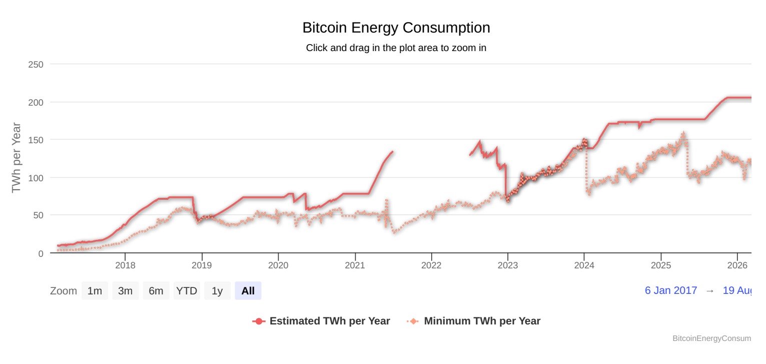
Bitcoin Energy Consumption Index

The Bitcoin Energy Consumption Index provides the latest estimate of the total energy consumption of the Bitcoin network.

LATEST RESEARCH: "Artificial intelligence: Supply chain constraints and energy implications" (May 2025); AI could consume more power than Bitcoin by the end of 2025.



Annualized Total Bitcoin Footprints

Carbon Footprint	Electrical Energy
113.64 Mt CO2	203.75 TWh
Comparable to the carbon footprint of **Czech Republic**.	Comparable to the power consumption of **Thailand**.

Electronic Waste	Fresh Water Consumption
20.27 kt	3,211 GL
Comparable to the small IT equipment waste of **the Netherlands**.	Comparable to the total water use of **Switzerland**.

Single Bitcoin Transaction Footprints

Carbon Footprint	Electrical Energy
482.30 kgCO2	864.70 kWh
Equivalent to the carbon footprint of **1,068,934** VISA transactions or **80,383** hours of watching Youtube.	Equivalent to the power consumption of an average U.S. household over **29.64** days.

Electronic Waste	Fresh Water Consumption
86.00 grams	13,628 liters
Equivalent to the weight of **0.52** iPhones 12 or **0.18** iPads. (Find more info on e-waste here.)	Equivalent to the amount of water in a **backyard swimming pool**.

Did you know Bitcoin runs on an energy-intensive network?

Ever since its inception Bitcoin's trust-minimizing consensus has been enabled by its proof-of-work algorithm. The machines performing the "work" are consuming huge amounts of energy while doing so. Moreover, the energy used is primarily sourced from fossil fuels. The Bitcoin Energy Consumption Index was created to provide insight into these amounts, and raise awareness on the unsustainability of the proof-of-work algorithm.

A separate index was created for Ethereum, which can be found here.

What kind of work are miners performing?

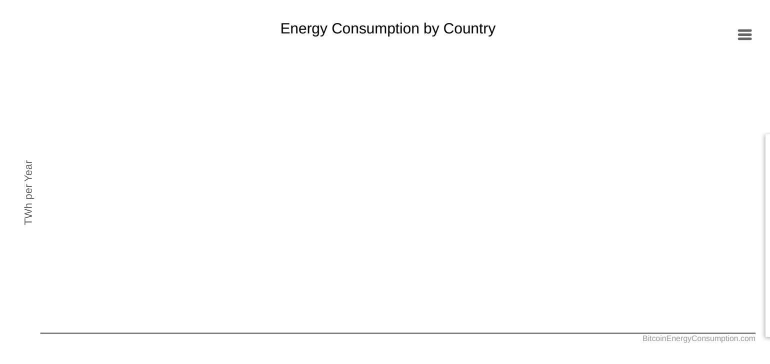
New sets of transactions (blocks) are added to Bitcoin's blockchain roughly every 10 minutes by so-called miners. While working on the blockchain these miners aren't required to trust each other. The only thing miners have to trust is the code that runs Bitcoin. The code includes several rules to validate new transactions. For example, a transaction can only be valid if the sender actually owns the sent amount. Every miner individually confirms whether transactions adhere to these rules, eliminating the need to trust other miners.

The trick is to get all miners to agree on the same history of transactions. Every miner in the network is constantly tasked with preparing the next batch of transactions for the blockchain. Only one of these blocks will be randomly selected to become the latest block on the chain. Random selection in a distributed network isn't easy, so this is where proof-of-work comes in. In proof-of-work, the next block comes from the first miner that produces a valid one. This is easier said than done, as the Bitcoin protocol makes it very difficult for miners to do so. In fact, the difficulty is regularly adjusted by the protocol to ensure that all miners in the network will only produce one valid block every 10 minutes on average. Once one of the miners finally manages to produce a valid block, it will inform the rest of the network. Other miners will accept this block once they confirm it adheres to all rules, and then discard whatever block they had been working on themselves. The lucky miner gets rewarded with a fixed amount of coins, along with the transaction fees belonging to the processed transactions in the new block. The cycle then starts again.

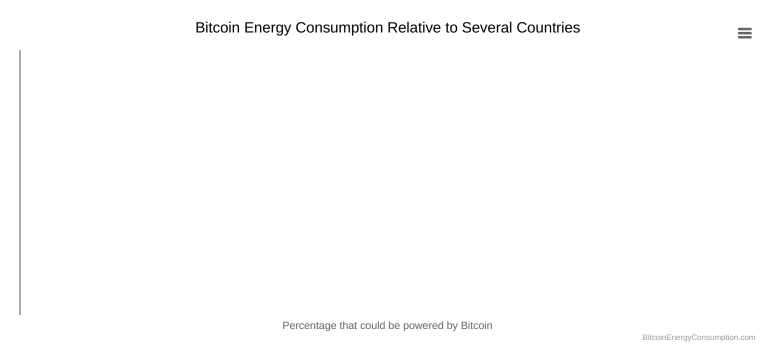
The process of producing a valid block is largely based on trial and error, where miners are making numerous attempts every second trying to find the right value for a block component called the "nonce", and hoping the resulting completed block will match the requirements (as there is no way to predict the outcome). For this reason, mining is sometimes compared to a lottery where you can pick your own numbers. The number of attempts (hashes) per second is given by your mining equipment's hashrate. This will typically be expressed in Gigahash per second (1 billion hashes per second).

Sustainability

The continuous block mining cycle incentivizes people all over the world to mine Bitcoin. As mining can provide a solid stream of revenue, people are very willing to run power-hungry machines to get a piece of it. Over the years this has caused the total energy consumption of the Bitcoin network to grow to epic proportions, as the price of the currency reached new highs. The entire Bitcoin network now consumes more energy than a number of countries. If Bitcoin was a country, it would rank as shown below.



Apart from the previous comparison, it also possible to compare Bitcoin's energy consumption to some of the world's biggest energy consuming nations. The result is shown hereafter.



Carbon footprint

Bitcoin's biggest problem is perhaps not even its massive energy consumption, but the fact most mining facilties in Bitcoin's network are powered by fossil fuels.

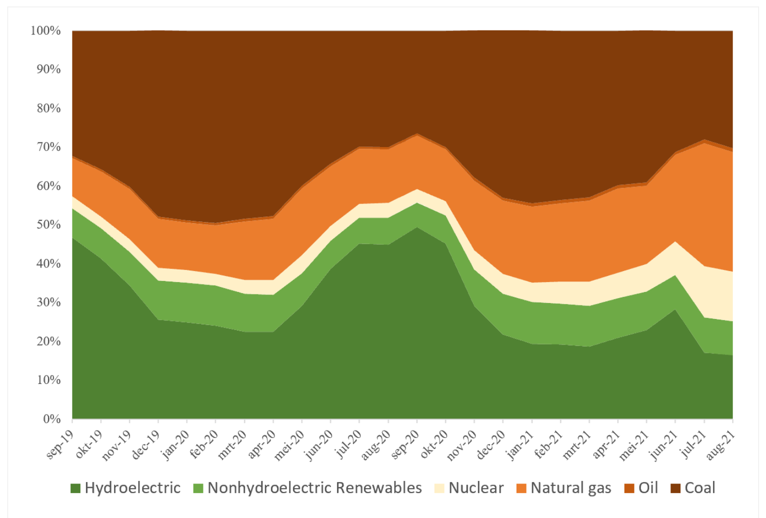
> **halfin** @halfin · Volgen
>
> Thinking about how to reduce CO2 emissions from a widespread Bitcoin implementation
>
> 9:14 p.m. · 27 jan. 2009
>
> 7K Antwoorden Link kopiëren
>
> 320 antwoorden lezen

Locating miners

Determining the exact carbon impact of the Bitcoin network has been a challenge for years. Not only does one need to know the power requirement of the Bitcoin network, but one also need to know where this power is coming from. The location of miners is a key ingredient to know how dirty or how clean the power is that they are using.

Since 2020 Cambridge provides detailed insights into the localization of Bitcoin miners over time. The article "Revisiting Bitcoin's carbon footprint" released in the scientific journal Joule on February 25, 2022, subsequently explains how this information on miner locations can be used to estimate the electricity mix and carbon footprint of the network.

The article specifically finds that that the share of renewables that power the network decreased from 41.6% to 25.1% following the mining crackdown in China during the Spring of 2021. Miners previously had access to a substantial amount of renewables (during a limited part of the year) when they were still in China (i.e. hydropower during the wet season in the summer months), but this was lost when they were forced to move to countries such as the U.S. and Kazakhstan. These locations now mainly supply Bitcoin miners with either coal- or gas-based electricity, which has also boosted the carbon intensity of the electricity used for Bitcoin mining. The article highlights that the average carbon intensity of electricity consumed by the Bitcoin network may have increased from 478.27 gCO2/kWh on average in 2020 to 557.76 gCO2/kWh in August 2021. The carbon footprint provided by the Bitcoin Energy Consumption Index is based on this carbon intensity.



The electricity mix of the Bitcoin network over time.

Key challenges for using renewables

It is important to realize that, while renewables are an intermittent source of energy, Bitcoin miners have a constant energy requirement. A Bitcoin ASIC miner will, once turned on, not be switched off until it either breaks down or becomes unable to mine Bitcoin at a profit. Because of this, Bitcoin miners increase the baseload demand on a grid. They don't just consume energy when there is an excess of renewables, but still require power during production shortages. In the latter case Bitcoin miners have historically ended up using fossil fuel based power (which is generally a more steady source of energy).

Further substantiation on why Bitcoin and renewable energy make for the worst match can be found in the peer-reviewed academic article "Renewable Energy Will Not Solve Bitcoin's Sustainability Problem" featured on Joule.

Comparing Bitcoin's energy consumption to other payment systems

To put the energy consumed by the Bitcoin network into perspective we can compare it to another payment system like VISA for example. According to VISA, the company consumed a total amount of 740,000 Gigajoules of energy (from various sources) globally for all its operations. This means that VISA has an energy need equal to that of around 19,304 U.S. households. We also know VISA processed 138.3 billion transactions in 2019. With the help of these numbers, it is possible to compare both networks and show that Bitcoin is extremely more energy intensive per transaction than VISA. The difference in carbon intensity per transaction is even greater (see footprints), as the energy used by VISA is relatively "greener" than the energy used by the Bitcoin mining network. The carbon footprint per VISA transaction is only 0.45 grams CO2eq.

Electrical Energy Comparison	Carbon Footprint Comparison
581,780	1,068,934
The number of **VISA transactions** that could be powered by the energy consumed for a **single Bitcoin transaction** on average (864.70 kWh).	The number of **VISA transactions** with a carbon footprint equal to the footprint of a **single Bitcoin transaction** (482.30 kgCO2) after factoring in the respective **energy mix**.

Of course, VISA isn't perfectly representative for the global financial system. But even a comparison with the average non-cash transaction in the regular financial system still reveals that an average Bitcoin transaction requires several thousands of times more energy.

Limited scalability causes extreme transaction footprints

One key reason why the CO2 emissions per Bitcoin transaction can be so extreme is that the underlying blockchain isn't just built on an energy-demanding algorithm, but it's also extremely limited in terms of transaction processing capacity. A block for Bitcoin's blockchain can contain 1 megabyte of data. As a new block will be generated only once every 10 minutes on average, this data limit prevents the network from handling more than 7 transactions per second. In the most optimistic scenario Bitcoin could therefore theoretically handle around 220 million transactions annually. Meanwhile, the global financial system is handling more than 700 billion digital payments per year (and a payment provider like VISA can handle over 65,000 per second if needed). Bitcoin's maximum transaction capacity represents only 0.03% of this (rapidly growing) number. This is less than the total number of electronic payments processed in a country like Hungary (more than 300 million per year), not even considering that cash still makes up for two thirds of all payment transactions here. With such an incredibly low limit, Bitcoin is simply incapable of achieving any form of mainstream adoption as a global currency and/or payment system. Unlike the network's transaction limit, the energy consumption of the network isn't capped. The price of Bitcoin is the main driver of the network's environmental impact, and there's no limit to how high this can go. Because of this, the Bitcoin network can consume several times as much electrical energy as the entire country of Hungary (which consumes 43 TWh annually).

Unfortunately for Bitcoin, there's no real solution for this scalability problem either. Proponents of the digital currency argue that so-called second layer solutions like the Lightning Network will help scaling Bitcoin, while dismissing that it is practically impossible to make such a solution work on a substantial scale. In order to move any amount of funds into the Lightning Network in the first place, a funding transaction on the main network is still required. It would take the Bitcoin network 35 years to process a single funding transaction for all 7.7 billion people (2021) on this planet, ignoring any other possible use of the main network and further population growth in the meanwhile. The only practical solution to Bitcoin's scalability problem has, so far, been to make use of trusted third parties, as these can process transactions internally without the need to actually use the Bitcoin blockchain. The obvious problem with this is that it merely reinvents the system we already have in place.

Another perspective

Because of the aforementioned scalability issues, it's often argued that Bitcoin is more like "digital gold" than a payment system. Hence we can also compare Bitcoin mining to gold mining instead. Every year, around 3,531 tonnes of gold are mined, with a total related emissions amounting to 81 million metric tonnes of CO2. When comparing this to the carbon intensity of mining Bitcoins, we can observe that the latter exceeds that of mining real gold (see below). Note that this includes mined fees, which has no comparison in mining for real gold (as we'd have to put previously mined gold back into the ground). Likewise, the comparison is also flawed because we can stop mining for real gold, whereas Bitcoin would simply stop existing without active mining.

Gold Mining Footprint	Bitcoin Mining Footprint
26 tonnes CO2	687 tonnes CO2
The carbon footprint of one Bitcoin's worth of gold mined.	The carbon footprint of a single mined Bitcoin (inc. fees).

One could argue that this is simply the price of a transaction that doesn't require a trusted third party, but this price doesn't have to be so high as will be discussed hereafter.

Alternatives

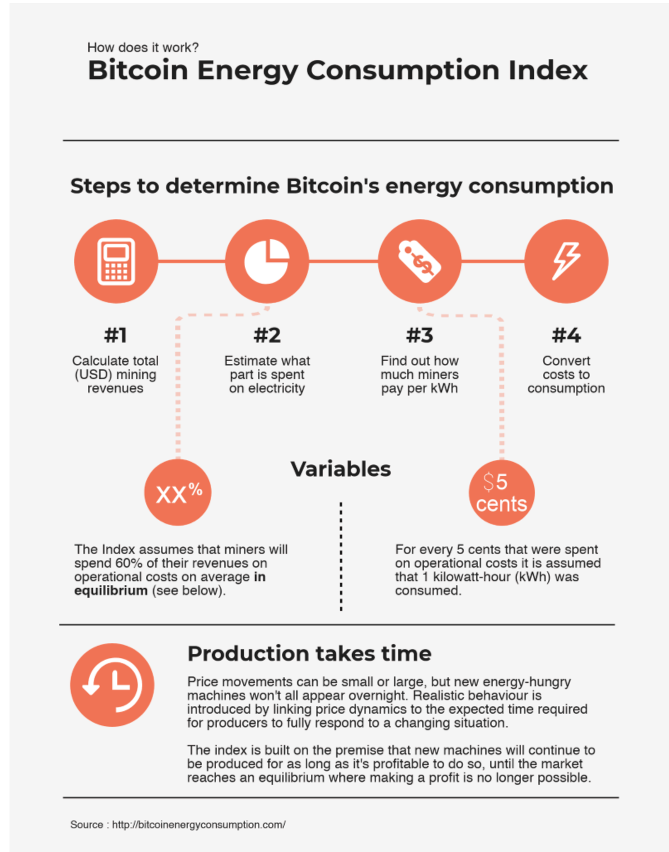
Proof-of-work was the first consensus algorithm that managed to prove itself, but it isn't the only consensus algorithm. More energy efficient algorithms, like proof-of-stake, have been in development over recent years. In proof-of-stake coin owners create blocks rather than miners, thus not requiring power hungry machines that produce as many hashes per second as possible. Because of this, the energy consumption of proof-of-stake is negligible compared to proof-of-work. Bitcoin could potentially switch to such an consensus algorithm, which would significantly improve environmental sustainability. It is estimated that a switch to proof-of-stake could save at least 99.85% of the energy currently required to run a proof-of-work based system.

Significant changes to the software may, however, also affect a network in other ways than merely impacting environmental sustainability. Mechanisms such as proof-of-work and proof-of-stake help to keep a network secure and do so in different ways, which also means that changing these mechanisms changes the risk profile of a network as well (infographic below). An deep dive into this dimension can be found here.

Energy consumption model and key assumptions

Even though the total network hashrate can easily be calculated, it is impossible to tell what this means in terms of energy consumption as there is no central register with all active machines (and their exact power consumption). In the past, energy consumption estimates typically included an assumption on what machines were still active and how they were distributed, in order to arrive at a certain number of Watts consumed per Gigahash/sec (GH/s). A detailed examination of a real-world Bitcoin mine shows why such an approach will certainly lead to underestimating the network's energy consumption, because it disregards relevant factors like machine-reliability, climate and cooling costs. This arbitrary approach has therefore led to a wide set of energy consumption estimates that strongly deviate from one another, sometimes with a disregard to the economic consequences of the chosen parameters. The Bitcoin Energy Consumption Index therefore proposes to turn the problem around, and approach energy consumption from an economic perspective.

The index is built on the premise that miner income and costs are related. Since electricity costs are a major component of the ongoing costs, it follows that the total electricity consumption of the Bitcoin network must be related to miner income as well. To put it simply, the higher mining revenues, the more energy-hungry machines can be supported. How the Bitcoin Energy Consumption Index uses miner income to arrive at an energy consumption estimate is explained in detail here (also in peer-reviewed academic literature here), and summarized in the following infographic:



Bitcoin miner earnings and (estimated) expenses are currenly as follows:

Annualized Income	Ann. Electricity Costs	Cost percentage
$10,612,551,788	$10,187,454,067	95.99%
Total value of mining rewards (including fees) per year.	Assuming a fixed rate of **5 cents per kilowatt-hour**.	Estimated ratio of electricity costs to total miner income.

Note that one may reach different conclusions on applying different assumptions (a calculator that allows for testing different assumptions has been made available here). The chosen assumptions have been chosen in such a way that they can be considered to be both intuitive and conservative, based on information of actual mining operations. In the end, the goal of the Index is not to produce a perfect estimate, but to produce an economically credible day-to-day estimate that is more accurate and robust than an estimate based on the efficiency of a selection of mining machines.