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# The Bitcoin Mining Breakdown: Is mining still profitable?

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## Abstract

We provide an updated estimation of the energy consumption of the Bitcoin network, and a calculation of the evolution of the production cost of Bitcoin over time. Using these data, we conclude that since June 2018 Bitcoin mining is no longer profitable for commodity miners without access to electricity prices below 0.14 \$/kWh. This phenomenon explains why many Western miners have dropped out of the circuit, further increasing the centralization of mining activity in China. In addition, we estimate that the marginal cost of the production of bitcoin is around 1,952 US dollars. Below this price the cost of mining would not be profitable, even with the most efficient equipment and the lowest possible price for the energy required. This could lead to a massive exit of the biggest mining players, with unpredictable consequences for the future of this cryptocurrency.

*Keywords:* Bitcoin, cryptocurrency, cost-benefit analysis

*JEL classification:* G13, G17

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## 1. Introduction

### Highlights

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- Our analysis shows that after June 2018, mining is only profitable for professional miners located in those countries where electricity costs less than 0.14\$/kWh.
- We estimate that the marginal cost of bitcoin stands somewhere around 1,952 US dollars for facilities located in the countries with the cheapest electricity costs, that also employ the most efficient producing (mining) technology.
- According to our calculations, June 23rd 2018 was the date at which bitcoin mining was no longer worth continuing for amateur miners outside China, while November 25th 2018 was the cutoff date for professional miners using the most efficient existing devices. We predict increased centralization of professional mining facilities in China.

Bitcoin has been the first successful attempt in history at issuing a decentralized electronic means of payment (Nakamoto (2009)). Since its introduction in 2009, it has achieved tremendous popularity: in November 2018 there were 17 million bitcoins in circulation, with an exchange value of 90 billion US dollars.

Cryptocurrencies enjoy several desirable properties. Firstly, unlike the traditional payment methods, transactions linked to cryptocurrencies do not require the involvement of any trusted intermediary or third party. Secondly, it is not necessary to reveal the identity of the users in a transaction. The Bitcoin network solves the problem of digital identity by identifying users pseudonymously, in such a way that there is no connection between the operation carried out and the user's public identity. Privacy is preserved. Thirdly, there is no possibility of a double expense, i.e. the same bill being used twice by the same agent (except in the case of counterfeiting or fraud). At this respect, the Bitcoin network makes public and encourages the revision of flows within the network through the mining mechanism. The mining mechanism is based on a cryptographic proof denominated *proof-of-work* (Preneel & Juels (1999)).

Essentially, *a proof-of-work (PoW) is an easy-to-check proof of computational effort*, and was originally intended for discouraging spam (Dwork & Naor (1992)). In Bitcoin, PoW is used to avoid the double-spending problem, and to build a consensus mechanism to approve valid transactions and reward miners. This construction is designed to be a computationally expensive task, because an approximation better than brute force, i.e., trial and error, is not known. When a miner eventually finds a valid solution, the transactions in a given block are permanently recorded in the blockchain, and the miner is rewarded with a fixed amount of new bitcoins (12.5 at the time of writing).

But all solutions come at a cost. In this case, the strength of Bitcoin is also one of its weaknesses. By design, the proof-of-work mechanism is computationally and energetically expensive. This is one of the greatest criticisms that Bitcoin has received in recent years (see Truby (2018)).

In this paper we address the following question: given any market price for bitcoin, what is the maximum acceptable price of electricity that would just keep the miners in the market?

Hardware generation	Introduction date	Hash rate R (Mhash/s)	Energy efficiency $\varepsilon$ (Mhash/J)	Device
CPU	2009	18.9	0.12	Core i7 950
		100	0.31	Atom N450
GPU	Mid 2010	101	0.92	ATI 4850
		214.5	1.95	ATI 5770
FPGA	Mid 2011	832 50000	10.40 20.40	The Single Rig Box
ASIC	Apr 2014	$10^9$	990	AntMiner S2
	Dec 2014	$1.15 \cdot 10^{12}$	1958	AntMiner S5
	Jul 2015	$4.86 \cdot 10^{12}$	4017	AntMiner S7
	Jun 2016	$14 \cdot 10^{12}$	10606	AntMiner S9i
	Sep 2018	$80 \cdot 10^{12}$	12698	Bitfury Tardis B8
	Oct 2018	$44 \cdot 10^{12}$	22222	Ebit Miner E11++

Table 1: Bitcoin mining equipment evolution. Only devices from ASIC generation are considered in this work. CPU, GPU and FPGA devices are only included for completion purposes.

### 1.1. Bitcoin Mining Equipment

In order to calculate the overall energy cost of the Bitcoin network, it is necessary to characterize the hardware equipment used for the mining process. At its inception, and until approximately mid-2011, Bitcoin could be mined using general purpose hardware such CPU, first, and latterly GPU cards, which were especially well-adapted to intensive hash calculation (Bedford Taylor (2017), Taylor (2013) and Malone & O'Dwyer (2014)).

From this year onwards, due to the growing popularity of Bitcoin, it was necessary to specifically design hardware, in order to provide very high hash rates with a low energy requirement. Table 1 summarizes each hardware generation, with the characteristics of the average and most efficient device in each time period (Michel Zadé (2018)). However, in any case, in this work we will only focus on the ASIC generation, which is the latest generation, the one used nowadays.

The two key factors in the characterization of the Bitcoin mining equipment are its *hash rate* and *the power usage*. The first one, denoted as  $H_{rate}$ , makes reference to how fast the equipment is and is usually measured in terahashes per second (TH/s). On the other hand, the power usage,  $P$ , determines the operation cost of the hardware and is closely related to its efficiency,  $\varepsilon$ , which is usually measured in Mhash/J, i.e., the number of megahashes calculated with one Joule of energy.

For example, the most efficient mining equipment currently available is Ebit Miner E11++ (ASIC Miner Value (2019)), with a power usage of 1980W and a hash rate of 44 TH/s. Taking into account that  $1J = 1W \cdot s$ , the efficiency of this device is  $\varepsilon = 44 \cdot 10^6 Mhash/s / 1980W = 22222 Mhash/J$ .

### 1.2. Data and methodology

This study uses the historical data from the creation of Bitcoin, on 4 January 2009, until 31 December 2018, which has been extracted from QUANDL, a popular site with freely available financial datasets (Quandl (2018)).

Based on the values for price, hash rate, difficulty and reward per block, our work derives other quantities such as the cost of production of Bitcoin for different electricity prices. All these data are available as a supplementary dataset to this paper, together with the source code of the programs implemented.

## 2. Bitcoin Variable Cost Of Production

The first estimated quantity is the variable cost of production of a bitcoin,  $C_{BTC}$ . To do this, we start with the cost of calculating just one hash operation with a mining equipment of efficiency  $\varepsilon$  (measured in Mhash/J), and an electricity cost of  $k$  (measured in \$/kWh):

$$C_{hash} = \varepsilon \cdot k \quad (1)$$

Taking into account that  $1 \text{ J} = 1 \text{ W} \cdot \text{s}$ ,

$$C_{hash} = \frac{1}{\varepsilon} \frac{\text{W} \cdot \text{s}}{\text{Mhash}} \cdot \frac{\$}{\text{kWh}} = \frac{k}{\varepsilon \cdot 3.6 \cdot 10^{12}} \$/_{hash} \quad (2)$$

taking into account that  $1 \text{ J} = 1 \text{ W} \cdot \text{s}$ . On the other hand, the expected number of hashes to find a valid block is  $D2^{32}$ , where  $D$  is a parameter associated with the Bitcoin network, whose mission is to adapt to the variability of the computational capacity of the miners (Nakamoto (2009)).

At this point, we can now estimate the variable cost of producing one bitcoin,  $C_{BTC}$ , as follows:

$$C_{BTC} = \text{number of hashes/block} \cdot C_{hash} = \frac{D2^{32}k}{3.6 \cdot 10^{12}\varepsilon R} \approx \alpha \frac{Dk}{\varepsilon R} \quad (3)$$

where  $R$  is the reward in bitcoins per valid mined block,  $\varepsilon$  is the device efficiency,  $D$  is the network difficulty and  $\alpha = 1.193 \cdot 10^{-3}$ .

## 3. Maximum Electricity Price for System Sustainability

Let us place ourselves in the shoes of a bitcoin miner. We take the fixed cost of production (buying the hardware) as sunk costs, since this is a cost that was assumed in the past and the miner cannot go back in time. The miner has to make the following decision: Either continue mining bitcoins or cease activity. This decision will entirely depend on the variable cost of production, i.e. the electricity cost. A natural question then arises: what is the maximum electricity cost for system sustainability,  $k_{max}$  given any bitcoin price?

According to economic theory, in a free market miners should continue mining until the price of a bitcoin is equal to the marginal cost of production. In

this case, the marginal cost of mining one extra bitcoin is nothing but the cost of the electricity used in the process of mining. Therefore, in this case, the marginal cost  $MC_{BTC}$  is nothing but the variable cost calculated above, which, at the same time, should be equal to the price of bitcoin in a free competitive market:

$$MC_{BTC} = C_{BTC} = p_{BTC} \quad (4)$$

Thus, the minimum price at which bitcoin miners will continue mining can be estimated by the following expression:

$$C_{BTC} = p_{BTC} \Rightarrow \alpha \frac{Dk}{R\varepsilon} = p_{BTC} \Rightarrow k_{max} = \frac{p_{BTC} \cdot R\varepsilon}{\alpha D} \quad (5)$$

where  $p_{BTC}$  is the market price of Bitcoin.

Figure 1 shows the evolution of  $k_{max}$  over time since 2017. Data shows that  $k_{max}$  stands between 0.14 y 0.06 \$/kWh for the most common and most efficient mining devices, respectively. It means that even for the most efficient device currently in existence, the maximum electricity cost for system sustainability is really close to the cheapest legal electricity price available in the world, which is around 0.05\$/kWh (Kaiser (2018)).

The solution for the price in the former equation renders a minimum bitcoin price of 1,952 US dollars for the most efficient miners in the best electricity cost conditions. Any bitcoin market price persistently under this price will leave the future of the Bitcoin network at stake.

For our calculations, we have assumed two main kinds of miners, *retail* and *professional*, with access to different efficiency devices, equipment and electricity prices. Typically, the first group is located in Europe or the United States and uses commodity mining devices such as the Ant Miner S9, probably the most common device ever used, and consumes electricity at an average price of 0.14 US dollars per kWh (see Cocco & Marchesi (2016)).

Conversely, the professional miners are usually located in China, which has some of the world's cheapest electricity rates. These can be as low as 0.05 US dollars in some regions such as Sichuan. In fact, current estimates place 70-80% of global hashing power in China, the majority of which is located in this region (Kaiser (2018)).

Figure 2 shows the evolution of the bitcoin production cost over time. Two interesting crossing points emerged in the second half of 2018 which correspond to the points at which both retail and professional miners outside China will stop mining respectively. According to our calculations, June 23rd 2018 was the date at which bitcoin mining was no longer worth continuing for amateur miners outside China, while November 25th 2018 was the cutoff date for professional miners using the most efficient existing devices.

For the first time in the history of Bitcoin, on June 23rd the variable cost of production exceeded the market price for miners using high-end devices. This caused many of the non-professional miners to disconnect their equipment, though not immediately. In fact, the hashrate continued to rise for two months

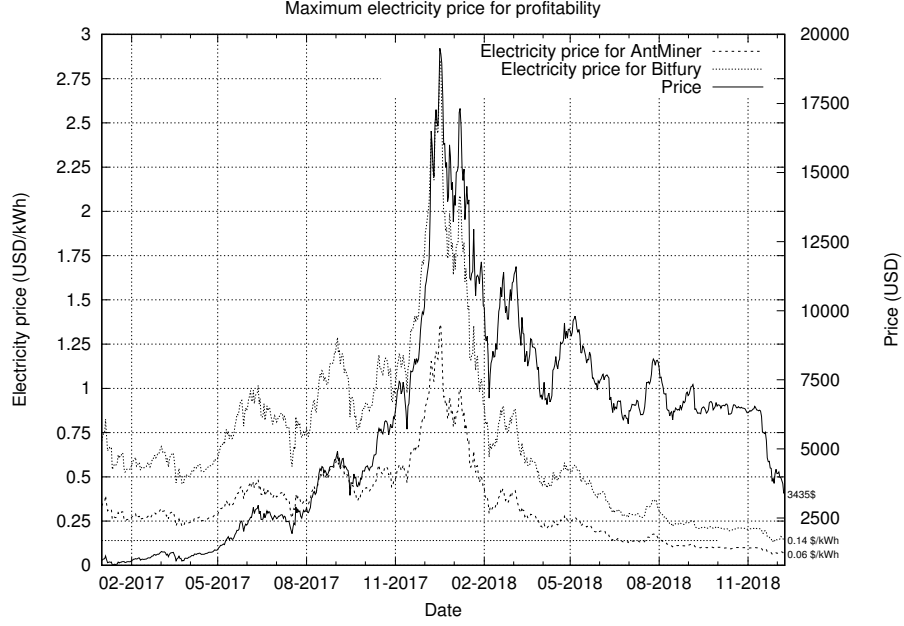


Figure 1: Maximum electricity price for profitability for professional and non-professional miners. Currently, this price is 0.06\$/kWh, only one cent above the cheapest electricity price in the world.

more to an all-time high at the end of August, before falling sharply to 20% below the first cutoff date.

Following this event, the situation did not improve and on November 25th there was a second cutoff point, which even affected the professional miners all over the world who did not have access to electricity prices below 0.14 \$/kWh. The direct consequence was an even greater centralization of mining in China, which is a single point of failure and goes against its decentralized philosophy as well as adding a significant risk to its future viability.

#### 4. Conclusions

This paper has studied the evolution of the production cost of Bitcoin across time. The sharp drop in Bitcoin prices, after years of a mounting race of arms in hash power, constitutes a challenge for miners and the Bitcoin community.

We have defined a marginal cost for bitcoin linked to electricity prices and the hash calculation technology available. According to our estimations, June 2018 was a major tipping point. Since then, bitcoin mining is no longer profitable for miners whose electricity costs are above 0.14\$/kWh, due to their prices falling below the marginal cost threshold.

These developments reinforce the increased centralization of professional mining facilities in China. Even for those players, for which 0.05\$/kWh is

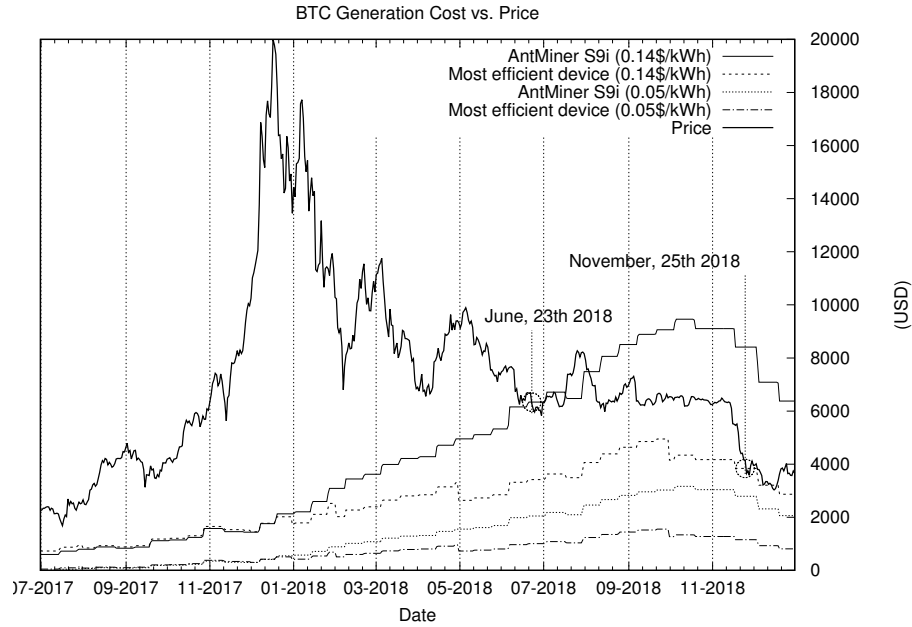


Figure 2: Marginal cost of production for Bitcoin for all the combinations of common and most efficient devices, and common and cheapest electricity prices.

a reasonable estimation of their electricity costs, and using the most efficient technology available, the marginal cost of producing a bitcoin would be around 1.952 US dollars. Any price below this level could create short term potential disruptions in the Bitcoin network with unpredictable consequences.

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