TECHNOLOGY INNOVATION SPOTLIGHT

Cryptocurrency's Energy Paradox

Rising Power Demands Amid Technological Advances

KEY TAKEAWAYS

- **Cryptocurrency electricity consumption in the U.S. is significant and rising**: In 2024, DOE estimates that the cryptocurrency industry used around 50 TWh or 1.2% of U.S. electricity.[1] Usage is uncertain due to a lack of reporting requirements and has increased markedly as mining grew and moved from China (due to 2021 policy restrictions) to the U.S. and other nations with low-cost electricity and more supportive policies.
- **Bitcoin dominates cryptocurrency value and electricity consumption**: Bitcoin (BTC) is the leading cryptocurrency, making up about 60% of the global cryptocurrency market value and, because securing it is more energy intensive than other coins, an even larger portion of the electricity used for mining.
- **Global BTC electricity usage has increased 17x since 2014**: BTC's global electricity use has grown from 0 TWh in 2009, when it was created, to around 10 TWh in 2014, and approximately 175 TWh today which is about 20% higher than the electricity consumed in Ohio in 2023.
- **BTC's demand grew rapidly despite improved mining efficiency**: BTC's electricity demand has surged despite a 17x improvement in mining hardware efficiency since 2014, exemplifying Jevon's paradox, where efficiency gains lead to increased energy use. By design, the effort required to secure a block of transactions has risen significantly—resulting in electricity use to secure a block rising from approximately 23 MWh in 2014 to around 3.75 TWh in 2025, a 163x increase, despite advancements in efficiency.
- **Future BTC load growth in the U.S. is uncertain despite increasing policy support**: BTC future energy demand remains uncertain, as it depends on whether price increases can continue to offset rising mining difficulty. Miners' revenue is tied to Bitcoin's price, which surged nearly 200x from $500 in 2014 to around $100,000 in January 2025 but remains highly volatile. Over time, revenue will rely more on transaction fees, adding to future uncertainty. Additionally, mining costs are largely driven by electricity prices, which, while relatively stable on an annual average, fluctuate significantly by season and time of day.

BITCOIN AND CRYPTOCURRENCY BASICS

Bitcoin (BTC) is the first cryptocurrency. Launched on January 3, 2009, the first bitcoins were valued at $0.00099.[2] In January 2025, its value hovered around $100,000/BTC and all the BTC in circulation were valued at around $2 trillion, representing around 60% of the value of all cryptocurrencies.

Rather than relying upon traditional, heavily regulated financial institutions to track transactions, cryptocurrency transactions are recorded in blockchains—distributed public ledgers stored at many locations around the globe. Transactions are verified, secured, and added to all these ledgers in blocks of data (each 1 megabyte or less for BTC).[3]

1 2024 United States Data Center Energy Usage Report, LBNL-2001637.

2 The first recorded value of BTC was approximately **$0.00099 per BTC**. This valuation came from an early transaction in 2009 where a user exchanged 5,050 BTC for $5.02 through PayPal.

3 See EPRI 3002013910 "Quick Insights: Bitcoin Mining, Blockchain, and Electricity Consumption" for more information about the advantage and disadvantages of blockchain, bitcoin mining, and its energy use.

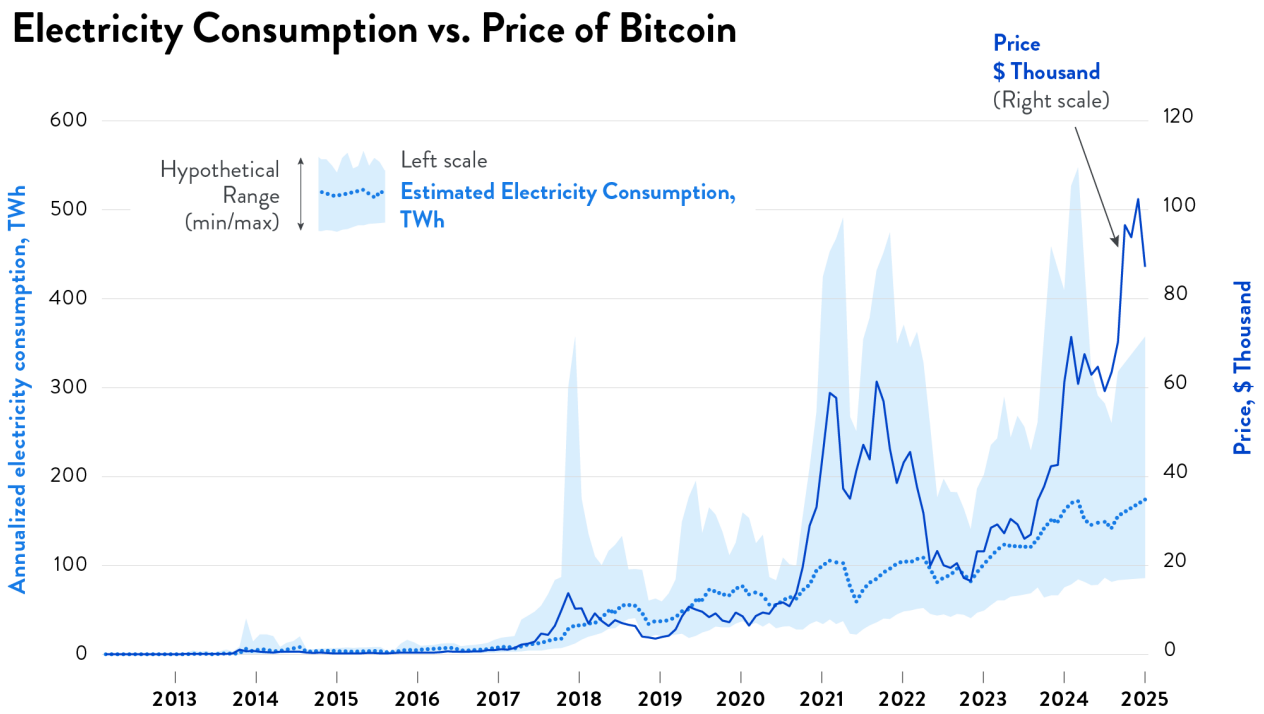

Figure 1. Global annualized bitcoin energy consumption over time, considering a lower bound (using most efficient mining hardware), upper bound (least efficient mining that remains profitable), and a best guess (a combination of efficiencies).
(Sources: Cambridge Blockchain Network Sustainability Index: CBECI *and* https://www.coingecko.com/en/coins/bitcoin*)*

Cryptocurrency electricity usage is driven by the methods used to secure and add blocks of transactions and varies by the currency. BTC and other early currencies rely on a Proof-of-Work (PoW) consensus algorithm where miners compete to be first to find a cryptographic hash (a vector of numbers) that will match the transaction data when run through a public cryptographic algorithm. Other currencies, for example, Ethereum, use less energy-intense methods for securing new blocks. Ethereum, the second most valuable cryptocurrency with about 10% of the market, shifted from a PoW security approach to a Proof-of-Stake (PoS) mechanism in 2022 that selects which participants will validate incoming transactions and add them as new blocks on the chain.

The extent of mining operations is determined by the potential earnings and expenses of the miners. The miner that first solves the cryptographic problem for a block currently receives 3.125 freshly minted BTC plus any fee payments offered by parties making the transactions in the block. In 2024, fees represented around 15% of BTC miner earnings. The marginal cost of mining is driven primarily by the electricity price, which can vary widely by hour, season, and location. Hence, the level of mining activity changes frequently.[4]

To consider where electricity consumption may go in the future, it is useful to consider some of the factors that underlie the load growth to date.

BITCOIN MINING HARDWARE IS IMPROVING

In Bitcoin's early days, mining used a standard desktop PC with a central processing unit (CPU). This made it possible for anyone to participate in the decentralized currency system. Competition increased as more miners joined the network, driving them to adopt more powerful hardware:

- **Late 2010**: Graphics Processing Units (GPUs) that leveraged parallel processing were adopted for mining to achieve much higher efficiency.
- **2011**: Field Programmable Gate Arrays (FPGAs) surpassed GPUs, mining at twice the speed but with higher costs.
- **2013**: Application-Specific Integrated Circuits (ASICs) were introduced specifically for mining to significantly improve both efficiency and performance.

4 The Cambridge Bitcoin Energy Consumption Index, Figure 1, which evaluates the cryptocurrency's environmental impact, estimates global BTC mining over time using a hybrid top-down approach. This approach assumes that miners use a mix of mining hardware that remains profitable at an electricity cost of $0.05 per kWh.

Manufacturers such as Canaan Creative, Bitmain, and MicroBT have continually improved mining "rigs" for greater performance and efficiency over time. Mining rigs, roughly the size of conventional servers, are stacked in racks within shipping containers or warehouses. Unlike traditional data centers, these facilities typically lack power conditioning, backup power, or active cooling, instead using large fans to circulate outdoor air for cooling.

The performance of mining hardware is measured in the number of hashes (guesses) that can be generated per second, typically given as tera-hash (trillions of hashes) per second (TH/s).[5]

By late 2014, the efficiency of mining hardware was ~500 W/TH. Today, that has reduced to around 30 W/TH for miners using the latest server technology and algorithms—an astonishing ~17x improvement.

5 The efficiency of mining is typically given as watts per tera-hash, but the more accurate unit of energy is watt-seconds per TH or equivalently Joule/TH.

MINER REVENUES ARE CHANGING AS COMPENSATION SHIFTS FROM NEWLY MINTED BTC TOWARDS FEES

New bitcoin is "minted" (created) as part of the reward mechanism to miners that support the currency. In exchange for providing the mining needed to encrypt bitcoin, miners are rewarded with a fixed amount of bitcoin per block added to the blockchain. By design, the mining reward for bitcoin is reduced by 50% after every 210,000 blocks are added (roughly every four years) until the entire supply of 21 million bitcoin has been created which is expected around the year 2140. Thus, the rate of BTC generation has dropped by 8x since late 2014, with the mining reward halving most recently from 6.25 to 3.125 BTC on April 20, 2024 (Figure 2). As a result, the total number of bitcoin mined per year has fallen from ~1.3 million in 2014, to 250,000 BTC mined in 2024—a 5x reduction. As of February 2024, only 1.18 million bitcoin remain to be awarded to miners. Consequently, there is significant uncertainty about future mining activity levels due to an expected shift from mining rewards to a greater reliance on transaction fees as miner compensation. This transition is expected to influence mining profitability as mining rewards decrease.

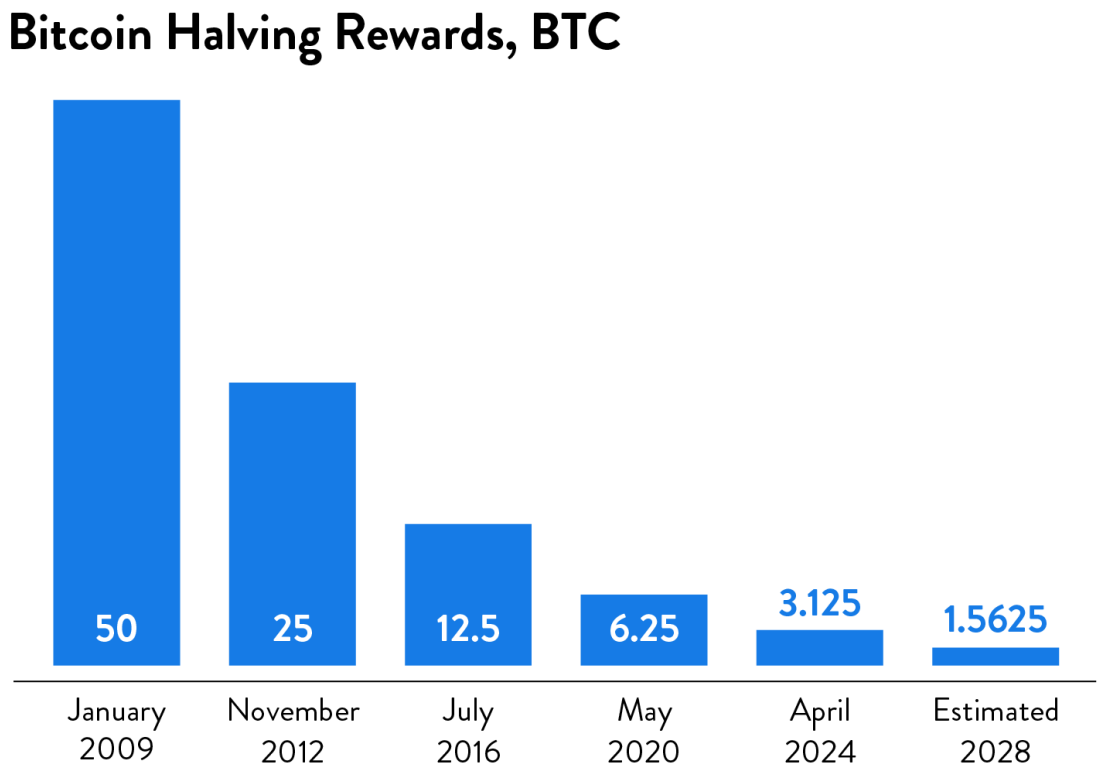

Figure 2. Bitcoin mining reward over time

THE CHANGING ECONOMICS OF MINING

Considering hardware improvements, increased mining difficulty, and reduced rewards, the computational power required to produce a bitcoin, measured in terawatt-hours per bitcoin (TWh/BTC), has skyrocketed.

Comparing the revenues and costs from October 2014 to January 2025 we see that:

- **Computation to mine one BTC increased ~20,000x**. A decade ago, each new bitcoin required 7 million TH to mine. It has risen to 140 billion TH today.
- **The energy to mine one BTC increased ~1,290x**. The energy use per bitcoin minted increased from 930 kWh per bitcoin in late 2014 to 1.2 million kWh/BTC (comparable to consumption of 1,300 average homes for a month or 260 EVs for a year).
- **The electricity cost to mine one BTC increased ~1,200x**. Assuming a constant real industrial electricity rate of $60/MWh (e.g., Texas industrial rate), the cost to mine increased from $56/BTC in 2014 to $67,000/BTC today. While miner costs vary regionally and over time, some estimate that electricity represents a majority of mining costs with other costs mainly fixed, related to equipment and land purchases, tax laws on income (including capital gains for BTC retained for a while), and equipment depreciation.
- **The BTC price increased ~284x**. The value of one bitcoin increased from $370 in October 2014 to $105,000 in January 2025, providing an ample, but volatile, incentive to expand mining even when non-electric costs are considered. Note the significant price rise over three months when, in October 2024, the value of one BTC was just over $50,000.

FUTURE U.S. ELECTRICITY DEMAND BY CRYPTOCURRENCIES

Lawrence Berkeley National Laboratory estimates that cryptocurrency uses from 25 to 100 TWh of electricity in the U.S. today, with a best estimate of ~50 TWh. They posit growth scenarios, assuming that the BTC price rises 2x and 5x through 2028, which basically extend recent trends.[9]

While Bitcoin has experienced an upwards trajectory in price over time and is expected to continue to do so due to its deflationary design (i.e., less is created over time, the price remains highly volatile and difficult to predict). Changes in the mechanism to secure Bitcoin are also difficult to predict. While Proof-of-Stake offers a vastly more energy efficient consensus algorithm than Proof-of-Work, there is no serious movement within the bitcoin community for this difficult transition to be made. Ultimately, bitcoin's energy consumption depends on mining remaining profitable, which has so far been driven by mining rewards and the currency's price. Thus, energy use of bitcoin is generally expected to rise over time, but any projections of future energy use are highly uncertain.

6 EIA (2022 data)
7 *Connected Residential Technologies: Unlocking Potential EE and DR Benefits*. EPRI, Palo Alto, CA: 2022. 3002024126
8 Assuming 30 kWh per 100 miles
9 https://eta.lbl.gov/publications/2024-lbnl-data-center-energy-usage-report

Table 1. Comparison of bitcoin mining energy use

	OCTOBER 2014	JANUARY 2025
Mining Efficiency	500 W/TH	30 W/TH
Total Mining Capacity	280,000 TH/s	750 million TH/s
Mining Reward	25 BTC/block	3.125 BTC/block
Terahashes (guesses) per BTC mined	6.7 million TH/BTC	14 trillion TH/BTC
Energy Use to Mine a Bitcoin	930 kWh/BTC	1.2 million kWh/BTC
Energy Comparison	• 1 average home for a month[6] • A typical electric washer and dryer in 13 months[7] • 1 electric car usage for 2.5 months[8]	• 1,300 average homes per month • 260 electric car usage per year

MINING REFRESHER

Mining is the energy intensive computing process used to secure many cryptocurrencies. For cryptocurrencies that rely on a Proof-of-Work (PoW) consensus algorithm, like bitcoin, mining is needed to generate the cryptographic hash that encrypts the blockchain. In other words, mining provides the security to the distributed ledger of transactions of the currency. See EPRI 3002013910 for more information on blockchain, bitcoin mining, and its energy use. In essence, mining involves the generation and validation of a large number of guesses of a cryptographic hash.

A key aspect of bitcoin mining is its adjustable difficulty factor, which ensures a consistent block creation rate of approximately 10 minutes per block, regardless of mining hardware efficiency or network capacity. This difficulty is recalibrated every 2016 blocks (roughly every two weeks), increasing as more mining capacity joins the network. Over time, the mining difficulty factor has closely followed the total mining capacity (measured in TH/s) connected to the bitcoin network, as shown in Figure 3.

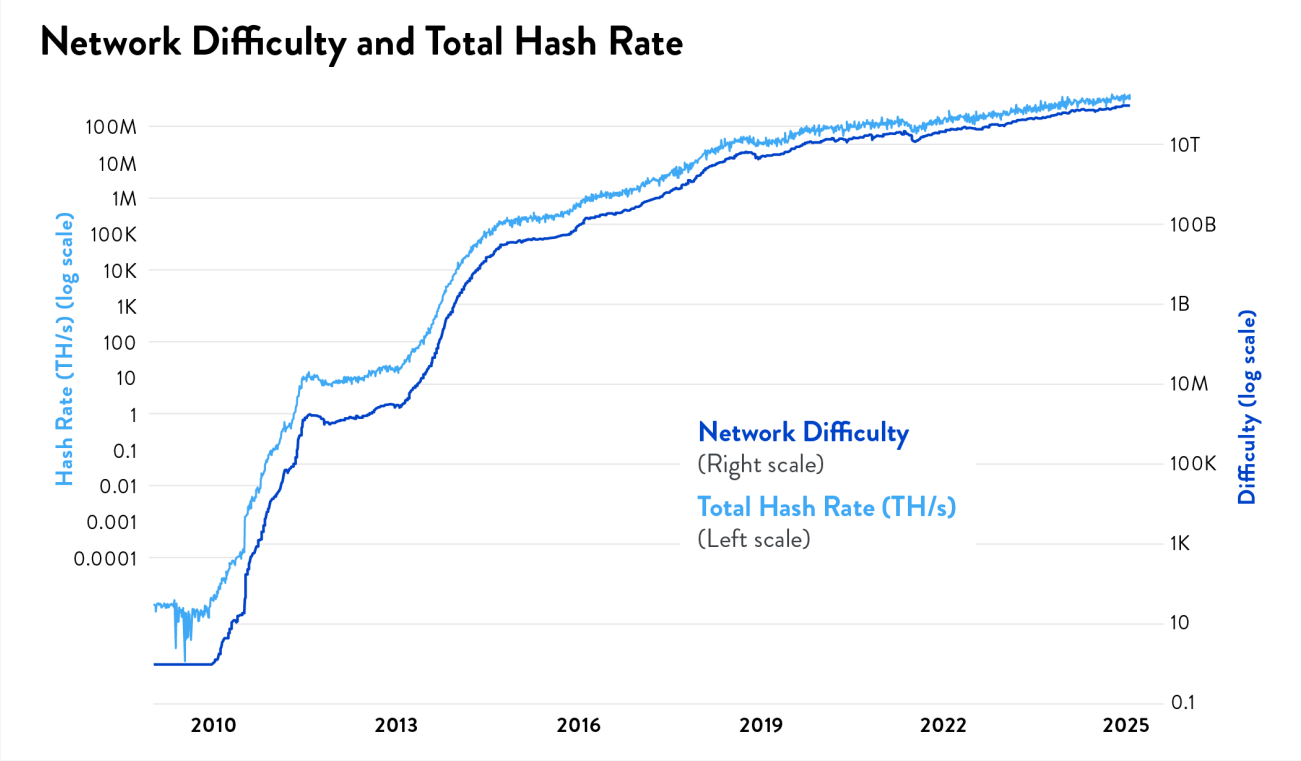

Figure 3. Bitcoin mining difficulty and total mining capacity (Hash Rate) since inception (log scale) (Source: blockchain.com)

About EPRI

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3002031799 **March 2025**

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