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Blockchain's Carbon and Environmental Footprints

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We analyze existing discourses surrounding blockchains' energy consumption and look at the actors and actions involved. We also provide an evaluation of various considerations and factors that affect blockchain networks' energy consumption and resulting environmental impacts.

Blockchain networks' energy consumption is a timely topic. According to the Cambridge Bitcoin Electricity Consumption Index, the Bitcoin network consumed 0.61% of world's total electricity production in March 2022. This is more than the total consumption by Ukraine or Norway.[1]

Crypto enthusiasts, policy-making agencies, activists, consumers, and corporations hold divergent perspectives about this. Regulators in China and Kosovo have banned Bitcoin mining. Bitcoin mining's high energy consumption and negative environmental impact have been key reasons. In December 2021, Kosovo imported 40% of its energy. In January 2022, the government decided to ban all cryptomining activities to address the global energy crisis.[2] Environmental activists have campaigned for a complete ban.

Cryptocurrencies' proponents, however, have pointed out that electricity consumed by blockchain networks comprises only a small proportion of the electricity wasted from other sources. Quoting a study of Cambridge Center for Alternative Finance (CCAF), a cointelegraph.com article noted that electricity losses in transmission and distribution in the United States could power the Bitcoin network 2.2 times.[3] Galaxy Digital Mining's study found that the amount of electricity lost in transmission and distribution is approximately 2,205 TWh/year, which is 19.4 times that of the Bitcoin network. Likewise, "always-on" electrical devices in U.S. households consume roughly 1,375 TWh/year, which is 12.1 times that of the Bitcoin network.[4] Hence, it's all relative to where you sit at the table.

Digital Object Identifier 10.1109/MC.2022.3176989
Date of current version: 2 August 2022

ACTORS AND ACTIONS

In some jurisdictions, cryptocurrency has been subjected to increased regulatory scrutiny due to energy supply shortages allegedly created by bitcoin mining activities and perceived adverse environmental impacts. Blackouts have been reported in several cities in countries such as Iran, Kazakhstan, China, and Kosovo. Blackouts have also left thousands of people without power for days.[5]

Regulatory actions have been taken in several jurisdictions. In May 2021, China prohibited the country's financial institutions from engaging in all crypto transactions. This was followed by a ban on cryptocurrency mining in June 2021. In September 2021, the country outlawed cryptocurrencies.[6] One of the main reasons behind the cryptocurrency mining ban was arguably an increase in illegal coal extraction, which made it difficult to attain China's ambitious environmental goals, and put people's lives in danger. The preliminary investigation of an April 2021 coal mine accident in Xinjiang that trapped 21 people found that the mine was restarted without government permission to meet cryptoserver farms' power demand.[7]

Similarly, in May 2021, the European Central Bank described the "exorbitant carbon footprint" of cryptoassets as "grounds for concern."[8] The European Union (EU) is under pressure from some member states to mitigate negative environmental impacts of blockchain applications. In November 2021, the Swedish government asked the EU to ban "energy-intensive" cryptomining activities.[9]

Likewise, in May 2021, a bill was introduced in the New York State Senate to establish a "moratorium on cryptocurrency mining operations that use proof-of-work (PoW) authentication methods to validate blockchain transactions."[10] In March 2022, the New York State Assembly Environmental Conservation Committee voted to pass the legislation.[11]

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Similar concerns have been raised by international developmental organizations.[12] Issuing a warning against El Salvador's Bitcoin Law, which made bitcoin a legal tender effective September 2021, the International Monetary Fund noted that adverse consequences on the environment are among many risks that countries that adopt cryptocurrencies as a national currency or legal tender can face.[13]

Social and environmental activists have played a vocal and visible role in explaining cryptocurrencies' adverse environmental impacts. When cryptocurrency miners started their activities in New York's industrial towns in 2021 using natural gas plants, environmental groups such as Earthjustice and the Sierra Club expressed concerns over the way the cryptomining companies were operating. These groups argued that huge computer farms' operations can increase greenhouse gas emissions and threaten the state's emission-reduction goals, which require more renewable power and reductions in fossil fuel emissions. There are also complaints against using renewable energy. Environmentalists argued that because Bitcoin mining plants can use more energy than most cities, their operations can increase the dependence of others on fossil fuels. And a blogger criticized a permit that allowed a cryptomining firm to draw more than 100 million gallons of water daily from Seneca Lake for cooling purposes. The water would then be returned at a warmer level to a trout stream tributary.[14]

The environmental organizations that had embraced cryptocurrencies and nonfungible tokens (NFTs) in their fundraising initiatives have been forced to reverse their actions. Nongovernmental environmental organization Greenpeace, which had accepted bitcoin donations since 2014, stopped accepting donations in the cryptocurrency in 2021 due to concerns regarding the amount of energy needed.[15] In February 2022, World Wildlife Fund U.K. tried to raise money with NFTs, specifically what it called *nonfungible animals*, but, facing sharp criticism from traditional conservation supporters, the organization was forced to immediately end sale of the tokens.[16]

Responding to criticisms, defenders of Bitcoin have argued that Bitcoin's environmental impact is significantly lower than that of the financial and banking sectors. One report suggested that the Bitcoin network uses less than half of the energy used by banks' large data centers.[4]

Bitcoin proponents have also argued that cryptocurrencies are helping build the future financial system and hence, their benefits outweigh the costs.[15]

CONSIDERATIONS AND FACTORS

A variety of considerations and factors can guide decisions regarding the use of blockchains and potentially minimize the energy use and environmental impacts of blockchain use (see Table 1). Although many collectible NFTs have little to no utility, blockchains can enable valuable applications such as securing property titles. However, whether certain applications of blockchain are good or bad is subjective. Some view blockchain as an opportunity to realize interests and

achieve goals that they value highly. A climate activist was quoted as saying that despite high energy consumption and adverse environmental impact, he would support cryptocurrencies as long as they fight the capitalist establishment and take power away from central banks.[9]

Energy consumption varies across phases and types of transactions. Mining accounts for most of the energy consumption of Bitcoin. For already-mined coins, minimal energy is required to validate transactions.[17] Memo Akten's analysis of 8,000 transactions from the NFT platform SuperRare suggested that an average NFT consumes 340 kWh of energy. According to Akten's calculation, the averages for energy consumption and carbon dioxide (CO_2) emission for different activities associated with NFTs were as follows: minting (creation)—142 kWh, 83 kg CO_2; bids—41 kWh, 24 kg CO_2; cancel bid—12 kWh, 7 kg CO_2; sale—87 kWh, 51 kg CO_2; and transfer of ownership—52 kWh, 30 kg CO_2.[18] Transferring ownership of an already-minted NFT thus creates fewer negative environmental impacts compared to minting a new NFT.

Another consideration is whether the energy used is renewable or not. Bitcoin network's carbon emission level is difficult to estimate with high certainty as miners prefer to hide the details of their operations from competitors. A 2019 report by CoinShares notes that 74% of the world's Bitcoin mining operations "heavily" relied on renewable energy due to the availability of hydropower in mining hubs such as China and Scandinavia.[19] In September 2020, the CCAF estimated renewable energy powered 39% of PoW mining.[20] The proportion further reduced to 25.1% in August 2021 as miners stopped using Chinese hydropower and moved to the United States, where gas supplies much of the power.[21]

Some bitcoin miners are positioning themselves as environmentally responsible. Canada-based HIVE Blockchain Technologies, which was listed on Nasdaq in 2021, claimed that it uses only renewable energy to mine Bitcoin and Ether.[22] Some critics, however, have questioned the justifiability of using energy, whether renewable or nonrenewable, to power energy-intensive applications such as Bitcoin mining. They suggest that the argument that Bitcoin's high energy consumption and environmental burden can be compensated for by plugging into renewable sources is convenient but possibly false. The renewable resources used to power blockchains could be deployed to more essential needs.[23]

Another way to reduce the environmental impact is to take advantage of arbitrage geographic opportunities, that is, moving activities across borders to utilize excess energy production. This is possible because blockchains' energy consumption differs from most other industries; whereas energy used for other activities must be produced close to its end users, bitcoin can be mined anywhere in the world. In this way, miners can utilize power sources that cannot be used by other applications.[20] Before cryptomining was outlawed in China, bitcoin miners used to migrate to the mountainous provinces with abundant hydropower resources during the rainy season. In these provinces, they took advantage of the excess electricity for several months each year.[24]

> Environmentalists argued that because Bitcoin mining plants can use more energy than most cities, their operations can increase the dependence of others on fossil fuels.

TABLE 1. The key considerations and factors that affect blockchain networks' energy consumption and resulting environmental impacts.

Consideration/ factor	Explanation	Example
The ultimate goal of blockchain use	Energy consumption could be more justified for valuable applications of cryptocurrencies or if they are used for good cause.	Although many collectible NFTs have little to no utility, applications such as securing property titles are valuable.
Phase and type of blockchain transactions	Some phases and types of transactions are less energy intensive.	Minting an NFT consumes more energy than transferring ownership.
The source of energy used	Transactions that use renewable energy are more justified.	HIVE claims that it uses only renewable energy to mine Bitcoin and Ether.
Where blockchain applications are carried out	Applications that take advantage of excess energy in some geographic locations can be more justifiable.	Before cryptomining was outlawed, Bitcoin miners in China migrated to locations with abundant hydropower during the rainy season.
Type of blockchain used	Energy consumption can be reduced by using blockchains that rely on PoS consensus model.	OneOf is built on Tezos.

PoS: proof of stake.

Finally, energy consumption and environmental impacts vary across the types of blockchain networks. The blockchains that rely on PoW consensus mechanisms consume more energy (Table 2). Moreover, the energy consumption of these networks is growing rapidly (Figure 1). By using blockchains based on the proof-of-stake (PoS) consensus model, in which only a small group of nodes can validate transactions, energy consumption can be reduced. Some platforms advertise lower energy consumption as a selling proposition. The NFT platform designed for the music industry is built on Tezos,[25] and OneOf promotes itself as a sustainable company.

Cryptocurrencies' high energy consumption is a basis for regulatory scrutiny. More energy-efficient blockchains exist that run on PoS algorithms, but their use has been limited because they lack the characteristics of completely decentralized blockchains.

Whether high energy consumption is viewed as justifiable or not depends on whether we value the functions and services blockchain provides. The question of whether millions of dollars should be spent on an NFT that consumes 340 kWh of electricity is a question of values. The individuals that consider cryptocurrencies to be a tool to build future financial systems and fight capitalism may view this energy consumption as justifiable. On the other hand, those that view cryptocurrencies as a "fraud" or "Ponzi scheme" may consider this energy consumption a waste.

Measures can be taken to mitigate the high energy consumption and adverse environmental impacts. Blockchain applications such as Bitcoin mining and minting NFTs can be performed throughout the world. The environmental impacts can thus be reduced if these activities are performed in locations with excess energy. Likewise, blockchain activities that employ renewable energy may be more justified due to their carbon-neutral nature.

TABLE 2. The electricity consumptions of different blockchains.

Blockchain	Annual electricity consumption (TWh)	Blockchain	Annual electricity consumption (TWh)
Bitcoin	204.5	Cardano	0.000598755
Ethereum	112.44	Tezos	0.000113249
Solana	0.01105	Algorand	0.000512671
Polygon	0.00079	Avalanche	0.000489311
Flow	0.00018	—	—

Data source: Bitcoin—estimate by Digiconomist based on annualized data as of 23 March 2022.[26] Ethereum: estimate by Digiconomist based on annualized data as of 23 March 2022,[27] Solana,[28] Polygon,[29] Flow,[30] and Cardano, Algorand, Tezos, and Avalanche.[31]

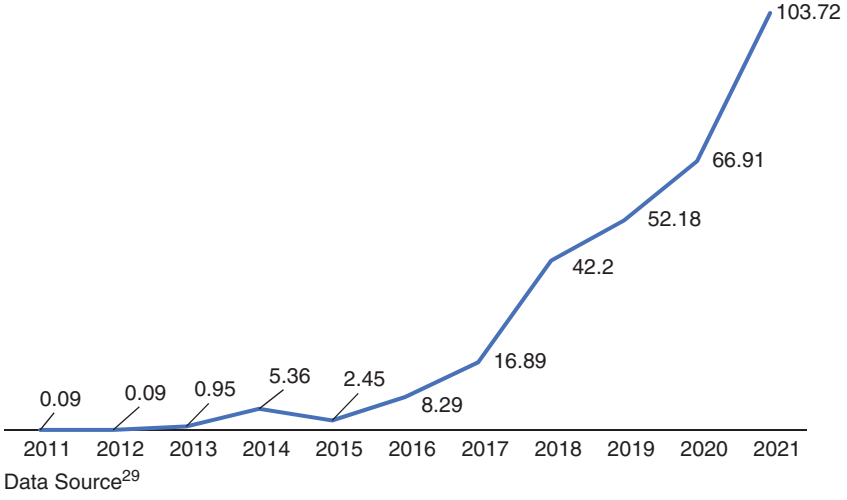

FIGURE 1. The bitcoin network's energy consumption (TWh).[1]

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Digital Object Identifier 10.1109/MC.2022.3188069