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Energy Consumption in Crypto: an Overview

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Executive Summary

Concerns about the sustainability of blockchain consensus mechanisms have become a popular topic. In this report, we provide an overview of blockchain networks' energy consumption, hardware requirements, and possible solutions to improve blockchain sustainability.

Background

- Rising global land and sea temperatures have resulted in a need to innovate in order to address energy consumption concerns in crypto, and blockchains like Ethereum are evolving from existing mechanisms towards a more sustainable existence.
- Depending on the energy mix used to maintain its network, **Ethereum's current consensus mechanism (Proof of Work, or PoW) may be headed towards unsustainability** — energy consumption increases as network difficulty increases, which is a function of the number of miners incentivised by monetary rewards entering the ecosystem

Hardware comparison across Proof of Stake Layer-1s

- Not all innovations are equal — blockchains like **Solana** and **Polkadot** require relatively higher capital cost as a result of sophisticated hardware.
- **Higher capital cost does not necessarily equate to higher energy consumption due to higher throughput,** which is the case for Solana when looking at energy spent per transaction. High capital cost may come at the expense of decentralisation, which is a core focus in blockchain technology.

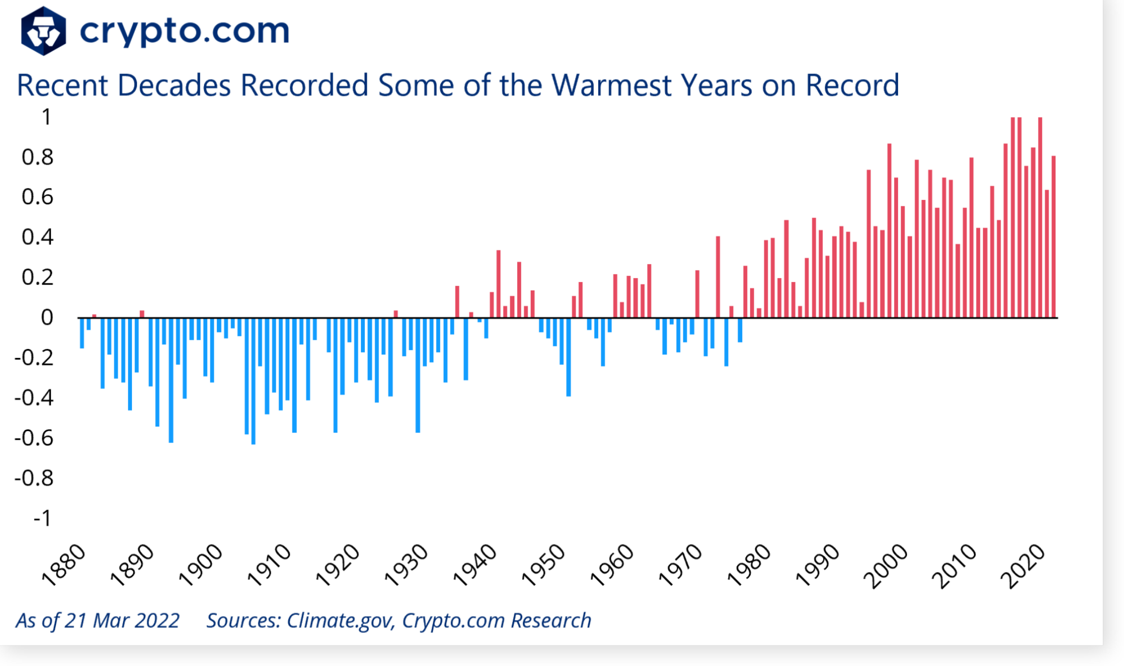
Layer-2s, alternative consensus mechanisms, carbon offsets

- Various Layer-2s have emerged, mostly targeted at **reducing gas fees and energy spent by miners to secure the network**.
- Chia Protocol's idea aims to **reuse and recycle old, existing hard disks as part of their novel Proof-of-Space and Proof-of-Time consensus in order to ensure sustainability;** IOTA and Hedera Hashgraph's Directed Acyclic Graph technology ensures their blockchains are sustainable.
- **Sustainable energy consumption is inadequate.** WAX Protocol and Immutable X ensure their networks become carbon neutral by purchasing carbon credits from organisations such as climatecare.org to offset carbon emissions. **Eventually, more blockchains will follow suit.**

1. Introduction

1.1 The Need to be Sustainable

With climate change, sea levels and global land temperatures continue to rise. The turn of the millennium marked an increase in attention to global climate control and a focus on reducing pollution. According to NOAA and NASA temperature records, 2019 and 2020 were among the top three warmest in over 140 years. There has been an ever-growing focus on renewable energy and sustainable development to help minimise global warming and its associated environmental impacts. The cryptocurrency industry is amongst those facing more and more calls to reduce its environmental footprint and energy consumption.



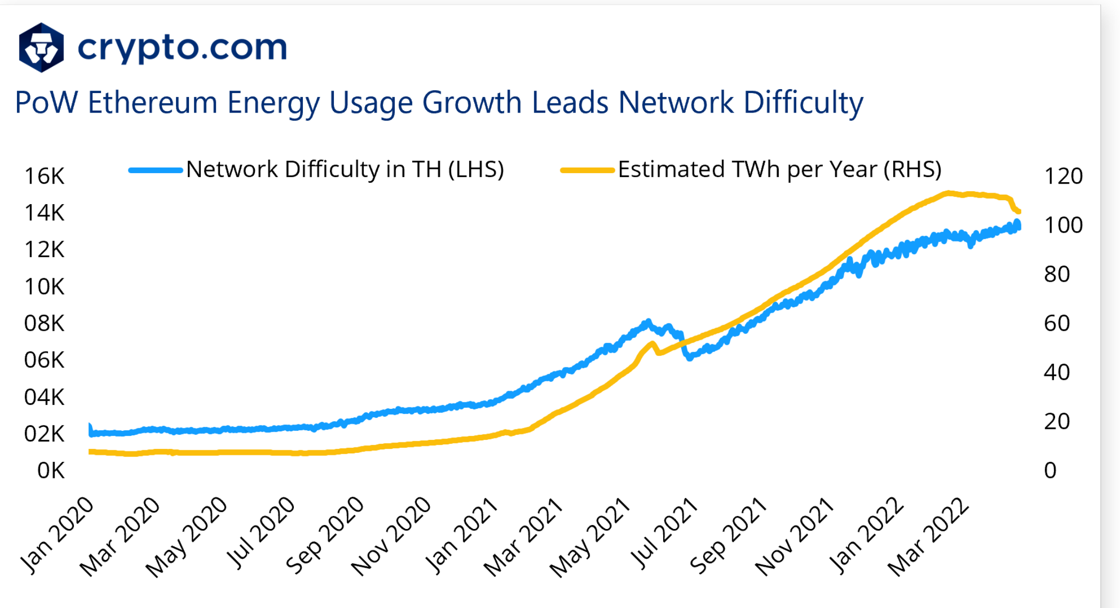
1.2 Eth 1.0 and its Transition

The onset of blockchain technology came with the publication of Satoshi Nakamoto's famous Bitcoin white paper. **The idea was simple — to remove the reliance on trusted third parties in financial transactions by applying cryptographic proofs in a peer-to-peer network.**

The Bitcoin white paper made use of the Proof of Work (PoW) consensus, which requires CPU power to validate each transaction based on a timestamp server. The average work required to validate the transaction is exponential to the number of zero bits required. At the time of writing, there are 19 zero bits in each newly discovered Bitcoin block's hash.

In 2014, Ethereum 1.0 was conceived as a next-generation blockchain, designed to be the base for a global decentralised computer. Ethereum followed Bitcoin's Proof of Work consensus model, but Ethereum's goals were rather to provide a Turing-complete programming language that allows for the creation of contracts ('smart contracts') to manage state transition functions and a transaction mechanism between both parties; in short, to be used for more than money.

Less than a decade later, in 2022 Ethereum is now the second-largest coin by market capitalisation and the main token used in Decentralised Finance (DeFi). According to Defi Llama, over US$100 billion has been locked in the Ethereum EVM since 4 January 2022, compared to roughly US$17.5 billion on 4 January 2021, suggesting increased demand and adoption. This demand growth from NFT minting and DeFi activities has caused network congestion and led to gas wars, where users incentivise validators to include their transactions in the upcoming blocks by offering a priority tip.



As of 21 Apr 2022   Sources: Etherscan.io, digiconomist.net, Crypto.com Research
**Network difficulty is a measure of how difficult it is to mine a block; to find a hash below a given nonce*

Following the Bitcoin mining guide from Braiins, network difficulty increases as more miners enter the fray. The combination of the monetary incentives of mining and the increased demand from decentralised applications has added to increasing network difficulty, and miners are compelled to hunt for greater computing power. According to Etherscan, the average network difficulty for 1 January 2021 and 1 January 2022 was 3,730.319 TH and 11,667.672 TH, respectively. This represents an increment of more than 200% in that one-year span, suggesting that Ethereum's energy consumption has ballooned. This calls for a transition to less energy-intensive methods to secure and improve efficiency of the network of Ethereum, which has led to the Beacon Chain upgrade.

1.3 Proof of Stake Ethereum's Energy Demands

The Proof of Work consensus mechanism requires nodes to validate transactions in an ordered timestamp server, following the rule of the longest blockchain. Ethereum miners who guess the correct nonce are awarded the current block reward of 2 ETH after Constantinople EIP-1234 implementation. As more miners enter the market and blocks are found more quickly, network difficulty will increase to ensure that blocks are found at a regular time interval.

The Beacon Chain upgrade, which shipped in December 2020, marked the first of several phases of evolution for Etherum, from Proof of Work to a Proof of Stake (PoS) consensus mechanism. Proof of Stake works by requiring validators to stake Ether (ETH) in order to validate transactions and create new blocks, activities that are similar to miners and nodes in the Proof of Work consensus. As the number of stakers increases, so do nodes or validators, which would then help to secure the network. Ethereum will eventually move to an entirely Proof of Stake consensus blockchain — commonly referred to as 'The Merge'.

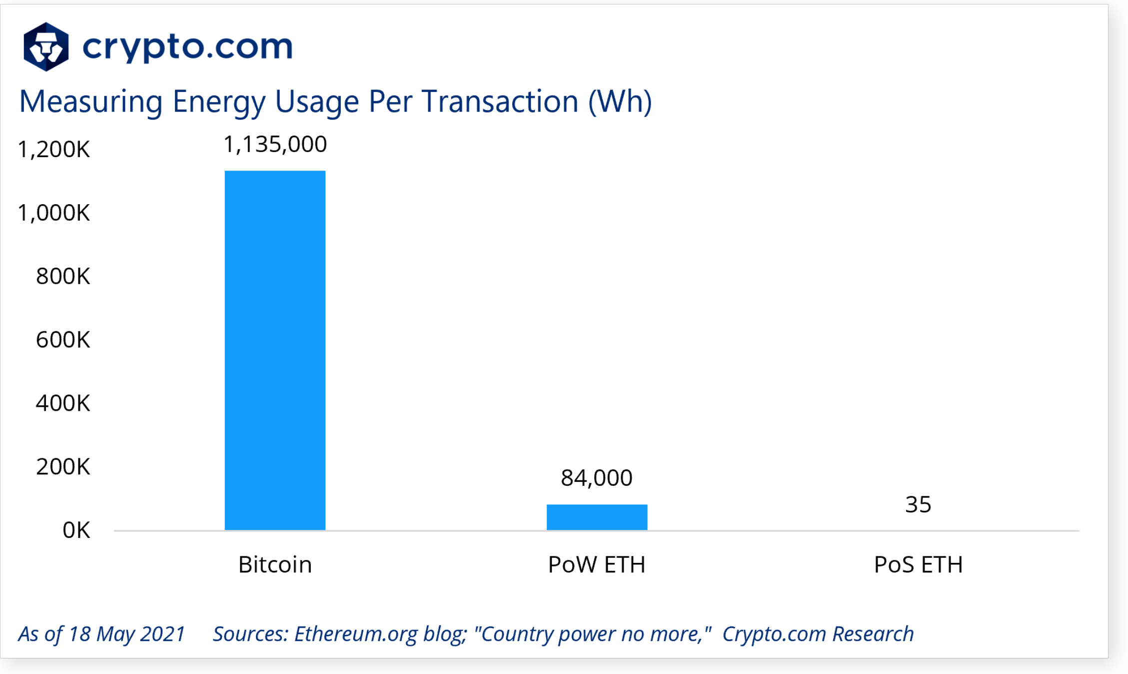
The immediate difference is an approximately 2000x reduction in energy consumption. A study published in the Ethereum Foundation blog estimated that post-merge, the Ethereum network's energy usage will decrease by a staggering 99.95%. To measure energy usage for Proof of Stake nodes, the study compares Ethereum's energy consumption with Visa's energy demands for 100,000 transactions. The foundation estimates that the transition to Proof of Stake would cost only 0.667 kWh to process 100,000 transactions, assuming a 1.44kWh daily usage.

In Proof of Stake, validators run nodes by staking their ETH tokens as collateral against dishonest behaviour, removing the high computational power required to guess the nonce in proposing a new block. Penalties are meted out to validators deemed non-performant.

As such, in the ETH 2.0 update, miner rewards will be phased out once The Merge is completed. At the time of writing, The Merge was completed on ETH's public testnet Kiln. By moving to Proof of Stake and phasing out the mining, miners may opt to host nodes or validators instead, creating a large decline in the energy consumption for the network.

To put this in perspective, visualise Proof of Stake Ethereum as a 2.5cm screw standing up and Proof of Work ETH standing 57m tall, while Bitcoin is as tall as the

Burj Khalifa (830m). With that, it is worth noting there have been different views on the appropriateness of energy usage per transaction as a metric for comparison between the different blockchains.



2. Comparing Various Proof of Stake Networks

2.1 Technical Requirements

Having discussed energy consumption estimates and the scope for energy savings as Ethereum moves to Proof of Stake, in this section we take a closer look at Proof of Stake in general at six other Proof of Stake networks, including **Cardano, Polkadot, Tezos, Avalanche, Solana,** and **Algorand.**

According to the Crypto Carbon Ratings Institute's 2022 report, hardware requirements differ across all networks. The table below shows the technical requirements are different across all Proof of Stake consensus mechanisms; some blockchain networks require more sophisticated hardware to run a node or validator, for example. Based on the **recommended setups by the respective blockchain networks,** it is likely that these would consume more electricity than a Raspberry Pi 4, which is at the lowest end of the energy usage spectrum.

Name	CPU	RAM	Storage	SSD/NVMe	Source
Cardano	2x2GHz	12 GB	50 GB	N/A	IOHK, 2022
Polkadot	i7-7700k	64 GB	80-160 GB	NVMe	Polkadot, 2022
Solana	12 x 2.8GHz	128 GB	2 TB	NVMe	Solana, 2022
Tezos	2 cores	8 GB	100 GB	SSD	Tezos Agora, 2022
Avalanche	8 cores, > 2GHz	16 GB	200 GB	N/A	Avalanche, 2022
Algorand	4/16 cores	4 -8/24 GB	100/500 GB	SSD	Algorand Foundation, 2021
Cronos	4 cores	16 GB	1 TB	N/A	Cronos, 2022
Ethereum 2.0	i7–4770/FX-8 310	16 GB	100 GB	SSD	Prysm 2.0.6

As of 21 Mar 2022 *Sources: Crypto Carbon Ratings Institute, Crypto.com Research*

A quick glance through the requirements shows a variation in them, and some blockchains require large amounts of Random Access Memory (RAM). RAM is used as a computer's short-term memory and likely runs computations for most, if not all, programs on any device. In addition, the **more demanding the hardware requirement to run a node, the higher the electricity consumption for each node.**

2.2 Features

Having looked at the hardware requirements to run a node in various Proof of Stake Layer-1s, we now look at the features throughput and electrical energy consumption for each node. Solana has the highest RAM requirements and also one of the highest throughputs (transactions per second), approximately 2,500 tps at the time of writing. Here we see that higher requirements would lead to a higher number of transactions verified per node. While energy consumption per node is high, the watt-hour usage per transaction is diminished.

Name	Transactions (Tx/yr)	kWh/year per node	Wh/tx per node	Node count†	Node known as
Tezos	2.5M	302.00	0.11054	412	Bakers
Polkadot	4.0M	236.49	0.05865	297	Validators
Cardano	11.9M	199.45	0.01718	3,214	Stake pool
Eth 2.0	—	525.60✦	0.00667✦	—	—
Avalanche	93.9M	451.40	0.00439	1,619	Validators
Algorand	190.0M	430.82	0.00227	2,130	Nodes
Solana	11.8B	1,938.85	0.00016	1,720	Validators

As of 21 Mar 2022 Sources: Crypto Carbon Ratings Institute, Crypto.com Research
† Taken from respective blockchain explorers, as of 20 April 2022
✦ Calculated, assuming each node runs at 1.44 kWh
↕ Estimated, averaged from daily transactions, then multiplied by 365 days.
± Estimated according to recommended node specifications at 121W PSU. The kWh is then calculated.

In sum, transitioning to the Proof of Stake consensus might not be as straightforward as it seems, given the varying technical and monetary requirements. This post by Braiins also provides details on why the transition may not be a perfect substitute for Proof of Work:

1. **Technical reasons:** Decentralisation may be forgone, as most individuals would not be able to meet the hardware requirements to run a node. This leaves only actors with access to capital with that ability. Various technical

concerns would arise due to having a large number of token holders staking with centralised third-party custodials, etc.

2. **Monetary reasons:** Under Proof of Stake, the whale with the largest stake would compound more quickly than the smaller actors. In terms of voting, having the largest stake would imply a naturally centralising force; which, if left unchecked, could impair the network.

With these shortcomings, it is inevitable that the community has to come up with further solutions.

3. Energy-Efficient Alternatives

Having discussed the various hardware requirements for Layer-1s, their energy usage, and the ability to scale at high throughput, we now review possible energy-efficient alternatives.

The alternative that is easiest to achieve is **Layer-2 solutions that facilitate transactions from the Layer-1 blockchains.** Second to this are the **alternative consensus mechanisms aimed at energy efficiency — for this we discuss a novel idea of using storage space.** Finally, we conclude this chapter with a short analysis of **carbon offsets, a mechanism that newer cryptocurrencies are employing in order to reduce their carbon footprints.**

3.1 Layer-2 Solutions

As discussed in Chapter 1, rising gas fees created the need to move to less energy-intensive mechanisms. The Merge, also known as ETH 2.0, has yet to happen on the Ethereum Mainnet and was first talked about more than two years ago. During this period, innovative ways to reduce gas fees appeared. Layer-2 solutions, also known as off-chain solutions, aim to scale the blockchain by moving transactions off Mainnet while taking advantage of Layer-1's security model. **Moving transactions off-chain reduces congestion, thus lowering gas fees and in turn the energy usage by miners to secure the network.** As mentioned in the previous chapter, Proof of Work and Proof of Stake are not perfect substitutes — both have their benefits and drawbacks.

Layer-2 solutions usually come with these features:

- High transaction volume per second
- Multiple transactions rolled up into a single transaction to Mainnet Ethereum
- Built on top of Ethereum or in parallel

Since multiple transactions are rolled up into a single transaction, we can expect this to be a more energy-efficient alternative. We take a look at some of the common types of Layer-2 solutions in the next part without getting too technical.

3.1.1 Optimistic Rollups

According to Ethereum developers, this method sits in parallel to Mainnet and does not perform any form of computation. After each transaction, the rollup proposes the new state to Mainnet. The transactions are written to the main chain via a smart contract function.

In addition to bundling these transactions together, Optimistic rollups have a call function to ensure that transactions are not fraudulent. In the event of a call, the transaction could be challenged by the validators within the seven-day time frame, which could lead to longer transaction confirmation time. At the time of writing, the fraud-proof feature is under development.

Taking these transactions to run in parallel with Mainnet reduces pressure on ETH gas fees and would most likely lead to a reduction in Mainnet energy consumption. Examples of protocols using Optimistic rollups include Arbitrum, Optimism, and Metis Andromeda.

3.1.2 Zero-Knowledge Rollups

ZK-rollups bundle or roll up transactions together as well, but they also generate a cryptographic proof. These proofs come in the form of **S**uccinct **N**on-interactive **Ar**gument of **K**nowledge (SNARK) or **S**calable **T**ransparent **Ar**gument of **K**nowledge (STARK).

With ZK-rollups, validating a block is much quicker and cheaper since only the validity proof is needed, instead of all transaction data, and less data is included. Protocols that use ZK-rollups include the dYdX protocol, Loopring protocol, and StarkNet.

3.1.3 Sidechains

A sidechain is a separate blockchain that runs in parallel with Mainnet and operates independently. It has its own consensus algorithm; for instance, **Byzantine Fault Tolerance (BFT)** or **delegated Proof of Stake (dPoS).** Most sidechains have a bridge connecting to Mainnet. Since sidechains are based on the Ethereum Virtual Machine (EVM), deploying DApps on them is easy because they're written using a similar codebase. Examples of sidechains include Ronin and Polygon Matic.

3.1.4 Layer-2 Comparison Table

Below are some examples of protocols using the Layer-2 technologies we previously mentioned that are actively used by the crypto community.

Name	Total Value Locked (US$)	Purpose	Technology
Polygon↕	3.89B	Universal	Sidechain
Arbitrum	3.55B	Universal	Optimistic rollup
dYdX	971M	Exchange	ZK-rollups
Optimism	548M	Universal	Optimistic rollup
Metis Andromeda	371M	Universal	Optimistic rollup
Loopring	329M	Tokens, NFTs, AMM	ZK-rollups
Boba Network	160M	Universal	Optimistic rollup
zkSync	114M	Tokens, NFTs	ZK-rollups
ZKSpace	72.35M	Tokens, NFTs, AMM	ZK-rollups
Immutable X	63.51M	NFTs, Exchange	Validum
StarkNet✝	–	Universal	ZK-rollups

As of 13 Apr 2022 Sources: L2beat.com, Defi Llama, Crypto.com Research
✝ No TVL as there are no bridges deployed on Mainnet
↕ Polygon's TVL from Defi Llama

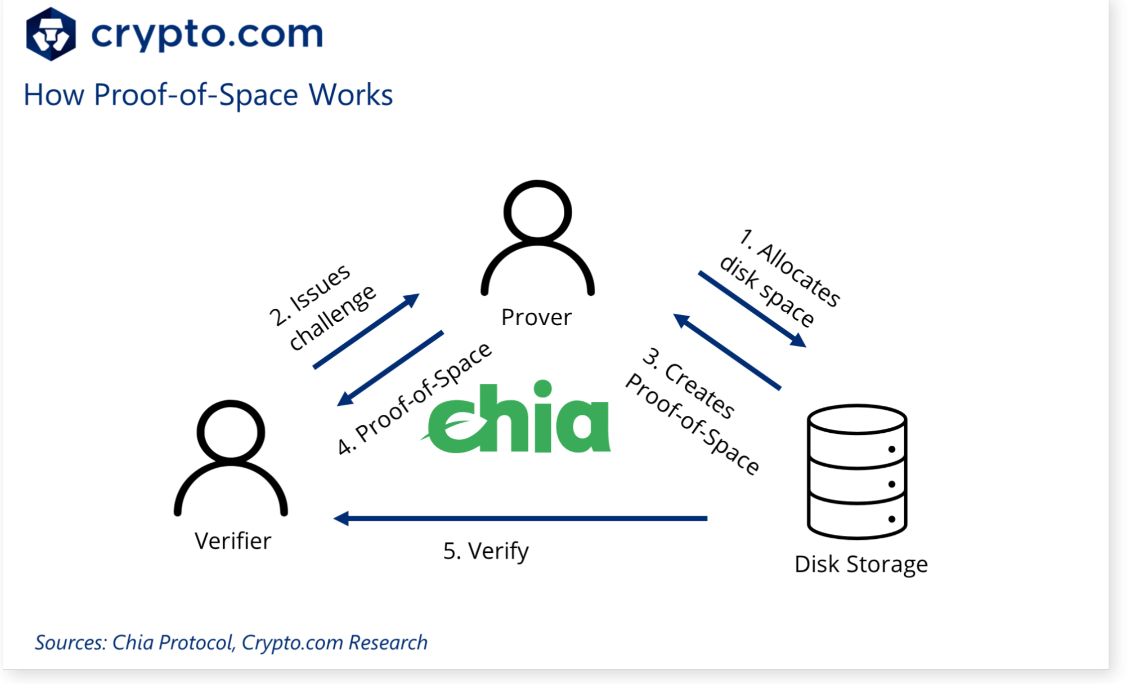
3.2 Alternative Consensus Mechanisms

In this segment, we take a look at alternative consensus mechanisms and their energy consumption apart from the regular Proof of Work and Proof of Stake mechanisms.

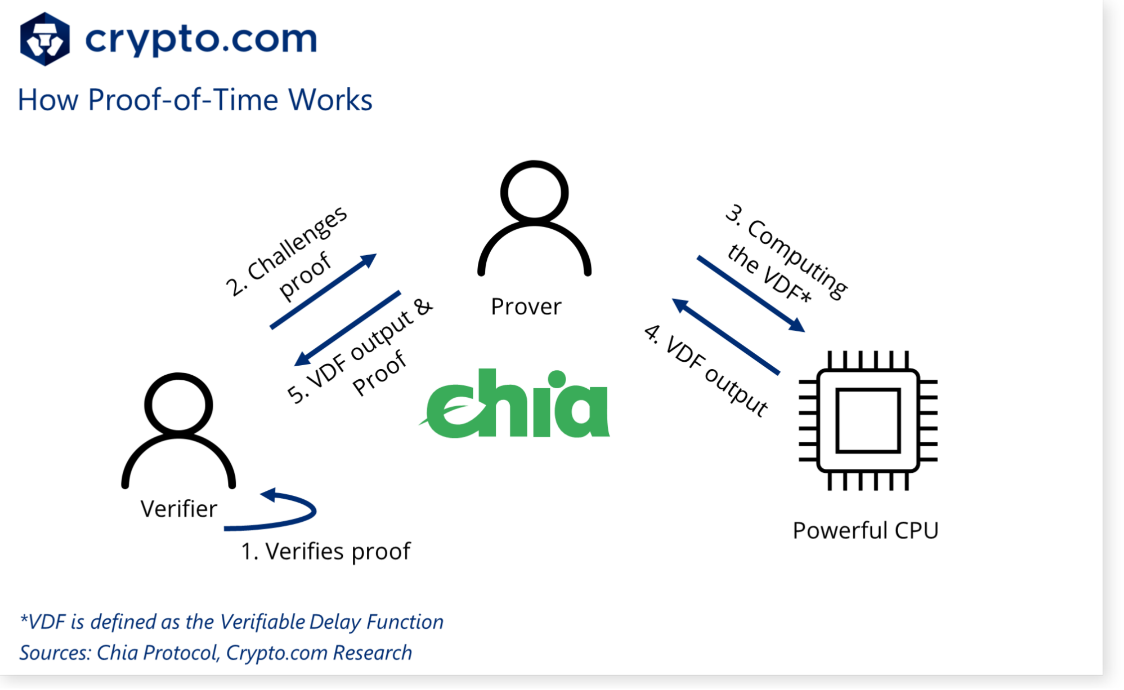
3.2.1 Chia Protocol and How it Works

Chia is a cryptocurrency and blockchain smart transaction platform focussed on delivering an alternative solution to Bitcoin's Proof of Work consensus. The idea is driven by increasing the energy efficiency of the network, which officially launched on 17 March 2021. **The Chia Protocol relies on a new Nakamoto consensus and uses a Proofs of Space & Time (PoST) consensus mechanism.**

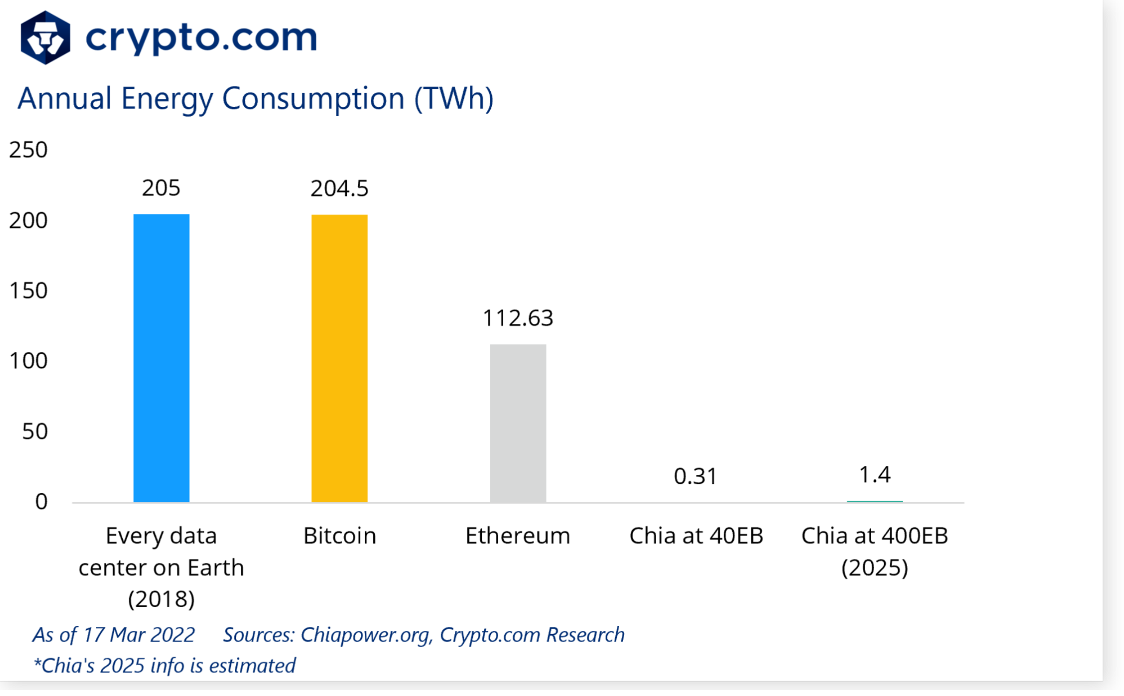
[Proof-of-Space] works by getting the prover to allocate a certain amount of disk space to solve a problem through a challenge provided by the verifier. Solving the puzzle requires performing a series of technical tasks on a hard disk. Once the puzzle has been solved, the allocated space is assigned a private key (Proof-of-Space). The proof would then be hashed and verified.



The [Proof-of-Time] component in the process comes after the Proof-of-Space verification. Proof-of-Time resolves whether the transaction took place and if an actual amount of time was spent to solve the puzzle. The details tend to be slightly more technical and will not be covered here.



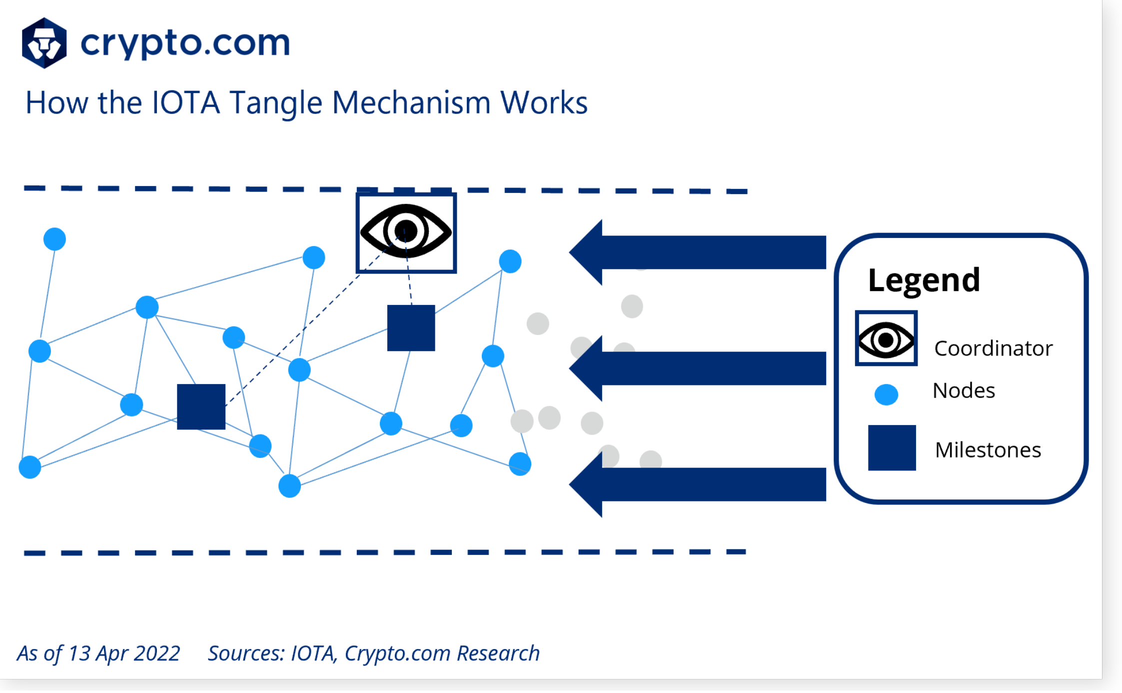
According to Chia Power, Chia's annual energy consumption of approximately 40EB (2^{60} bytes, or approximately 40 billion gigabytes) is only 0.31 TWh per year as of 17 March 2022. This is a fraction of Bitcoin or Ethereum's Proof of Work consensus. Currently, the netspace used by Chia's network is 28.2EB, much lower than the estimated 40EB. Chia Protocol shared in its business white paper that the more affordable SSD for consumers, and the significant decrease in energy to farm chia plots, will eventually lead to it being a highly decentralised protocol where retail can run nodes easily.



3.2.2 IOTA and How it Works

The IOTA data structure is a type of Directed Acyclic Graph (DAG), and differs from traditional blockchains. In a typical blockchain, each block will be proposed and have transactions attached to it. Standard blockchains experience bottlenecks due to validators proposing blocks and having a single third-party entity validating transactions for that single block. Instead of running in a linear fashion, DAGs are immutable, and they run parallel in only one direction. IOTA's DAG is called **'the Tangle'**. According to its documentation, messages or transactions can be attached to different places in front of the Tangle.

Unlike Bitcoin or Ethereum, IOTA's Proof of Work consensus does not validate transactions or messages. Sending messages in the IOTA network does not require fees because there are no miners or stakers. Instead, Proof of Work is used only to discourage spam messages.



The IOTA network consists of nodes and a coordinator. Within the network, coordinators act as clients, sending signed messages to create milestones that nodes trust and use to confirm messages.

In an IOTA blog post, its team studied the energy efficiency of the DAG network. The test was conducted on a Raspberry Pi 4, running the Hornet node. According to its findings, when the node was performing Proof of Work, the energy requirement was as low as 4.026 Joules per transaction/message **— this works out to a millionth of a kWh per transaction.**

3.2.3 Hedera Hashgraph and How it Works

Hedera Hashgraph is a permissioned blockchain that runs on a DAG mechanism. A permissioned blockchain is a blockchain that is not accessible to the public. According to Hedera's Mainnet node list, there are 26 nodes running from various countries by various enterprises within the permissioned blockchain; these 26 nodes form the governing council members for the network. One can think of it as a private blockchain, and in Hedera's case, it is used by 26 enterprises who host individual nodes.

In the Hedera Hashgraph DAG network, there are no blocks; rather, all transaction history is transmitted across nodes in a 'gossip about gossip' network, where new information is spread through the network. At a more technical level, the DAG network works on an Asynchronous Byzantine Fault Tolerance (aBFT) mechanism where snapshots of previous transactions are taken as gossip and transmitted between the various nodes asynchronously.

According to the Power Transition Blockchain Sustainability report, the Hedera Hashgraph protocol powers the Power Transition microgrid and has helped provide significant energy savings per home. In addition, it only costs 0.00017 kWh per transaction in Hedera, as compared to VISA's 0.001486 kWh per transaction.

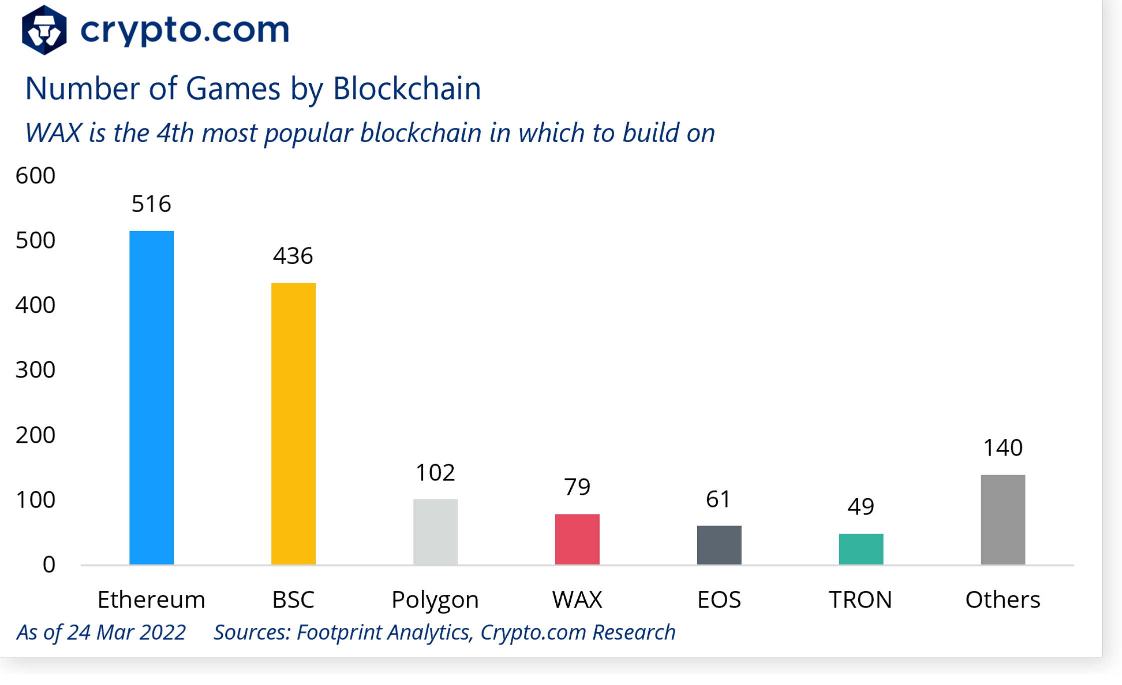
3.3 The Use of Carbon-Neutral Offsets

As the cryptocurrency industry grows, policymakers, regulators, and society as a whole are increasingly aware of the need to reduce carbon in all sectors, including crypto. In response to these external voices, blockchain protocols have adopted mainstream techniques like carbon credits to reduce their carbon footprint.

In the following section, we focus on how blockchain projects transit into sustainability projects, turning their blockchain operations carbon neutral, or even negative.

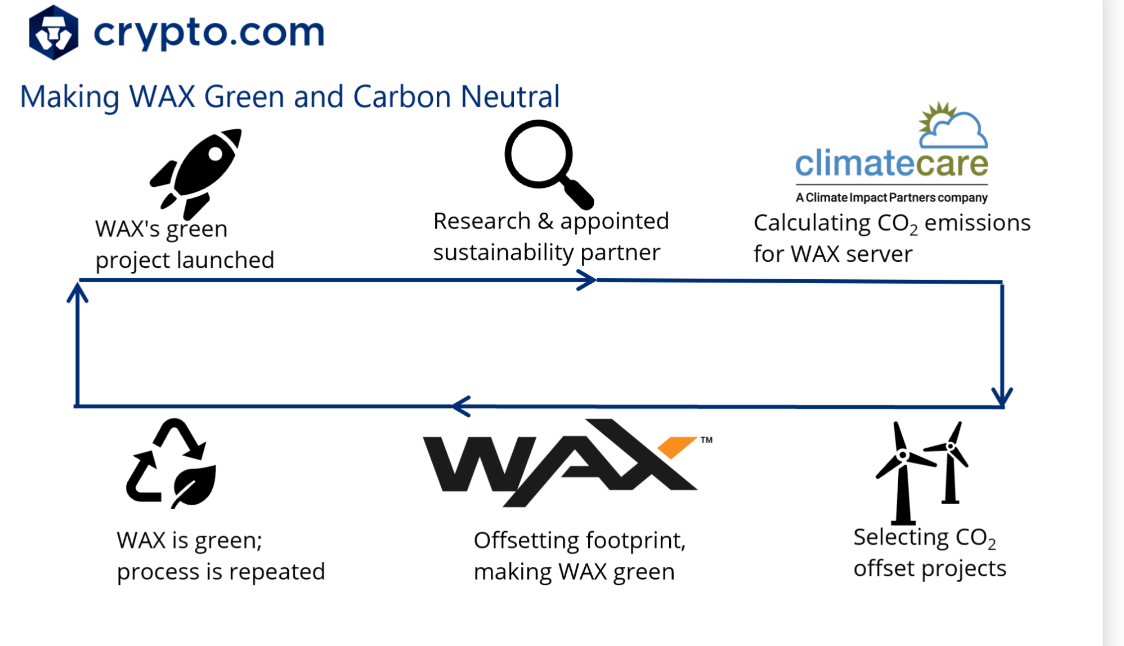
3.3.1 How WAX Protocol Maintains Carbon Neutrality for Blockchain Gamers

According to Footprint Analytics, WAX protocol is the fourth most popular blockchain in which to build games, and some of the games – like Splinterlands, AlienWorlds, and Farmers World – clock the most number of users.



WAX Protocol stands for Worldwide Asset eXchange Protocol. The blockchain works as a variant from the Proof of Stake concept and utilises the delegated Proof of Stake (dPoS) consensus mechanism.

Utilising a dPoS, the blockchain has 21 dedicated block producers (called WAX guilds or nodes) at any time. Like most Proof of Stake mechanisms, WAX Protocol uses a Byzantine Fault Tolerance (BFT) framework to prevent dishonest activity; any such activity results in WAX guilds being voted out. Additionally, any block becomes permanent and immutable the moment 15 guilds or more signs it. As of March 2022, there are currently 30 WAX guilds that have been audited and ready to rotate amongst themselves.



Sources: EOS Authority, WAX Protocol, climatecare.org, Crypto.com Research

To make WAX green, the protocol partners with climatecare.org to calculate and estimate the amount of energy used and the status of its carbon footprint on an annual basis. Climatecare has worked with various companies to support decarbonisation of their production lines, often through offsets.

How does the WAX Protocol offset its carbon footprint? By going through Climatecare, it picks out certain projects and purchases carbon credits corresponding to the amount of emission the blockchain produces. However, it does not mean that WAX consumes a higher amount of energy relative to other blockchains. As mentioned above, it uses a delegated Proof of Stake mechanism that, in fact, uses very little energy. Finally, having a lower number of nodes, despite reducing decentralisation, reduces the amount of power consumed.

3.3.2 Immutable X

Immutable X provides an efficient Layer-2 solution on Ethereum for games like Gods Unchained (the NFT trading card game), Guild of Guardians Heroes, and GreenPark Sports. Any NFTs created or traded on Immutable X are carbon neutral.

Fundamentally, Immutable X leverages zero-knowledge technology to achieve efficiency, which consumes less energy (less carbon used). For example, minting eight million Gods Unchained cards on Ethereum would consume approximately 490 million kWh (490 mWh); while on Immutable X, it roughly takes 1,030 kWh — That's 475,000 times less energy consumed.

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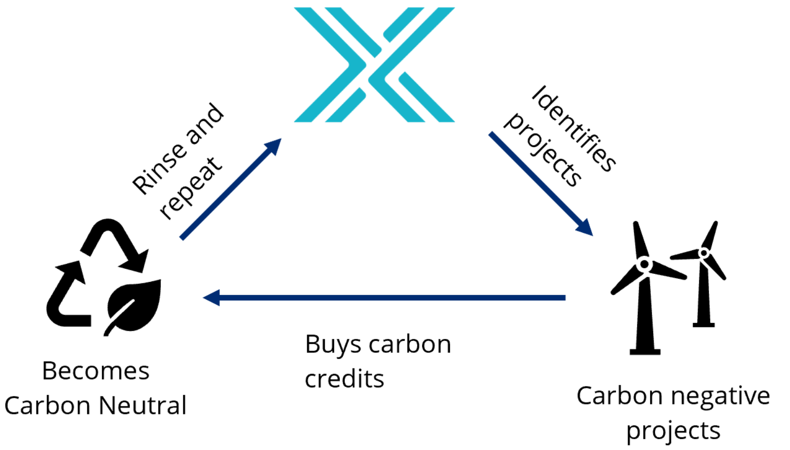
How Immutable X goes Carbon Neutral

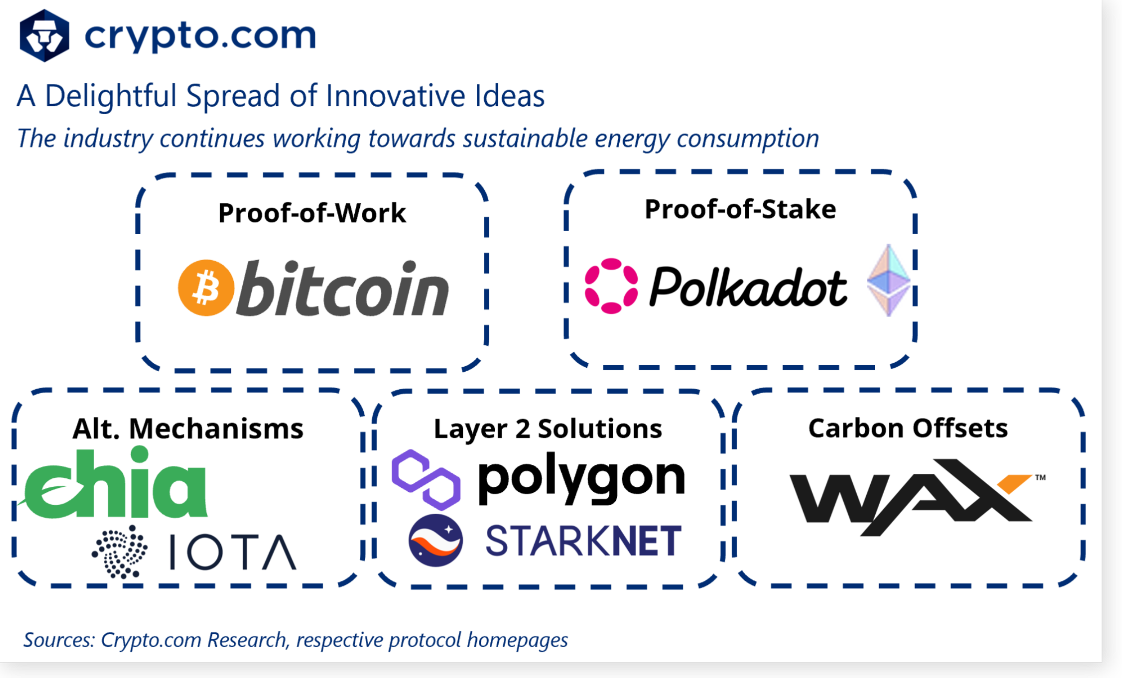


Sources: Immutable X, Crypto.com Research

According to a blog post by Immutable X, the platform calculates carbon emission using a top-down approach, beginning with Ethereum's annual consumption and taking a percentage of the number of Ethereum blocks that Immutable X uses. The platform then estimates about one Validum ZK-proof to the Layer-1 every hour. Thereafter, it converts the energy consumption to emissions based on the energy produced in the United States.

After estimating the carbon emission, Immutable X buys needed carbon credits to offset the carbon footprint of any NFT created or traded on its platform in order to be net-zero. In short, any activities and applications (e.g., NFT creation, NFT trading, NFT games, and NFT marketplace) that happen on Immutable X are carbon neutral.

4. Conclusion



Ethereum's founder, Vitalik Buterin, wrote about both Proof of Work and Proof of Stake; each consensus mechanism has its advantages and disadvantages. The problem of high energy consumption drives innovation, thus turning to different blockchain networks and their node requirements. Some of the hardware used in the nodes, however, consumes more electricity than others, but they are able to handle a higher transaction capacity.

We examined how the newer Proof of Stake blockchains turn to novel methods to solve blockchain and energy consumption problems, but energy consumption will continue to be debated within the distributed ledger space. Since a considerable amount of energy is required to validate transactions and are passed through sophisticated hardware to achieve higher throughput, it is likely that more blockchain projects will turn to carbon neutrality in the form of purchasing carbon credits or contributing to carbon offsetting programmes.

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