Minimize The Effect of Energy Consumption in Block-Chain Technology

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Abstract. One of the most innovative technologies, blockchain is recognized to have a broad range of applications in business, education, and other fields. Originally, blockchain was presented as a bitcoin technology. It is now a crucial piece of technology for safely storing data online without the need of middlemen. As blockchain technology has grown over time, there have been growing worries about how it may affect the environment, particularly with regard to energy use. It is discovered that blockchain consumes enormous amounts of energy because of the algorithm it uses. This paper examines numerous algorithms produced and their effects on the environment, with a primary focus on blockchain technology.

Keywords: Blockchain, Consensus Mechanisms, Bitcoin, Energy Consumption.

1 Introduction

A distributed and unchangeable ledger, blockchain is made up of blocks connected to one another by a prior hash produced by a cryptographic algorithm. Due to its immutable ledger, blockchain guarantees safe and open transactions [8][27]. It has a database that is continuously updated and shared by a number of machines on a network. Every node linked to a specific network has an accurate and current copy of the blockchain on hand. An interconnected system of computers known as nodes verifies each transaction that occurs within the network. The first blockchain application was released in 2009 with the launching of the bitcoin cryptocurrency by Satoshi Nakamoto. Furthermore, according to its description, Bitcoin is a digital currency that permits peer-to-peer exchanges inside the blockchain network without the need for intermediaries [1]. As can be seen in Fig. 1, every block in the blockchain network, except from the first block, which is occasionally called the genesis block, furthermore includes the hash of the previous block in addition to the current hash, guaranteeing that the data is always tamper-proof. Hashing is used in every blockchain block to make sure that the data written there cannot be altered [2]. The Nakamoto consensus protocol is the name of the consensus process utilised in bitcoin. Using this protocol, Bitcoin was able to prevent double-spending attacks in a distributed peer-to-peer network [3]. A block is added to the blockchain network by miners competing with each other to solve a difficult cryptographic puzzle. Upon successfully completing the allotted task, the miners are rewarded with cryptocurrency. Additionally, blockchain is further separated into four main groups, as shown in Fig. 2 [4]: consortium, public, private, and hybrid blockchains. While blockchain offers several advantages, significant challenges need to be addressed before practical implementations can be made of it. In order to contribute new blocks to the blockchain network, miners have to address energy consumption as one of their primary challenges.

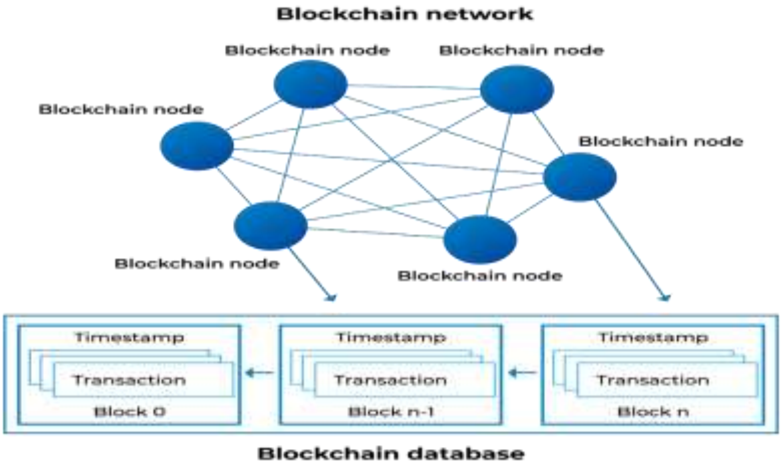

Fig. 1. Blockchain Network Structure

To add a block to the blockchain network, miners must work out a challenging mathematical puzzle, which requires a significant amount of energy. Since fossil fuels are the primary energy sources, they simultaneously harm the environment and release massive volumes of carbon dioxide into the atmosphere [5]. Because there are only so many energy resources available and because environmental degradation is getting worse, this is a major social problem. In sections two and three of this paper, the blockchain architecture is briefly examined, and challenges related to energy usage and several approaches to address them are discussed.

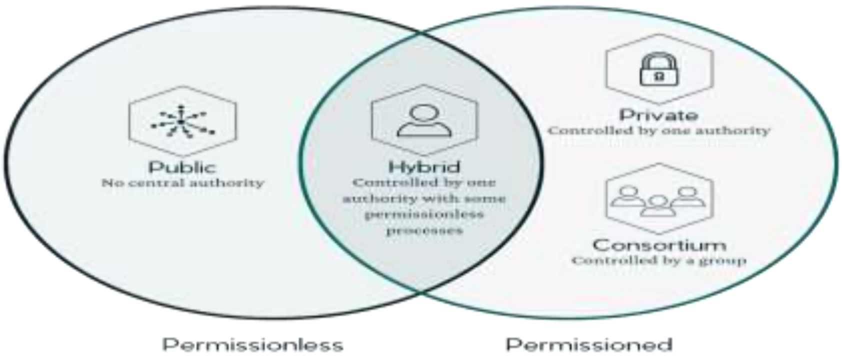

Fig. 2. Different categories of Blockchain

2 Blockchain Architecture and Consensus Mechanism

2.1 Blockchain Architecture

A blockchain network's design is very different from that of a conventional centralized database system. In a blockchain, data is decentralized and kept in blocks, or nodes, as opposed to traditional databases, which have a centralized structure [6]. To guarantee authenticity and integrity and prevent data manipulation by outside parties, the digital documents are time-stamped. A cryptographic algorithm connects the blocks that make up the blockchain network. A block consists of two distinct fields: a nonce, or "number used once," and a data field containing all required information [1][27]. Because it enables users to modify a block's hash value without altering the block's contents field, it is important to the blockchain. Additionally, a block is made up of two hashes: the block's current hash and its preceding hash. These hashes aid in connecting blocks throughout the blockchain network and guard against data manipulation. A blockchain network is made up of the hashes of the previous block connected to the next block, and so on [27][8]. Due to the enormous processing cost involved, altering data in a block would need recalculating the hash for that block and all following blocks [4][28]. This makes the manipulation of data almost impossible. In Fig. 4, for instance, a basic blockchain network is depicted, with the hash values of the genesis block being 0 and the subsequent blocks having hash values of 8Y5C9, 914z1, and so on. It is nearly hard to tamper with the information because of the network's intricate structure. Every hash value in the network must be updated if any piece of data is compromised, and at least 51% of the nodes must concur to make the modifications [7].

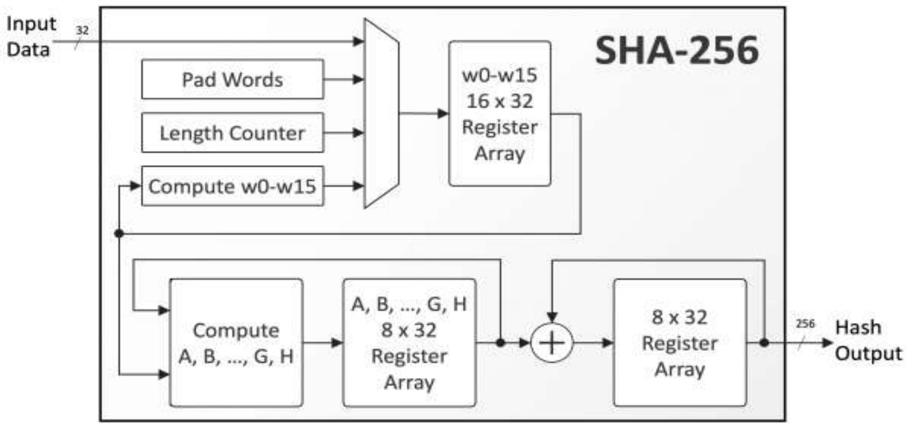

Fig. 3. SHA-256 Algorithm

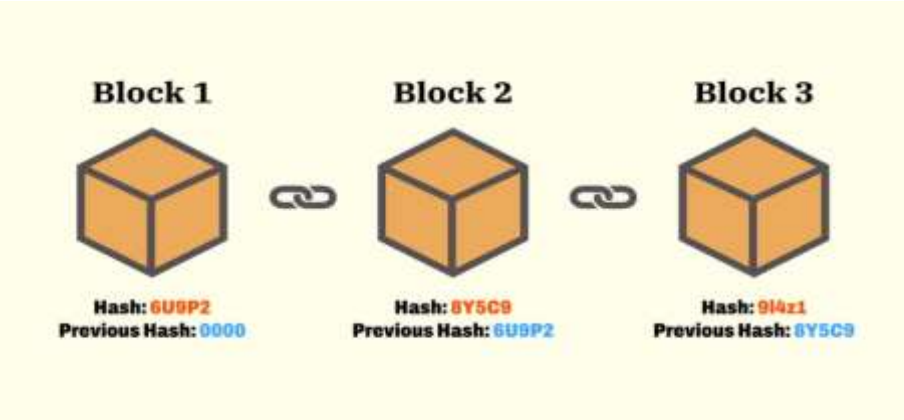

Fig. 4. Blockchain network

2.2 Consensus Mechanism

In blockchain technology, a consensus mechanism is a system that validates transactions and issues a certificate of authenticity. A blockchain network's performance and energy usage are mostly determined by its consensus mechanism. In a decentralized system such as blockchain, where middlemen are absent to authenticate transactions, a consensus process is necessary to confirm the authenticity of a new transaction prior to adding it to the network [8]. The consensus technique assumes that most nodes in the network are genuine and honest. A block cannot be added to the network unless a consensus is established by at least 51% of the nodes, which confirms the block's legitimacy [9]. Numerous consensus methods exist, each with unique benefits and drawbacks.

Proof-of-Work (PoW) in [3] was to reduce network duplication. PoW requires that in order to add a given block to the blockchain network, miners must solve a difficult mathematical challenge. This consensus process is executed by Bitcoin miners each time a new block is added to the network. In order to validate transactions and solve a cryptographic puzzle, mining nodes compete with one another. Once the issue is resolved, the node that uploads the block to the blockchain and receives payment in bitcoin [8]. PoW is predicated on the notion that the overall processing power of the attacking nodes ought to be lower than that of the truthful nodes [10]. Data manipulation is practically difficult with PoW, but mining a block consumes a lot of energy. The annual energy usage of bitcoin, for example, is 127 Terawatt-hours (TWh) [20]. It is indeed true that 707 kilowatt-hours of power are used in each bitcoin transaction [20].

Proof-of-Stake (PoS) was proposed since it consumes significantly less energy [11]. Proof of Work (PoW) mining pits participants against one another in an attempt to crack a cryptographic puzzle and add a block to the network. PoS, on the other hand, gives validators the ability to create new blocks and authorize transactions based on the amount of bitcoin they are willing to stake as security [8]. The energy usage in this scenario is far less than in a proof of work scenario since there aren't any miners competing with one another to finish a profitable assignment. To prevent massive energy waste, Ethereum is now adopting PoS rather than PoW. Furthermore, compared to other proof-of-work (PoW)-based networks, Polkadot and other blockchain networks based on this technology have reported energy use of around one gigawatt-hour (GWh).

Delegated Proof of Stake (DPoS): In contrast to Proof of Stake (PoS), which selects validators at random from the pool of network nodes, Delegated Proof of Stake (DPoS) validators are chosen by other nodes inside the network to add blocks to the blockchain [8][13]. The network may resemble a more centralized structure because validators are selected by other nodes [8][13]. But because DPoS does not ensure that there are enough legitimate block producers, there is a chance that an immoral block node may be elected and given the authority to add new blocks to the network, thus creating a security issue [8][13].

Proof of Elapsed Time (PoET) is a specifically intended for permissioned blockchain networks, Intel's Proof of Elapsed Time (PoET) consensus method was created in conjunction with their Software Guard Extension technology [8]. Before being able to construct a block in PoET, each user has to wait a certain amount of time. PoET is a PoW enhancement that does away with the mining process in an effort to cut down on PoW's excessive energy use. PoET, on the other hand, has a timing system in which users must queue up in order to build blocks [8][14]. The duty of a miner is bestowed upon the user who has waited the fewest seconds. Prior to being added to the network, every other node or user in the queue must validate the block created by this miner [14]. When compared to alternative consensus techniques like PoW, PoET uses a lot less energy. PoET often reaches millions of transactions per second, which is an extremely high transaction rate. The following formula is used by each node to determine how long it will wait:delay time is equal to

$$\log(r) \cdot \text{minimum\_wait} - \text{local average wait}.$$

Here, the value of r, a real integer derived from the hash value of the node's previous value, spans from [0,1], and minimum_wait is a fixed system option. Depending on the number of nodes present, the wait time is modified using the local average wait [14].

Proof of Capacity (PoC), also known as proof-of-space, is a consensus mechanism protocol used by some cryptocurrencies. In PoC, miners utilize their local hard drive capacity to mine new coins and validate transactions [15]. Miners in PoC conduct mathematical calculations and store the results on their hard drives before the mining process begins. The miner who successfully solves the puzzle in the shortest amount of time is granted the opportunity to participate in the consensus process [8]. The chances for a particular miner increase if it has the maximum number of solutions (plots) stored in its drives [8]. It is a two-step process involving plotting, where miners create a list of all possible nonce values by repeatedly hashing with a hash function called Shabal and store these values on their drives, and mining, where miners mine blocks and validate transactions by matching these solutions to the challenges present in the blockchain network [8]. PoC faces several problems in practical implementation, with one of the major issues being the drive space problem, as all possible hash values are stored on drives.

3 Issues on the energy consumption of blockchains

In addition to its remarkable ability to increase security, blockchain technology has some serious drawbacks that made scientists hesitant to adopt it widely in the near future. The main issue among a number of issues is energy use. To mine a certain network node, miners must use a significant amount of energy. According to article [17][18], bitcoin alone uses about 141.85 TWh of electricity annually, which is nearly equal to the energy consumption of many nations like Ukraine. It also produces a carbon footprint of about 79.12 Mt CO2 annually, which is comparable to Oman's carbon footprint. While the use of cryptocurrencies varies by nation, as Fig. 5 illustrates, the pace of utilization rises annually for practically all nations. Nige-ria is the region with the biggest cryptocurrency usage, as seen in Fig. 5, and over the past five years, the proportion has dramatically grown [19]. The utilization rate was just 28% in 2019 and changed to 47% in 2023. This indicates that an increase of more than 50% occurred in just five years [19]. However, in only five years, Turkey saw a growth of almost 100%.

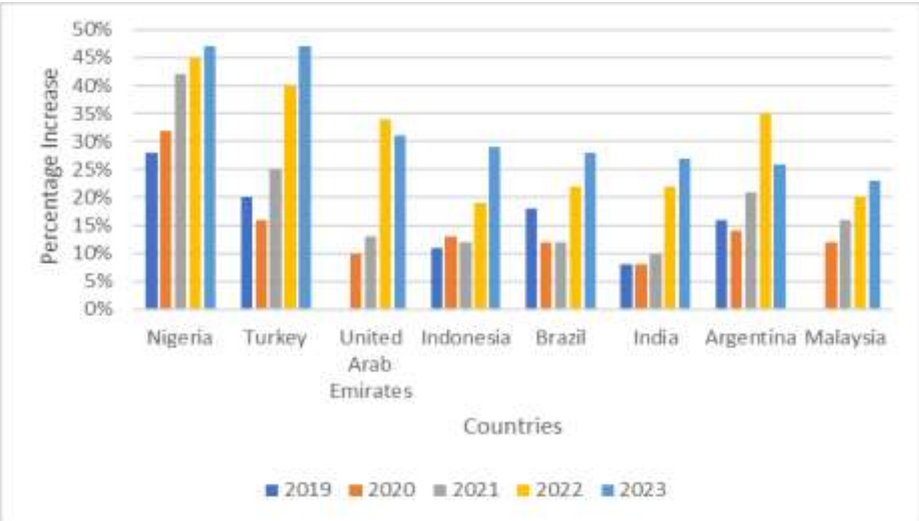

Fig. 5. Cryptocurrency adoption in different countries

Serious environmental concerns are raised by the sharp rise in energy usage that coincides with the growing popularity of cryptocurrencies. Figure 6 shows how much energy Bitcoin uses in comparison to other nations. A list of different nations is represented by the Y-axis, and the percentage is shown by the X-axis [18]. Figure 5 makes it evident that Bitcoin uses 200% more energy than the Czech Republic and 125% more energy than the Netherlands. Furthermore, as seen in Figure 7, one article [20] compares the value of a single Bitcoin transaction to hundreds of thousands of Visa card transactions. This shows how much power a miner uses to verify a transaction.

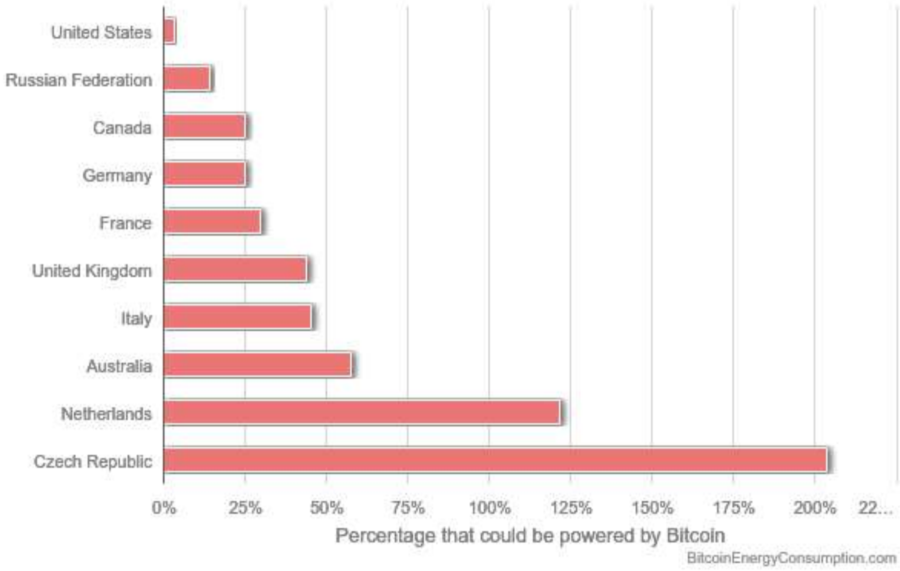

Fig. 6. Bitcoin energy consumption relative to other countries.

When it comes to energy efficiency, Bitcoin is thought to be the least efficient cryptocurrency available. Its use of the proof-of-work (PoW) consensus mechanism, which uses a lot of energy during mining, is mostly to blame for this. By comparison, Ethereum uses a lot less energy than Bitcoin since it operates on a proof-of-stake (PoS) consensus mechanism. In [21], Table 1 presents a comparison of the energy usage of Bitcoin, Ethereum, and Visa. Approximately half of Bitcoin's energy use, at 135.12 TWh, is consumed by Ethereum, at 55.01 TWh. Furthermore, compared to Bitcoin, Ethereum has a carbon footprint that is at least three times smaller at 26.13 million metric tons of CO2 [21].

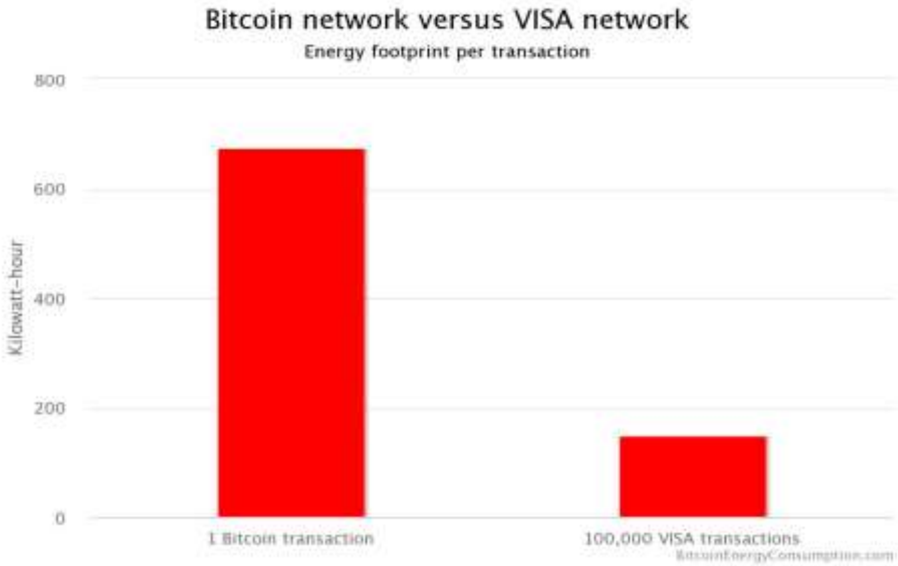

Fig. 7. Bitcoin vs Visa energy consumption

Table 1. Energy consumption and carbon footprint metric of different cryptocurrencies

Transaction method	Market cap ($ Billion)	Transactions/ day (Million)	Emission ($MtCO_2$)	Energy consumption (TWh)
Bitcoin	617.05	0.4	64.18	135.12
Ethereum	247.8	1.23	26.13	55.01
Visa	520.62	500	62,400	197.57

Further analysis of Figure 8 shows that cryptocurrencies based on proof-of-work (PoW) use more energy than cryptocurrencies based on alternative consensus methods. [8]21]. While miners in proof of work (PoW) must overcome a difficult cryptographic puzzle, in proof of stake (PoS) a randomly selected validator creates a block and validates a transaction [8].[11] [12]. Figure 9 displays the mining share allocation based on hash rates as of 2022. The leading nations mining Bitcoin include the USA (38%), China (21%), Kazakhstan (13%), Canada (7%), Russia (5%), Germany (3%), Malaysia (3%), and Ireland (2.0%). [21–22]. Excessive mining can affect the temperature of the environment since most energy is derived from non-renewable sources, which emit CO2 into the atmosphere as a byproduct and contribute to global warming. The increase in environmental temperature can lead to health issues such as breathing problems and pose a threat to biodiversity.

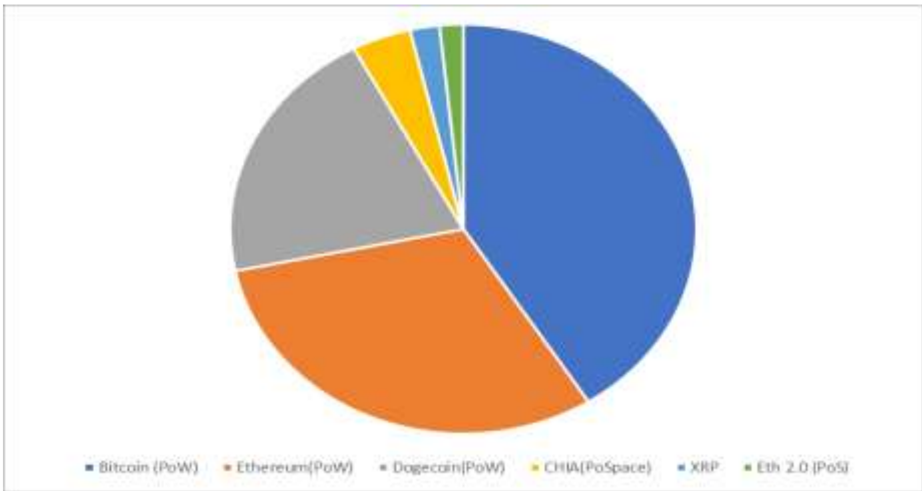

Fig. 8. PoW consensus vs other consensus protocols

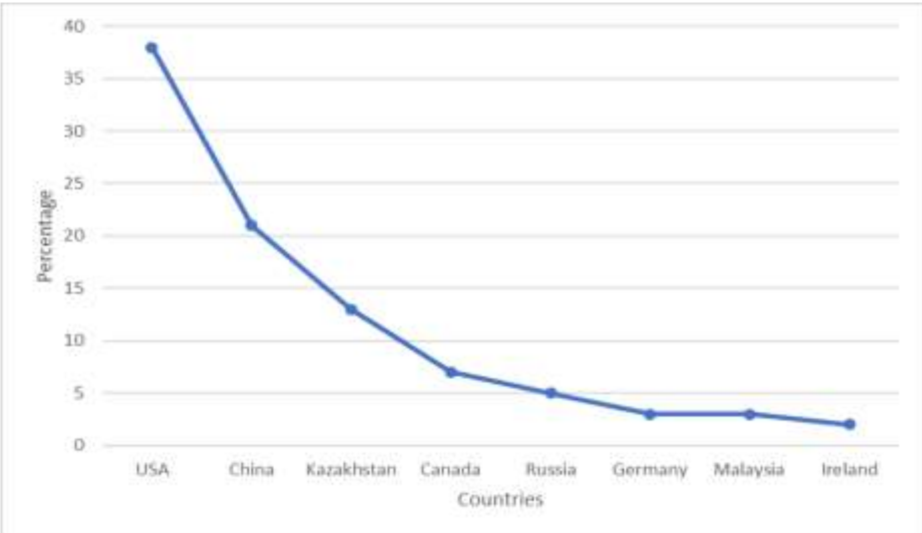

Fig. 9. Mining shares of different countries based on hash rates.

4 Methods to reduce the effect of energy consumption in blockchain technology

Blockchain may use a variety of methods to reduce its energy use. One strategy is to power mining operations with renewable energy, which lessens pollution and eases the shortage of resources. Article [24] claims that renewable energy sources currently provide a sizable share of Bitcoin's mining power. In addition to using wind and nuclear energy, over 25% of Bitcoin miners also utilize water. It is imperative that all Bitcoin miners switch to renewable energy sources since, while 52.4% of them utilize it, 43% still rely on non-renewable sources. Making the switch from the energy-intensive Proof-of-Work (PoW) consensus method is another tactic to consider.
Alternatively, implementing Delegated Proof-of-Stake (DPoS) or Proof-of-Stake (PoS) can significantly lower energy use. The 2022 PoW to PoS transition on Ethereum resulted in a sharp drop in energy use. With PoW, Ethereum used 99.99% more energy than it used in 2023, at around 0.0026 TWh/yr. A variation of PoS called DPoS lowers energy consumption even more by doing away with the random selection of validators, which lowers computing power. PoS and PoW systems are compared in Table 2 in [27].

Table 2. Comparison between PoW and PoS

Consensus Protocols	**Characteristics**
Proof-Of-Work (PoW)	1. All user takes part in mining process 2. Consumes exorbitant amount of energy 3. Very Slow 4. Costlier as compared to other protocols
Proof-Of-Stake (PoS)	1. Participation is determined by the user with the highest wealth. 2. Consumes less power as compared to PoW 3. Fast computation 4. Less costly as compared to PoW

5 DISCUSSION

In this paper, we have discussed blockchain architecture, different consensus protocols, their corresponding impacts on the environment, and methods to reduce these effects in detail. To reduce carbon emissions while mining cryptocurrencies, several approaches can be considered:

1. Transition from PoW to Sustainable Protocols: Moving away from the PoW consensus protocol to more sustainable alternatives like PoS can minimize en-

ergy consumption. For instance, Ethereum's shift to PoS in 2022 led to a significant reduction in power consumption, up to 99.99% [26].

2. Utilization of Renewable Energy: Using renewable energy sources can help reduce energy consumption and carbon emissions. Miners could continue to mine cryptocurrencies using PoW while relying on renewable energy sources, further lessening the environmental impact.

6 CONCLUSION

The distributed and immutable ledger of blockchain technology has allowed it to significantly evolve in recent years, becoming a leading security solution. Applications for it may be found in a number of industries, including banking, education, and the Internet of Things (IoT). But at the moment, mining cryptocurrencies—Bitcoin and Ethereum being the most well-known examples—remains its main application. Notwithstanding its benefits, many miners find it difficult to obtain the processing power needed for cryptocurrency mining, which restricts the use of this technology. To lessen the negative effects of PoW, other methods including proof-of-stake (PoS) have been suggested. Furthermore, the sustainability of blockchain technology may be further improved by providing miners with an alternate source of energy, namely renewable energy. By putting these suggestions into practice soon, blockchain technology can become more flexible and sustainable.

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