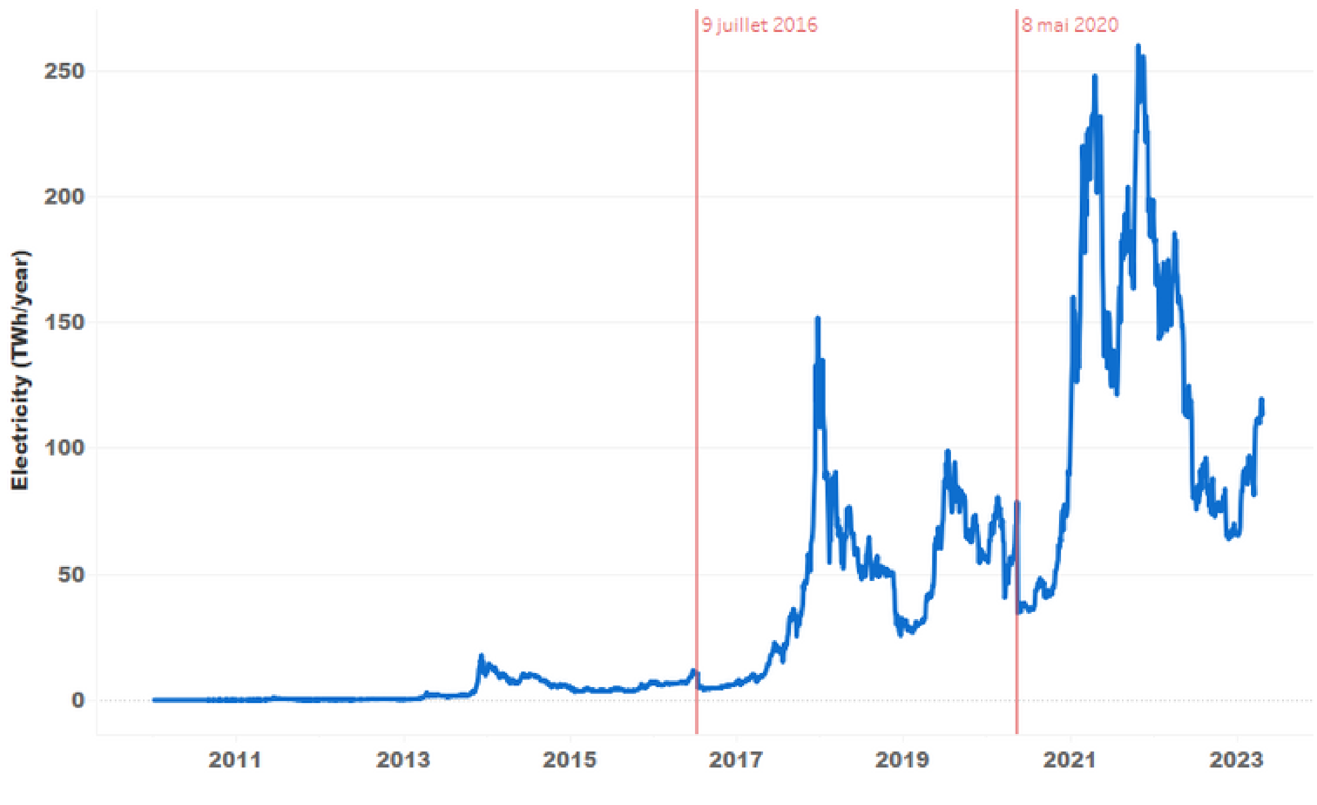
While it was released in 2019, some argue that the Lightning Network could increase rewards from transaction fees. Indeed a layer 2 enables a higher number of transactions which could lead to more transaction fees. In practice we see that it is not the case.

THE RESULT

Not surprisingly, the evolution of electricity consumption (shown on the next figure) is following the evolution of the block rewards in dollars, and by extension, of the Bitcoin’s price (*corr(BTC_Price, Elec_consumption) = 0.975*).

It is important to keep in mind that halvings will increase the importance of fees and so decrease this correlation. On the folowing figure the halvings are represented by the red lines.

Figure 6: Electricity consumption



TESTING

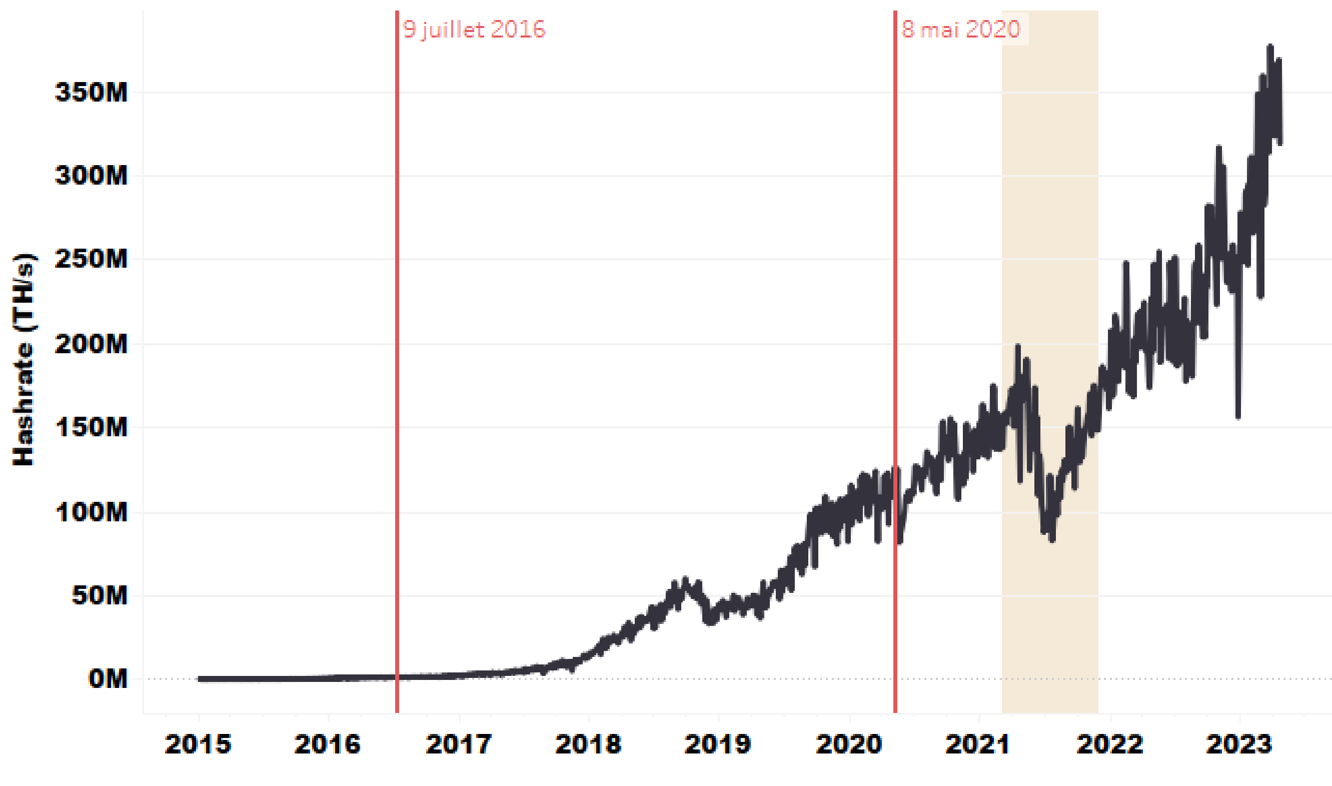
To build this model we assumed that Miners were rational. We will now test this hypothesis by examining the hashrate. The hashrate represents the total computational power provided by Miners. In practice, it is the number of attempts to solve 'the difficult mathematical problem' in one second.

To increase the hashrate, you can either increase the efficiency of the computers (which has drastically increased since 2010) or add new computers,resulting in higher electricity consumption.

Therefore, halvings should cause the hashrate to decrease by half of its value until miners have enough time to purchase more efficient computers, which could take time due to market inertia."

We can see from Figure 7 that this is not the case [12]. The halving in May 2020 appears to have had only a small impact on the hashrate, which is not what we would expect from rational agents.
Note: The red band (in 2021) corresponds to when China banned Bitcoin mining within its borders.

Figure 7: Hashrate



Both the Cambridge Center for Alternative Finance [15] and Digiconomist [16] (since 2017) have built models to estimate the electricity consumption of the blockchain. Like me, they use the rewards of Miners, but they also take into account the hashrate and the average efficiency of mining computers. That's why I believe that comparing my model to these two is a good way to test its accuracy. The following figure gives the estimations coming from the 3 models (in log scale).

Figure 8: Model testing

We notice that all three models provide similar results. After a deeper analysis, I observed that my model tends to overestimate electricity consumption when the Bitcoin price rapidly rises to a new ATH and underestimate it when the Bitcoin price reaches bottom values.

Figure 9: Correlations between models

corr(My_model, Cambridge)	0,8941
corr(My_model, Digiconomist)	0,7419
corr(Digiconomist, Cambridge)	0,8235

PREDICITON

In this section we will try to predict the electricity consumption of the network using the model we just built. First we will state the hypothesis we need to get a prediction. After that, we will look at the results of the model and try to analyze them.

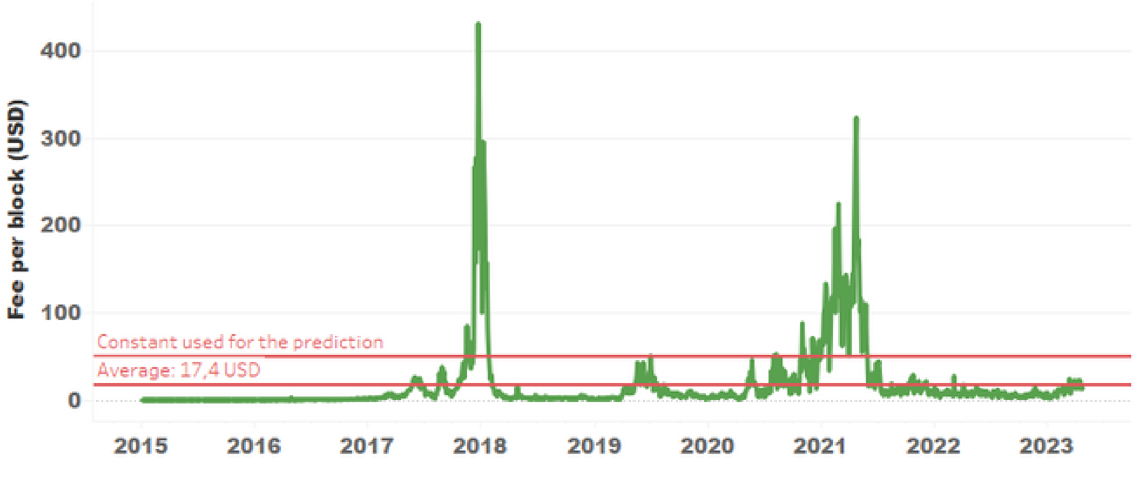
HYPOTHESIS

If we take a look at the formula of the model, we can see that we need three values to be able to predict the electricity consumption of the network: block rewards, transaction fees per block, and the price of Bitcoin.

Block rewards: As stated earlier, block rewards are divided by two every four years on average. It is easy to estimate the block rewards if we know the date of the last halving (May 8, 2020) and the current value of the block rewards (6.25 BTC).

Transaction fees: We saw that transaction fees are not a function of the price. In fact, fees increase when the market is volatile and people are willing to pay more to quickly get rid of their bitcoins. The average fee reward per block was $17.4 between 2015 and 2023. For our prediction, we will use a constant reward of $50 per block from fees (see the figure below). [12]

Figure 10: transaction fees



Bitcoin price: The price of Bitcoin is the most challenging variable to estimate, and it is almost impossible to make a reliable prediction. However, is it necessary to have one? In this section, we will attempt to identify potential trends that could emerge if Bitcoin continues to thrive.

We will consider that Bitcoin will have a '*mass adoption*' until 2028 and then the price will grow at a rate of 3% each year, which is a more normal rate in traditional finance.

For the mass adoption, we will use a famous indicator in the Bitcoin community: the Rainbow Chart [17]. This chart is more of a decorative graph than an actual indicator, but as we need a price to make our prediction, we'll use this fancy chart. It is built using a logarithmic non-linear regression on the price. This regression we will used to predict the price until 2028.

You can see the rainbow chart on the figure below and an explaination on how to read it on the newt page

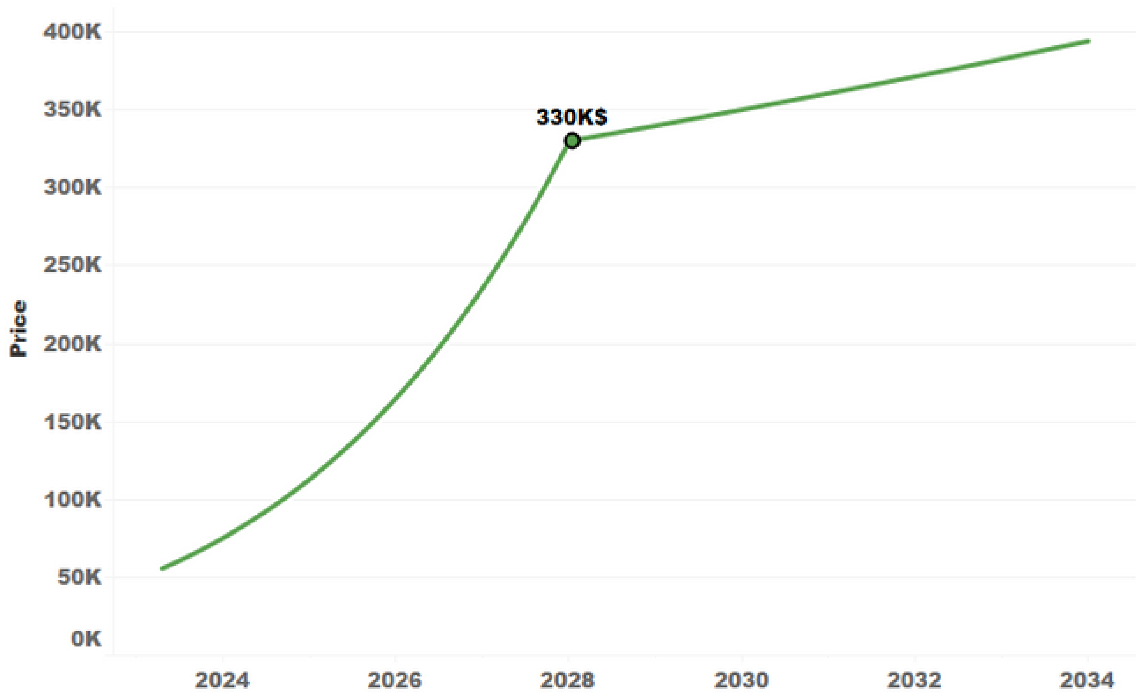
Figure 11: rainbow chart

The rainbow chart is supposed to enable the prediction of the price of Bitcoin. The different color zones represent different states of the market, with the yellow zone indicating the price of 1 BTC in a 'normal' market, the blue zone indicating a market in crisis, and the red zone indicating a bubble. If you extrapolate these lines, you should be able to determine when Bitcoin is undervalued or overvalued, and thus when to buy or sell your Bitcoins.

If the price follows the rainbow chart indicator until 2028 (with a growth rate of about 45% per year), on the 01-01-2018, one Bitcoin will be worth 330 000$.

You can have a look at the evolution of the price by looking at figure 12. Even though it looks linear after 2028, keep it mind that it remains exponential, with a rate of 3% per year.

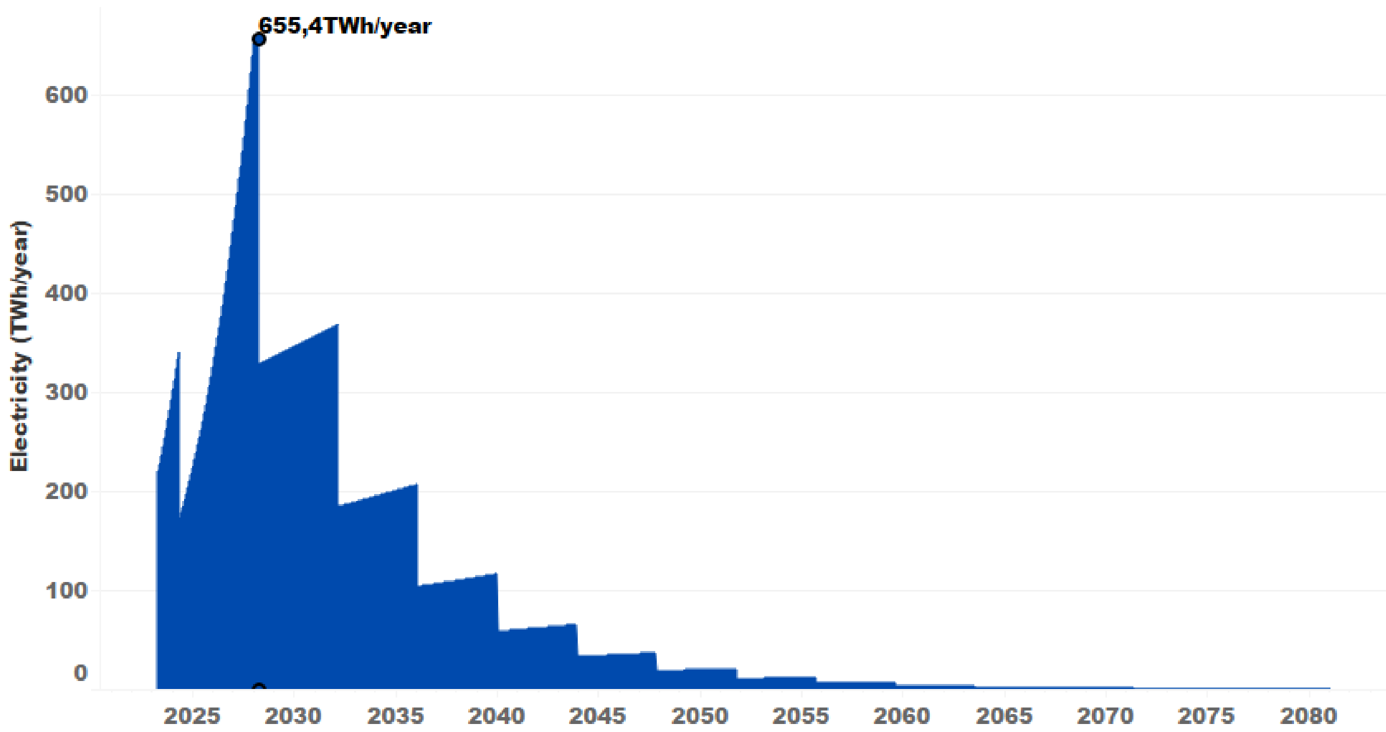
Figure 12: Price prediction



THE RESULT

It is now time to have a look at the results of this model. Figure 13 displays the prediction of the model for the following decades.

Figure 13: Electricity consumption prediction



Firstly, the electricity consumption of Bitcoin will explode and reach its maximum value (655.4 TWh/year) before the halving of 2028. After that, the electricity consumption will drop.

These two phases are caused by the different growth rates of the price. If the '*mass adoption*' never happens, Bitcoin will not see its energy consumption increase as much. On the other hand, if Bitcoin's price increases more and for a longer time than predicted, this energy consumption could increase drastically.

Anyway, at one point all bitcoin will be mined and only transaction fees will rewards Miners. We could wonder what would happen at Bitcoin at this moment, as remember, we stated that energy consumption meant security for this network. If rewards are low, so is the amount of energy used by Miners. A low security could pull the price down [7].

KEEP IN MIND

The hypothesis of the model are big: constant electricity price, constant transaction fees, exponential evolution of the price, rational miners,...

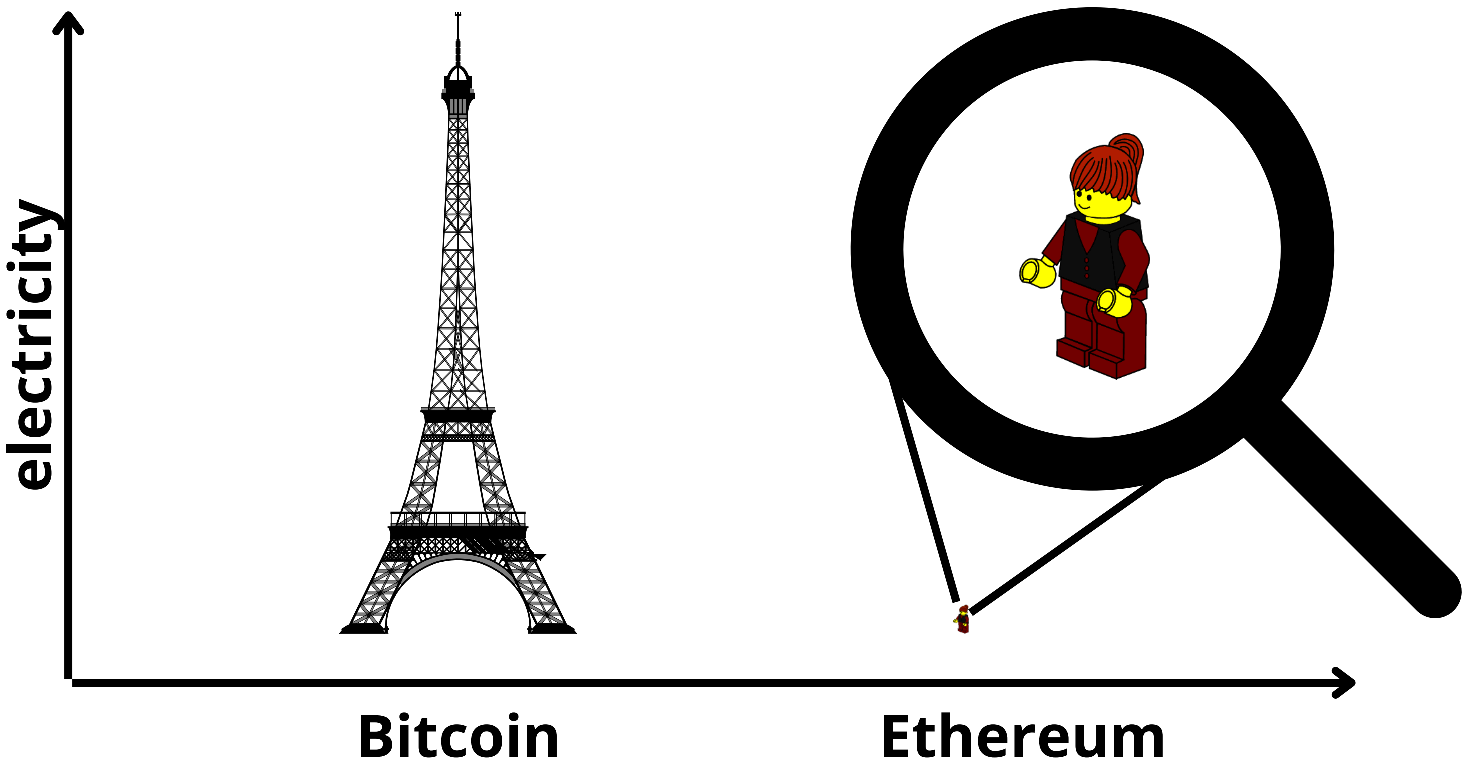
The electricity consumption will rise until the growth rate of the price is greater than the decrease rate of the rewards caused by the halvings.

Energy consumption means security, a drop in the electricity consumption could induce a drop in the price (and create a loop).

LAST WORD

Bitcoin needs high electricity consumption to operate efficiently. But is this the case for all cryptocurrencies? Ethereum, the second-largest cryptocurrency, is a prime example that disproves this notion. Unlike Bitcoin, Ethereum doesn't require a significant amount of energy to secure its network. As a result, it consumes much less electricity (see the figure below). However, it's worth noting that Ethereum is not necessarily a "green" cryptocurrency. As a decentralized blockchain, it still requires a certain level of redundancy, which makes its energy consumption higher than that of centralized systems. Nevertheless, these issues can be addressed with the help of new technologies like sharding or zk-rollups. These innovative consensus mechanisms decrease the redundancies and should lead to lower energy consumption if they are successfully implemented. [10]

Figure 14: Bitcoin vs ethereum consumption



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