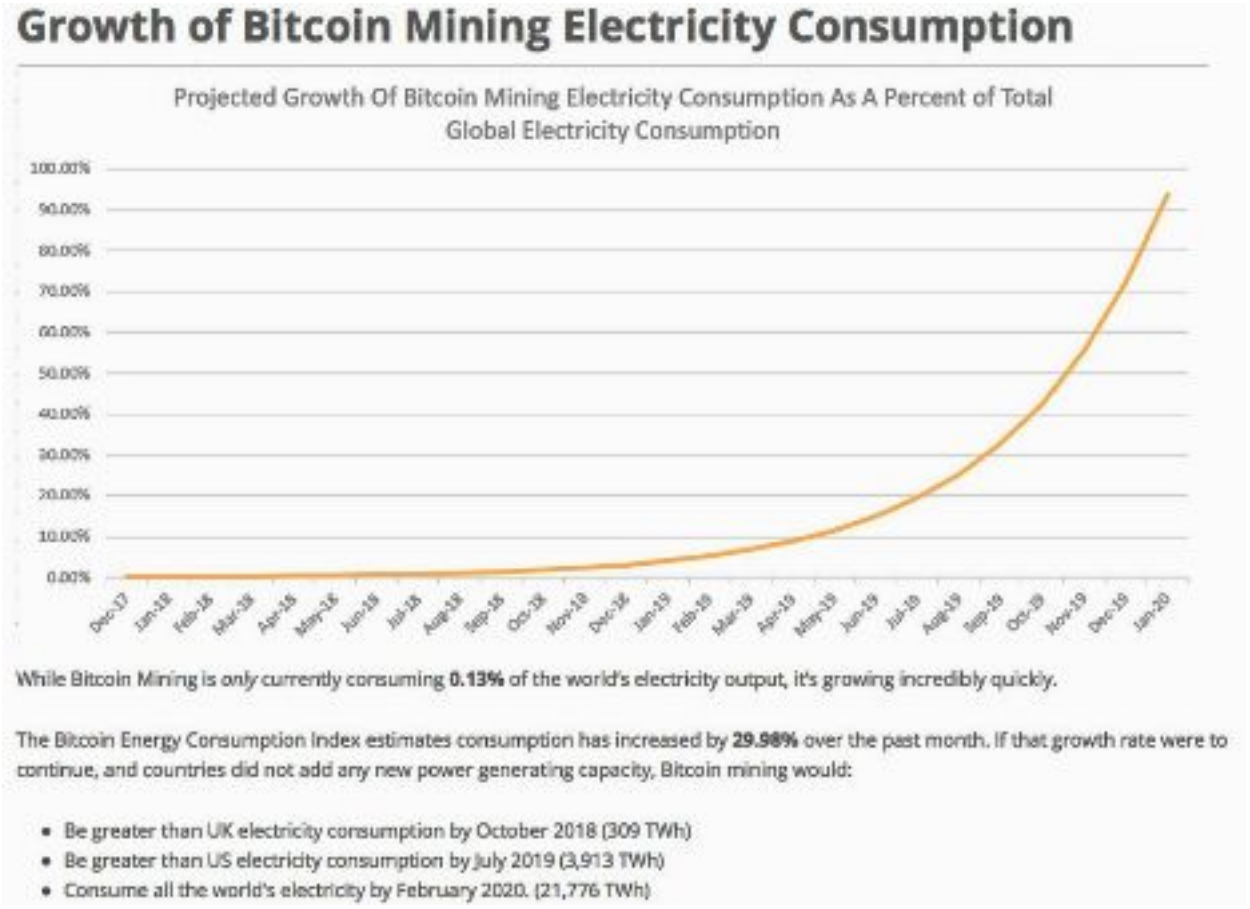
# Bitcoin miners true energy consumption

**Abstract**

Bitcoin mining is an energy-hungry process. According PowerCompare.co.uk[1] due to exponential growth it might consume the world's entire electrical energy by February 2020.

(1)




Can it be true that the Bitcoin network has such a huge environmental footprint? It is a media-effective story picked up by a large number of media outlets, but one cannot expect continuous, exponential growth. Let's look at how to calculate the power consumption of the Bitcoin-blockchain and if there is any reason at all that this voracious energy consumption continue endlessly.

## Power consumption formula

The proof-of-work process makes Bitcoin a very secure, decentralized network. Due to its decentralized nature, nobody knows exactly how much power is required by the network. There have been many very sophisticated attempts to directly determine the energy demand. However, these results cannot be used due to too many uncertain assumptions and apparently unrealistic results, e. g. [1] .

That is why an indirect calculation approach makes sense here, by calculating miners' income and deducing the energy costs and energy consumption as a percentage. Based on the assumptions on bitcoinenergyconsumption.com[B] I have derived the following formula.

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On average, the power consumption of all Bitcoin miners in ten minutes is:

$$E = \frac{0.6\,(f+rp)}{k}$$

where
E = Average total hashing electricity consumption of all miners (not other nodes) to get a new block in the blockchain (kWh, not included is power needed for ASIC production, for Miner's office, light etc…)
f = Total fees paid for all transactions in the block in US$
r = Coinbase block reward for winning miner (50BTC, 25BTC, currently 12.5 BTC, ….)
p = Bitcoin (average) exchange price in US$/BTC
k = Average price to buy a kWh (US$/kWh). If assuming a price of $0.05/kWh, formula is E = 12kWh (f+rp)

This formula helps us to answer many questions regarding Bitcoin's energy consumption. Let's investigate them one by one. Does this formula include any variables capable of causing an exponential growth in E with a monthly rate of 29.98% corresponding to an annual rate of 2225.5%?

- k might grow exponentially with inflation, if at all then this works against exponential growth of E. If k would drop exponentially , then this would promote exponential growth of E, at least partly. This is a very unlikely scenario.
- r definitely goes exponentially in the other direction and is not helping E in any way to reach stratospheric growth.
- f might increase, but if exponentially and at an extraordinary rate, it would stand in the way of this growth itself (auto-cannibalisation). Users would therefore avoid transactions and switch to other currencies wherever possible, which would drive charges down again.
- p is getting less and less important for the energy consumption over time (due to exponential decrease of r). Currently, given that we are in Bitcoin's early years, it still has significant impact. In case p would grow exponentially, the formula shows that this might drive E into growth at a similar rate. The p factor is demand driven. What would be Bitcoin's price in February 2020 assuming the monthly energy consumption growth is 29.98% (k=0.05$, r=12.5 BTC and f=$9160.50 flat)? 21,776,000,000 kWh = 21,776 TWh = E = 12 kWh (f+rp) ⇒ p = $145.2m. This again would have auto-cannibalisation effects. The $ price for all 18.16m bitcoins ($2,637 Trillion) would by far exceed existing supply[5], so this would require huge inflation. This amount is more than 12 times higher than the estimated value of all developed real estate in the world[5]. The inflation would in this scenario raise the price per kWh significantly which would cause energy consumption decrease according to our formula.

**Example**

Calculation of 2017 Bitcoin average power consumption for one block (10 minutes timeframe) with the formula (numbers extracted from [3][4]):

Average price p = $3524
block reward r = 12.5 BTC
Average number of transactions/block: 1970
Average transaction fee: $4.65 ⇒ total fees per block f = $9160.50
With k=$0.05 follows
E = 638,526 kWh

⇒ Energy consumption per transaction = 324 kWh
⇒ Electricity costs per average transaction = $16.20
⇒ Total power consumption of Bitcoin network 2017: 33,56 TWh or 3831 MW permanent average

**Questions and Answers**

### Will the power consumption of the Bitcoin network continue to increase in the future?

Not necessarily. Factors influencing electricity consumption are

f Total fees paid. This is market driven. If demand goes down, fees go down.

r Coinbase reward. It is dropping exponentially (halving every 4 years) which is a reduction factor

p The higher the exchange price, the higher the consumption in the early years, later on the price has no influence anymore because it is multiplied with a value going fast to zero.

k assumed as stable [(A)]. If going up, power consumption goes down.

For example, if Bitcoin's price under current protocol and hashing power would be $100,000 in year 2049 this causes 'only' 0.6*0.0244140625 * $100,000/0.05$ = 150 MWh per block where $10,000 today cause 0.6*12.5*$10,000/0.05$ = 1500 MWh per block. Or if people hold their Bitcoins and there is low demand for trade, then fees are close to 0.

### Will miners' power consumption fall because more and more efficient power-saving ASICs are being invented and less power is needed to calculate a hash?

No, technical progress is not helping here (and if so only in the short term). If miners use more efficient tools, then the difficulty of the hashing puzzle will increase accordingly. Each single hash would then be calculated consuming less power, but this is compensated by the fact that more hashes have to be calculated. Bottom line is that 60% of miners' income goes into electricity bills, if they can now calculate more hashes, then competitors can do so too and all of them coincide with the same percentage of success at a higher level.

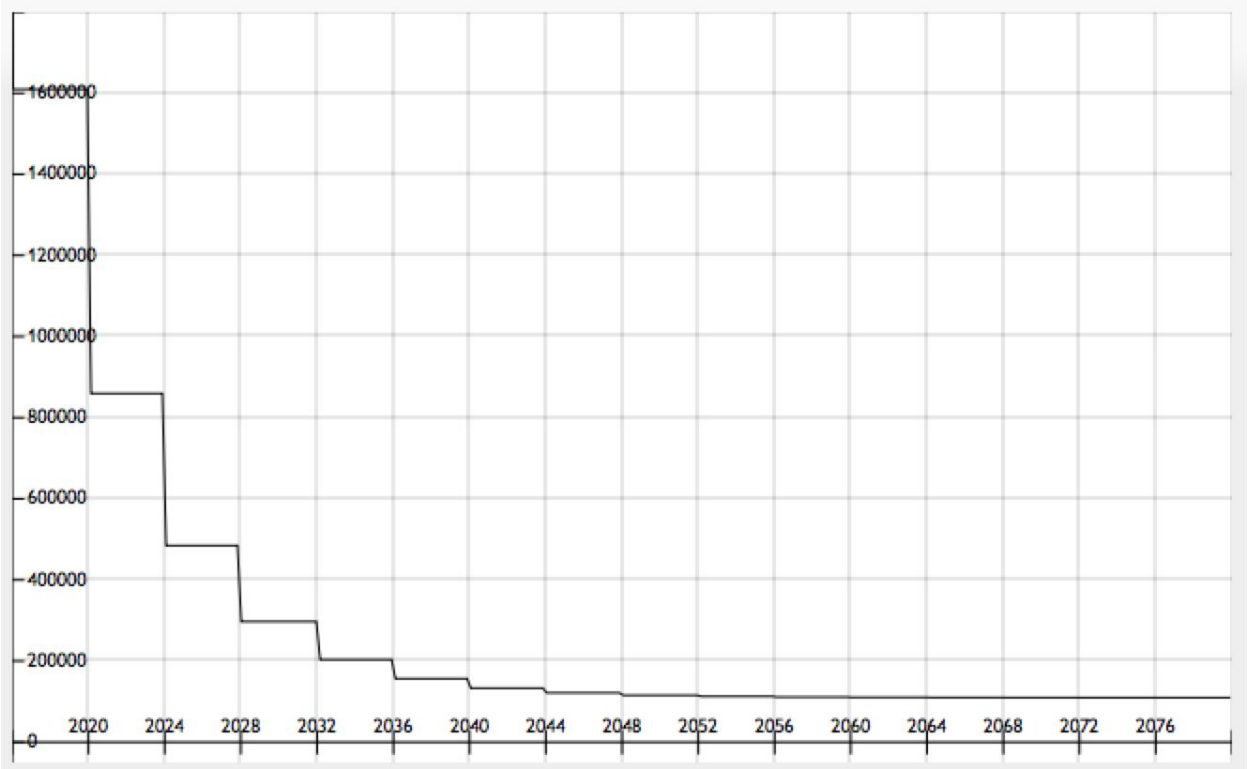
### Will bitcoin transaction fees increase when miners can no longer generate revenue from the coinbase rewards?

No, at least not for this reason. There is no relation between transaction fees and the coinbase reward but fees are directly related to the demand for transactions. Obviously, transaction fee changes have no influence on the hardcoded coinbase reward and vice versa. For quick processing of transactions, fees are purely determined by market demand (transactions with the highest fees get into the next block until the block is full) and the coinbase reward is defined by the bitcoin protocol. For example, if the Bitcoin price p is $100.000 (or $1) and only 5 people buy and sell every 10 minutes then transaction fees are very low, if tens of thousands of transactions compete under current circumstances then fees are very high. Fees might increase but there is no connection to the reward.

### Does a lower coinbase reward reduce the power consumption of the Bitcoin network?

Yes. Coinbase reward reduction takes place on the so called halving days (estimated next halving day is on June 8, 2020: http://www.bitcoinblockhalf.com/ , before halving days were 2016 and 2012). What happens when comparing the halving day with the day before? Miners get only half of the coinbase reward in bitcoin, but the demand for bitcoins thus also the fees and thus the $ price for bitcoins are not influenced by this reward reduction. The effect is that large numbers of miners leave the business until the remaining make a profit again. Hashing power goes down and therefore electric consumption drops. This means that over time the hard coded exponential drop in the coinbase reward reduces the power consumption of the Bitcoin network. Of course, the overall consumption can increase if demand +

exchange rate go up, however the coinbase reward reduction moderates this increase. The lower coinbase reward decelerates the power consumption. This effect is visible in the formula: A reduction of r causes a reduction of E. Here is an example of how electricity consumption E in kWh falls over the years per block, with r halving every four years and the other values assumed as stable for comparison reasons (f=9,160.50, p=10,000, k=0.05):




### Is a rising Bitcoin demand causing higher electricity consumption?

Yes. If demand goes up above a certain level, the unspent transactions don't fit into the next block, so only the ones with highest fees (top down) are selected. In the formula, you see that higher fees f cause higher consumption of KWh. The same happens when a lot of people sell their bitcoins (which is actually the same, because with a bitcoin transfer, one person is usually selling and another person at the same time buying).

### Does a high (low) bitcoin price cause high (low) power consumption?

Not necessarily (see example above). As time moves on from Bitcoin's beginning in 2009, the less impact the price of Bitcoin has on power consumption. Today the impact is 25% of the initial impact (reward is now only 25% of 2009 value) which is still strong, in 2140 there is no impact anymore (under current rules). However, should there be a remarkable and verifiable correlation between the bitcoin price and the number of transactions (which I do not suspect) then this statement would have to be put into perspective.

### Do higher transaction fees increase the power costs of the miners?

If we look at the formula, definitely yes. But these are self-limiting because the number of transactions decreases with excessively high fees.

### Is an energy consumption close to zero conceivable for the Bitcoin network?

This could theoretically be the case in the future with a sophisticated new consensus algorithm introduced by fork. With today's proof-of-work algorithm, this would only work in theory, according to our formula, if the electricity price k goes against infinity or if the bitcoin price or the fees would be negative, namely p = -f/r. However, this scenario can be disregarded because the protocol doesn't allow for it. In any case, everyone would keep their bitcoins if the price were negative (miners would stop adding transactions into their blocks if the fees were negative) and incidentally the security of transactions would no longer be guaranteed. Future layer 2 technologies such as the lightning network (sidechains, atomic swap …) could have a very positive influence on this energy balance.

### Under the assumption that miners have to cash out quickly a high percentage of their fee+reward income (they have to pay their bills in fiat), does this influence the power consumption?

The factors f,k and r are not affected in the formula, so p is the remaining candidate. Sales (earliest possible after 100 confirmations - appr. 17 hours) would cause a downtick to the BTC/fiat exchange rate and support lower p and therefore lower energy consumption. In a strong upward price trend, this would not have measurable effects, in a strong downward trend this accelerates the trend (but the effect is low knowing that per day 12,5*6*24 BTC = 1800 BTC are newly generated with 50% reduction every four years and that currently more than 300,000 BTCs are traded daily ). This could change in case the number of transactions went down significantly before the reward disperses.

### Do Altcoins have an effect on Bitcoin power consumption?

Mining is a highly competitive business with a low entry threshold. Miners must therefore work as efficiently as possible and will switch, often automatically, to other coins if there is a higher turnover with the same hashing power. Any switch, of course, results in a lower power consumption on the Bitcoin blockchain. However this power is redirected to another coin. This shows that the power consumption of the Bitcoin network should not be seen in total isolation from the rest of the proof-of-work Cryptoworld. The relations are complex.

### Are useful proof-of-work puzzles a solution?

No. There are approaches to redesign a proof-of-work algorithm in such a way that the many calculations still have a useful collateral effect. For example, Intel recently filed a patent for such a proof-of-work algorithm[6]. Does this have an effect on the miner's power consumption? Should miners be able to generate new income from additional benefits of mining, this would actually increase power consumption, not reduce it. The difficulty would increase, miners would gain additional revenue along with more hashes. The formulas' numerator would change to 0.6(f+rp+c) with c standing for the income from the collateral beneficiary. For this reason, energy consumption would also increase. If a blockchain uses a POW (proof-of-work) algorithm forcing the miner to provide the additional benefit free of charge, then the energy consumption would not increase (but not decrease). This would make sense if the collateral benefit serves the common good.

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### Does the use of waste heat, from bitcoin mining farms, as a heating system reduce energy consumption, since the houses that use it would have to be heated with other energy sources?

Unfortunately, no. This is currently used in Siberia [7]. Miners then act as an energy supplier (heat energy) and will thus generate additional income. Temporarily, this may only increase the profit of individuals, but then to remain competitive, this will become the standard and the additional revenue would increase the difficulty and power consumption. There would again be a “+c” in the formula. The automatic difficulty adjusting prevents this from having a positive effect. So only first miners can benefit and only temporarily. This does not make the energy balance more positive, it remains the same or deteriorates.

## Conclusion

There is no risk that the Bitcoin network consumes the entire world’s electrical energy. If one is to calculate the future power consumption of the Bitcoin network, one needs to take into account several factors. One is that the coinbase halving lowers power consumption. Also, power consumption costs are lower than miners’ total revenue and fees do not increase when block rewards reduces. One needs to bear in mind that power costs might increase which would reduce power consumption. A further limiting factor for fees (and thus also the electricity consumption) is that with very high fees, transactions would be shifted to other currencies (fiat or altcoins). Hashing puzzles with useful side effects or more efficient energy use do not improve the energy balance. Instead of comparing the power consumption of the Bitcoin network with that of countries, it would make more sense to choose other payment systems as a comparison point[8].

It is neither a given nor is it likely that the power consumption of the Bitcoin network will continue to increase in the long term. However, if the built-in mechanisms interacting with users and the rest of the cryptographic world would lead to a very low power consumption, the security of the decentralised blockchain could suffer. All this applies under the current rules. I am sure that there will be future developments that can solve the scalability problem and handle a large number of transactions without significant additional resources. We are just at the beginning of a great new technology.

Thanks to my buddies who gave me important suggestions and help with the topic.

Conflict of interests declaration:
The author declares that there is no conflict of interest



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**Appendix**

**(A)**

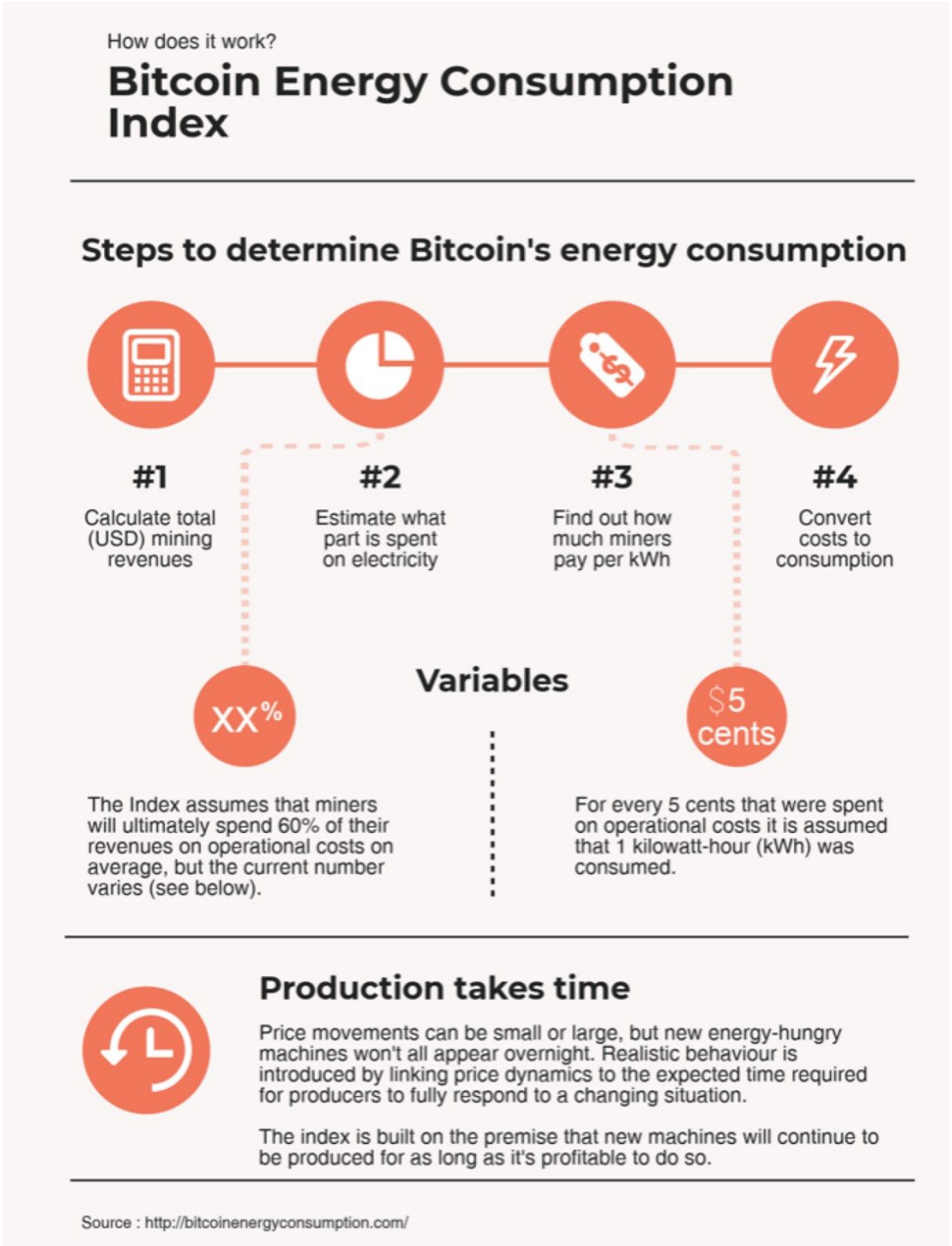
## Electricity costs in China ($/kWh)

| | 1990 | 2000 | 2010 |
|---|---|---|---|
| wind | $0.08-$0.10 | $0.04-$0.07 | $0.03-$0.05 |
| coal | $0.01-0.02 | $0.03-$0.04 | $0.04-$0.07 |
| gas | $0.04-0.07 | $0.06-$0.08 | $0.07-$0.10 |

Costs are in US$, converted from Chinese Yuan at $1 = 8.2 Yuan.

**Source: Page 18:**
**https://www.slideshare.net/yiboobaby/chinas-emergence-in-the-global-wind-power-industry**

**(B)**

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