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Cryptocurrencies and their Energy Consumption

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ABSTRACT

The research aims to analyze and compare the energy consumption and carbon emissions of various cryptocurrencies, focusing on aspects like market capitalization, consensus mechanisms (Proof of Work and Proof of Stake), mining devices (ASIC, GPU, CPU, FPGA), and comparisons with the traditional transaction method such as Visa. Since the first cryptocurrency, Bitcoin, which was created in 2009, there is a constant interest in it owing to the fact it offers secure and trustworthy ways of making payments without involving any intermediaries like banks or money systems. Although cryptocurrency and its underlying technology have great potential in finance and various other sectors like agriculture, education, insurance, etc, there are concerns that using cryptocurrencies can contribute to huge energy consumption and carbon emissions leading to adverse environmental impact.

What is Cryptocurrency and Why is it Energy-Intensive?

Before we get into the details of the purpose of this study, it is important first to understand the basics of cryptocurrency and why this technology could use a lot of electrical energy causing concerns regarding its environmental impact.

Problem With the Traditional Finance System

In order to understand the need for cryptocurrency, we can take an example. Suppose person X owes person Y, $10. The simplest way would be that person X to directly give person Y $10 in cash. There is no third party involved and is a peer-to-peer transaction. It would also be a private transaction as there is no middleman involved and there is no third party to trust.

However, this would not be effective if there are larger amounts in the transaction if both persons are not in the same place, or if the transaction needs to be quick.

In the current traditional financial system, there are different ways to do it. Money could be transferred electronically via a Bank transfer, using a money transfer service, or by using a credit/debit card, etc. These methods may not be quick, may involve hefty fees and they all will involve trusting a third party.

It's a very difficult problem to solve to have people transact over the internet without having a centralized authority keeping track of every transaction and making sure everyone is only spending what they have.

Introducing Crypto

Cryptocurrency solves the problem of transacting without having to trust an intermediary financial institution like banks. The idea of cryptocurrency is to introduce digital cash that can be transferred peer-to-peer securely and quickly without trusting any other third-party financial system by decentralizing the transaction records.

Cryptocurrency implements a distributed ledger system across its network, with each computer in its network acting as a node. Rather than having a centralized entity keeping track of all transactions, anyone running a node on

its network keeps a record of all transactions and balances. Each node is basically a computer that acts like an individual bookkeeper similar to a distributed accounts ledger, that gets updated in real time.

Every few minutes, these validated transactions are grouped together as a block. These blocks get linked together to form a chain of blocks called a blockchain. Each block in the chain is linked to its previous block using an encoding process known as hashing. This makes the blockchain secure if someone tries to alter a block, they cannot do so without altering all the blocks that come after it. This would alert the network and the change would be rejected. This makes the blockchain an immutable and trustworthy record of transactions.

The nodes that maintain the transaction records do not require a vast amount of processing power but need decent storage to store full transaction history. There are no financial rewards for running a node other than that a node is playing a part in maintaining the network. However, there are specialized nodes that are more involved in running the network and are financially incentivized. These are called **miners**.

When a block of transactions is created, it is the job of miners to add the block to the blockchain to keep the transactions verified and honest. The process of keeping the records honest is called a **consensus mechanism**. For example, Bitcoin uses a Proof of Work (PoW) consensus mechanism. In PoW, every time a block is added to the blockchain, a block reward in the form of cryptocurrency is allocated to the miner. All the miners compete for these block records. To do so, the miners have to solve a complex math puzzle. This requires miners to submit a huge number of computations, in which one miner gets eventually lucky. It is this process of mining, which requires a lot of computing power which in turn uses a lot of electricity.

Purpose

While cryptocurrency is undeniably a great idea at many levels, energy consumption and its environmental impact, is a subject for more investigation.

This study explores the energy consumption and carbon emissions due to cryptocurrency mining using the following techniques.

1. Energy consumption with respect to a conventional credit card transaction such as using Visa network. Visa is a very well-known and commonly used form of the traditional transaction system. The first step of this research is to compare the energy consumption of popular cryptocurrencies against Visa.

2. Energy consumption with respect to other cryptocurrencies - There are multiple cryptocurrencies in the market currently. The next step of the research is to compare the energy consumption of different cryptocurrencies based on the following aspects
    1. Consensus Mechanism - It is the mining process that requires a lot of processing power. Therefore, the algorithm or consensus mechanism used in cryptocurrency software to validate, verify, and add a block of transactions to the blockchain is an important factor. This study compares the energy consumption of popular cryptos based on what consensus mechanisms are used such as Proof of Work (PoW) and Proof of Stake (PoS)
    2. Market Capitalization - Higher Market capitalization of a cryptocurrency shows how popular and widespread the crypto is. Therefore, it makes sense to compare the energy consumption of different cryptos in this aspect to fully understand the environmental impact.
    3. Mining Devices - Different mining devices have different levels of energy efficiency. Different cryptos use different types of mining devices. For example, Bitcoin miners use ASIC (Application-Specific Integrated Circuit) miners which are efficient for Bitcoin's SHA-256 algorithm but not for other cryptos that don't use this algorithm.

Methods

The data used in this research study was compiled from various resources after hours of research exploring these sources.

White House Report on Climate and Energy Implications of Crypto-Assets in The United States Sept 2022

Using this data source, I extracted information regarding the market valuation of popular cryptocurrencies and the corresponding energy consumption during the year 2022.

Articles on Cryptocurrencies from ScienceDirect.com

I explored many articles from ScienceDirect.com to understand how a digital cash system like cryptocurrency can be a major contributor to energy consumption and carbon emissions. The articles provided data from various sources to perform the energy consumption of these cryptocurrencies based on aspects like consensus mechanism, and mining devices used. It also provided data for comparison of energy consumption against traditional and common transaction methods like Visa.

Various Research Papers Published in International Journals

I explored various research papers to gain insights into the various aspects used for comparing energy consumption and carbon emission due to cryptocurrencies.

Various Articles and Blogs Published On Internet

Lastly, I explored various newspaper articles and research blogs to further gain insights into the energy consumption and carbon emission due to cryptocurrencies.

Results and Insights

Energy Consumption and Carbon Emission with Respect to Visa

Table 1 below shows the Energy Consumption and Carbon Emission of popular cryptocurrencies Bitcoin and Ethereum with respect to the traditional payment method Visa for a number of transactions per day. According to the source sciencedirect.com, the data collected for Visa includes electricity consumption carbon emissions required to run office and servers and commute

Table 1. Energy consumption and carbon footprints of Bitcoin, Ethereum, and Visa (total) as of July 2021

Transaction method	Market cap ($ Billion)	Transactions/day (Million)	Emission (Mt$CO2$)	Energy consumption (TWh)

Bitcoin [23]	617.05	0.4	64.18	135.12
Ethereum [27]	247.8	1.23	26.13	55.01
Visa [51]	520.62	500	62,400	197.57

From Table 1, it appears that Visa has very high energy consumption and carbon emission when compared to Bitcoin and Ethereum. However, the number of transactions per day for Visa at around 500 million is way more than the daily transactions for Bitcoin and Ethereum at 0.4 and 1.23 million respectively.

Figure 1 below compares the energy consumption and carbon emission for these three finance systems for each transaction. It can be seen that per transaction energy consumption and carbon emission for Bitcoin and Ethereum is way more than that of Visa. This implies that these new cryptocurrency transaction methods have over-proportionate consumption.

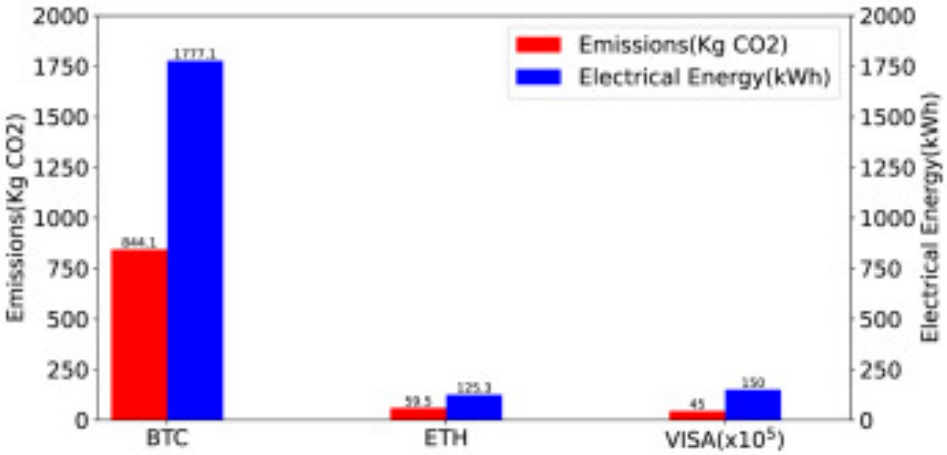

Figure 1. Electrical energy consumption and *CO*2 emissions per transaction for Bitcoin, Ethereum and Visa (2021)

Energy Consumption with Respect to Other Cryptocurrencies

Consensus Mechanism

As mentioned earlier in this research, when a block of transactions is proposed to the cryptocurrency network, to ensure that records are true and honest before added to the blockchain, a consensus mechanism is required. There are several mechanisms through which consensus can be reached. The most popular ones are Proof of Work (PoW) and Proof of Stake (PoS). The transactions themselves do not consume as much energy as the consensus mechanism.

We have already discussed PoW in the introduction section, where miners compete to solve a computational puzzle associated with each block in order to add a block to the blockchain. Bitcoin and Ethereum use PoW as the consensus mechanism.

In Proof of Stake (PoS) consensus mechanism, a validator is chosen randomly based on how much stake they commit to the network. The higher the stake is placed the higher the chance of getting selected.

Figure 2 compares the energy consumption per transaction for various cryptocurrencies based on the consensus mechanism used.

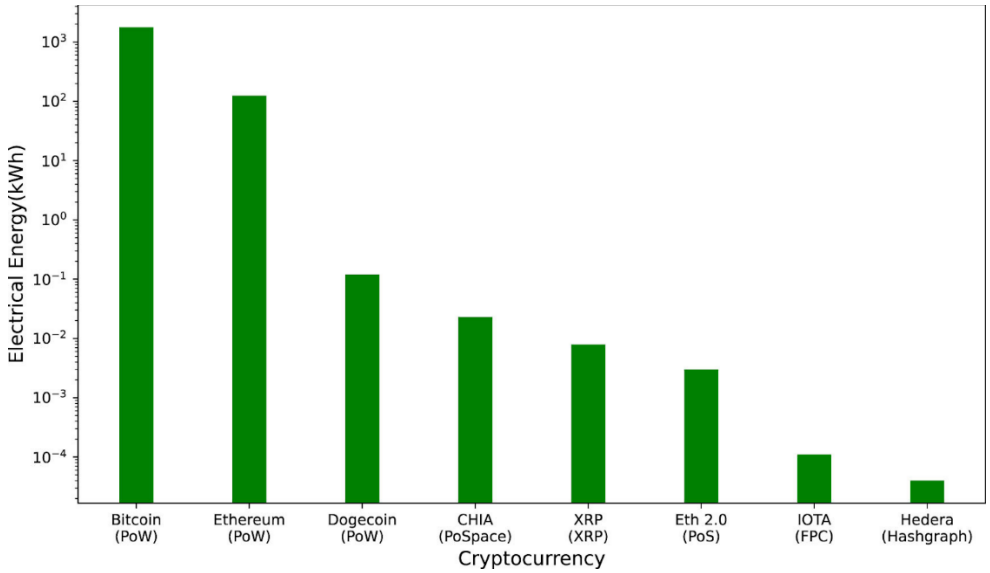

Figure 2. Energy consumption per transaction for various cryptocurrencies and their consensus mechanisms.

We can see that the highest contributor to energy consumption is the PoW-based cryptocurrencies. The figure also shows that the emerging and more promising consensus mechanism PoS fares way better than PoW. The updated cryptocurrency Ethereum called Ethereum 2.0 has moved from PoW to PoS. PoS is a low energy consumption consensus mechanism as it leverages the contributions of miners and thus eliminates the need for intensive mining.

Market Capitalization

When Satoshi Nakamoto published his research on blockchain technology, Bitcoin emerged as its first well-known application in 2009. There have been various cryptocurrencies that have emerged after that for example Ethereum, Tether, Binance, Cardano, Solana and Dodgecoin etc. However, Bitcoin soon became the biggest cryptocurrency, enjoying a market capitalization of USD $389 billion as of August 2022. Fig 3 depicts the global electricity usage of popular cryptocurrencies based on their market valuations in 2021-2022 with Bitcoin leading as the biggest contributor.

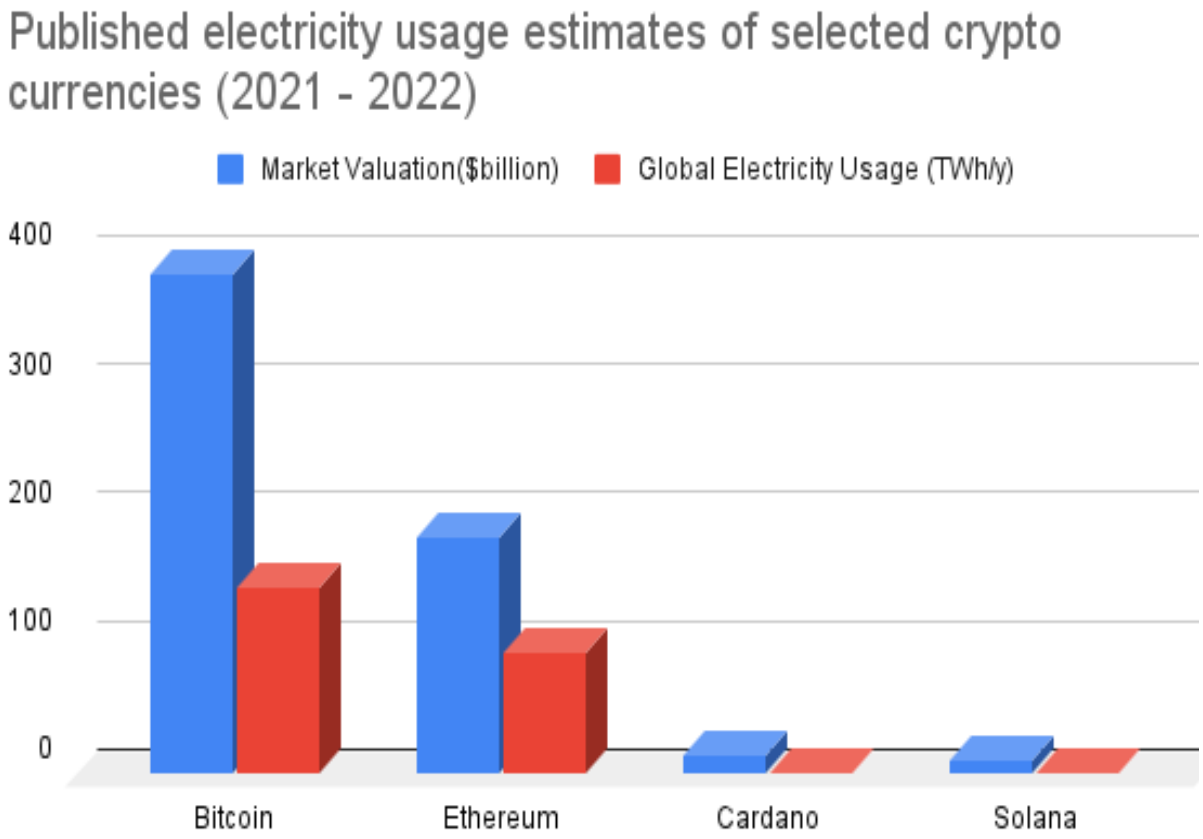

Figure 3. Electricity usage estimates of cryptocurrencies (2021 - 2022)

Mining Devices

One of the major contributors to energy consumption in cryptocurrency mining is the use of inefficient mining devices. There are several hardware models like the Central Processing Unit (CPU), Graphics Processing Unit (GPU), Field-Programmable Gate Array (FPGA), and Application-Specific Integrated Circuit (ASIC) used for mining. The computational power of these hardware devices is calculated in Giga-Hashes (GH). Figure 4 shows the energy consumption of these devices in the logarithmic scale against their computed GH. We can see that CPU devices have the highest energy consumption followed by GPU, FGPA, and then ASIC mining devices being the most efficient.

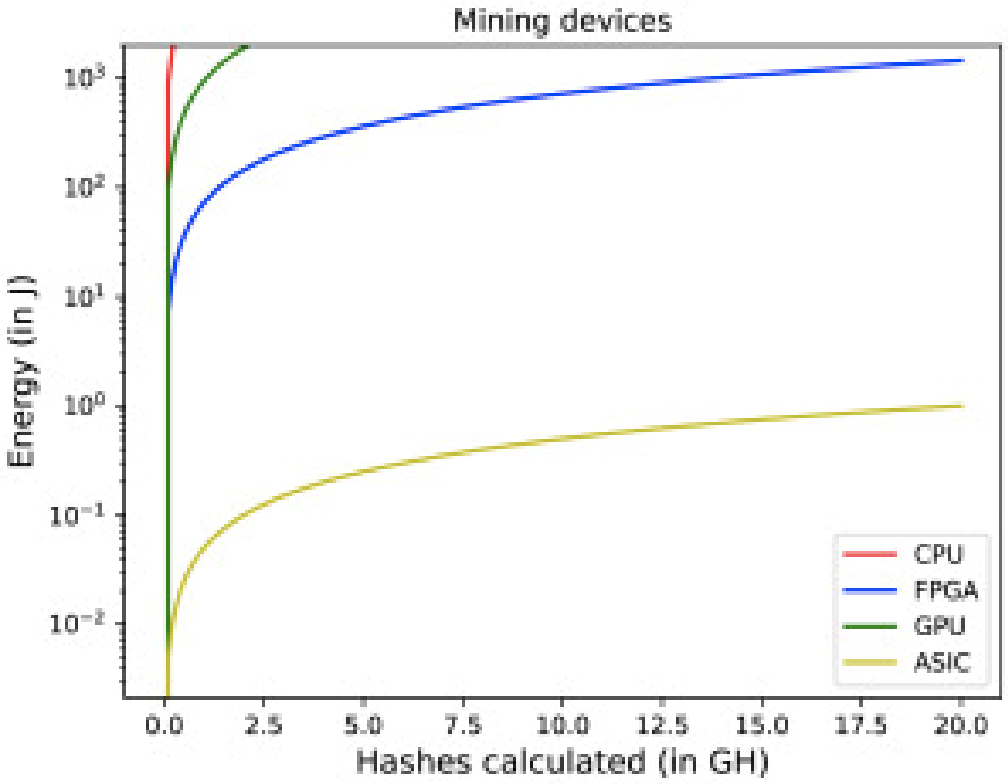

Figure 4. Electrical energy versus hashes calculated for Application-Specific Integrated Circuit (ASIC), Field-Programmable Gate Array (FPGA), Graphics Processing Unit (GPU), and Central Processing Unit (CPU) devices

Next Steps

Following are the further study areas on the cryptocurrency energy consumption footprint and the possible opportunities to mitigate the consumption going out of control.

Alternative Ways for Mining

We need to further explore different consensus mechanisms apart from PoW and PoS. For example, a Proof of Authority consensus mechanism is another mechanism where nodes earn the right to generate new blocks through a reputation-based process. This mechanism is another energy-efficient technique that could replace the Proof of Work or Proof of Stake.

Some cryptocurrencies have also introduced a concept of pre-mining to be energy efficient. In this technique, coins are created beforehand before they are released to the block in the network. In this case, the currency's blockchain record is still validated by the decentralized network.

Alternative Energy Sources

We need to further study the positive environmental impact of cryptocurrencies that rely on greener energy sources. Some of them now use hydropower, some use excess gas leaks from oil fields and some use solar-powered machines. As more companies get into cryptocurrencies, alternative energy sources for mining will become increasingly

necessary. Startups like LiquidStack aim to efficiently lower the temperature of mining rigs, or Genesis Mining that purely uses green energy sources.

Many underdeveloped countries face a challenge in investing in conventional coal-based electricity generation infrastructure. In these underdeveloped regions there is an emerging concept of bitcoin-based frontier towns like the gold-based frontier towns in the past. Energy sources like small waterfalls are being used as green energy sources to mine Bitcoins in these bitcoin-based frontier towns.

Environmental Regulations and Carbon Credits

Governments and policymakers have started to bring in regulations for cryptocurrencies to limit carbon emissions. For example, Quebec province in Canada has introduced a moratorium on cryptocurrency mining.
Carbon credits are another way where a government can allow a company to emit a certain amount of carbon emission into the environment. These credits are traded by companies with low emissions to the companies with higher emissions, thus encouraging businesses to produce less emissions than their allotment. Further study is needed as to how these regulations and carbon credit government programs are changing the trend on cryptocurrency driven impact on the environment.

Conclusion

Cryptocurrencies, with energy-intensive operations, lead to significant greenhouse gas emissions. The energy use and carbon impact correlate with their consensus mechanisms and mining equipment. PoS reduces power usage compared to PoW. If PoW persists, using efficient devices like ASICs is vital. Traditional systems like Visa are more energy-efficient, emphasizing the need for sustainable practices in crypto. However, as cryptocurrencies are an extremely new and developing space, further study is needed to assess the fuller picture of energy consumption by considering alternate mining methods, alternate energy sources along with the government's regulations and their carbon credits program adoptions.

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