BITCOIN

An Analysis of Resource Consumption and Environmental Sustainability

Abstract:

This paper explores the environmental impact of Bitcoin's use as a digital currency, as it compares to the environmental impact of legacy digital financial transaction methods.

This research demonstrates that due to the enormous computing resource consumption of the Bitcoin network, that Bitcoin's secure transfer protocols deem it inherently incapable of supporting even modest rates of mass adoption as a de-facto payment transfer network.

To illustrate this with data, we compare the energy demand for the Bitcoin network against the energy demand of legacy payment networks, and contextualize these energy resource consumptions relative to the broad energy use in the United States, and the carbon emissions both networks would be expected to generate by supporting all banking transactions in a given year.

Definitions and Disambiguations:

Digital currency transaction: the electronic medium of exchange and/or transfer of value of a currency over a network

Environmental costs: proxied by carbon dioxide emission resulting from electricity consumption, at the rate of 420g CO_2 per kilowatt-hour.

Legacy payment networks: commonplace digital financial transaction facilitators, most notably the Visa Incorporated merchant network and the Federal Reserve Automated Clearing House.

Banking transactions: Credit cards, debit cards, prepaid cards, ACH transfers, wire transfers

Hypotheses:

Null Hypothesis: Bitcoin has no difference in environmental impact compared with legacy digital financial transactions methods.

Alternative Hypothesis: Bitcoin's environmental impact, as proxied by carbon emission from energy consumption, differs from that of traditional financial transaction methods.

The basis for this hypothesis is that the fundamental inefficiencies of blockchain technology consume scarce resources and impose negative externalities on users and non-users alike through carbon emissions that vastly exceed the carbon emission generated by legacy digital transfers methods, such as credit card payments or bank transfers.

About Bitcoin:

Since emerging in 2009, Bitcoin has in many ways disrupted aspects of both the technology and global finance industries. The underlying distributed ledger network technology of Bitcoin has been replicated by many other cryptocurrencies, many with large networks of their own. The original cryptocurrency, demand has for this scarce digital asset has driven the price of the USD/BTC exchange rate to more than $50,000 USD at the time of this writing, representing more than one trillion dollars of asset valuation on the network as of 2021.

Two key features of Bitcoin have contributed to this rise in valuation. First, there is an inherent limited supply of Bitcoins that can be "mined", earning it the moniker "digital gold" for its use as a digital currency and store of value. Similar to how there is limited amount of gold that can be mined from planet earth, this scarcity is a feature of Bitcoin that contrasts with fiat currencies to which the value is compared. Fiat currencies like the dollar, yen, and euro instead allow their supply of money controlled by a central bank, such as the Federal Reserve of the United States. Since the time that Bitcoin was created in 2009, the Federal Reserve has increased the quantity of US dollars in the economy (M3 money supply) by more than double in 2021.

The other key aspect contributing to Bitcoin's demand is the elite and anonymous security Bitcoin transactions enjoy. Bitcoin transactions are secure and non-fungible because any nefarious alterations to transaction ledger is reconciled against other instances of the distributed ledger. Therefore, if a hacker was able to breach and alter one transaction ledger, those changes will be overruled by the overwhelming majority of ledgers in the blockchain that were not altered. Therefore, in order to successfully pirate a bitcoin, hackers would need to infiltrate a majority of distributed ledgers on the blockchain, rendering it a nearly impossible target for cyber theft.

However, the decentralized distributed ledger of Bitcoin's blockchain that is the structural basis for its security also results in unavoidable inefficiency that renders the technology significantly more expensive and less practical than non-distributed ledger-based transactional account systems, such as those used by the Federal Reserve, Visa, and major banks.

This difference is anything but trivial. **In fact, the energy consumed per Bitcoin transaction approximates 722,000 times the energy consumed by a typical credit card transaction.**

The Price of Security:

The nature of a distributed ledger means it must be supported by many more computers than a centralized ledger. The Bitcoin mining process is the mechanism which supports the distributed ledger and the probability of being awarded a Bitcoin through the mining provides an incentive as payoff for contributing computing resources to the network.

When computers are engaged in Bitcoin mining, it facilitates the verification of transactions on the blockchain, resulting in new blocks on the blockchain. Miners must find a 64-character hexadecimal number called a "hash". When computers engaged in mining complete a hash, there is a probabilistic chance that the miner will be awarded an amount of Bitcoin. When Bitcoin first launched, that probability was 1:1. As both the number of transactions occurring on the Bitcoin network has increased, as well as the competition amongst miners, the probability of matching a hash to be awarded a Bitcoin in 2021 is as high as 1:16.7 trillion.

Bitcoin miners are incentivized to devote more and more computing resources to increase the probability of successfully mining a Bitcoin. As the price of Bitcoin rises, the expected return of investments in mining hardware also increases, and as a result, the network grows. These mining rigs are often energy-intensive operations, often outfitted with dozens of the latest high-performance GPUs, and are increasingly consuming vast amounts of electricity. Whether using purpose-built Application-Specific Integrated Circuits, or warehouses full of obsolete servers, the energy consumed to compute each block of the blockchain is orders of magnitude greater than the energy consumed by a typical non-distributed ledger banking transaction record. When Bitcoin miners compete on the electricity grid with more productive uses, this results in economic deadweight loss to society, who must now bear the burden of higher energy prices. There is also an opportunity cost to consider of the vast computational resources currently supporting the Bitcoin network: could these computing resources be used for a higher and better societal use, perhaps facilitating medical research and scientific breakthroughs?

In sum, the high security of Bitcoin transactions also bears a high cost in energy, which is accompanied by significant economic and climate externalities.

Contextualizing Energy Consumption:

To evaluate the environmental cost of Bitcoin, we define environmental cost as carbon emissions resulting from energy consumed to compute an exchange transaction of Bitcoin.

To standardize the comparison of energy costs, the same energy mix will be assumed for both types of transactions. That is, it is assumed that on average the same percentage of fossil fuels and renewables are used to produce the electricity that powers the servers at the Federal Reserve as does the aggregation of Bitcoin miners.

To proxy the energy consumed in a bank card transaction (credit card or debit card), Visa, the largest and most widely used merchant payment network publishes an average consumption of 0.001486 kWh per transaction. In stark contrast, the average number electricity consumed to process a Bitcoin transaction in 2021 was 1074 kWh. Therefore, <u>on a per-transaction basis, a bank card transaction is 722,000 times more efficient than a Bitcoin transaction.</u>

According to the 2019 Federal Reserve Payments Study, there were 159 billion bank card transactions in the United States. Applying Visa's consumption for these transactions as a proxy for all credit processors (MasterCard, American Express, etc.), the total resources consumed for bank card transactions in the United States equates to 236 billion Kwh. If the same rate of consumption was also applied to all banking transactions, including interbank automated clearing house (ACH) and wire transfers, the energy consumed would amounts to 819 billion Kwh.

If the same amount of credit and debit transactions were made on the Bitcoin network, rather than the centralized credit card processors, the energy needed to complete the block would be 171 quadrillion kWh. Including interbank transfers, that number jumps to 592 quadrillion.

The United States Energy Information Administration publishes total annual electricity consumption, industrial and residential, in the United States as 3.8 trillion kWh in 2019. In this context, legacy digital transactions consume approximately 0.022% of total annual electricity consumption. By contrast, if the Bitcoin network were to host all of these transactions, the energy requirement would exceed 15586% of total annual electricity consumption in the United States.

To translate these figures into climate impact, we apply the same rate of carbon emission of 420 gCO2 per kWh, a figured based on the energy mix of the United States and published by the United States Department of Energy.

Using the same metrics, the carbon impact of centralized credit card processing is estimated at 99 million kgCO2 per year. Including interbank transfers, the number is 344 million kgCO2.

When this same rate of emissions applied to Bitcoin's energy use, assuming Bitcoin replaced all credit and debit card transaction in one year, the resource demand would emit 34 quadrillion kgCO2 into the atmosphere. Including interbank transactions, that figure balloons to 118 quadrillion.

To contextualize these emission figures, the United States Environmental Protection Agency publishes annual carbon emissions in 2019 as 6.55 trillion kgCO2. Therefore the estimated energy consumption of legacy financial transactions amounts to 0.005% of the total annual CO2 emissions in the United States on an annual basis, while the Bitcoin network would increase CO2 emission by 3798%.

Conclusion:

Bitcoin, along with other cryptocurrencies may well have other use cases as a store of value or secure transfer mechanism. However, due to the vast sums of energy the network consumes, it cannot be adopted as a mass-use currency, unless underlying fundamentals about its efficiency change, or new sources of energy are discovered.

The proposed alternative hypothesis has been validated: Bitcoin's environmental impact, as proxied by carbon emission from energy consumption, greatly exceeds the environmental impact of traditional financial transaction methods. Because the scale of the differential is many orders of magnitude disparate by comparison (nearly one million to one), the conclusion can be drawn from the data without further statistical proofing.