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The environmental implications of cryptocurrencies

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Abstract

In the twenty-first century, the financial world has been revolutionized by the digitized, decentralized database commonly known as blockchain. Blockchain technology plays a vital role in guaranteeing the privacy and security of financial transactions based on the inherent system of blocks and chains, where each block contains financial assets linked together through chains of verification and encryption, which are simply methods of protecting information from unwanted parties. As a result of blockchain's increasing popularity and productivity in the financial market, the creation of cryptocurrencies has ushered in a new financial asset class besides stocks, bonds, and mutual funds, to name a few. However, the emergence of cryptocurrency has sparked some controversy, particularly in the form of concerns around its impact on the environment. Since cryptocurrencies are decentralized, crypto mining is one way that users validate transactions on ledgers and gain more crypto assets. The competitive nature of crypto mining encourages the creation of extensive data mining servers that require megawatts of electricity. As cryptocurrencies and other blockchain technologies continue to expand, so does the sustainability risk of maintaining blockchain-based platforms. While there are very real concerns about the current eco-destructive factors of cryptocurrency, the increasing awareness and support for instituting potential solutions and sustainability measures in crypto-related fields is a promising future for the balance between cryptocurrency and the natural world.

Keywords

Cryptocurrency, Blockchain, Climate change, Environmental impact, Sustainability, Mining, Proof of stake, Proof of work, Merged mining, Carbon credits

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Introduction

In the twenty-first century, the financial world has been revolutionized by the digitized, decentralized database commonly known as blockchain. Blockchain technology plays a vital role in guaranteeing the privacy and security of financial transactions based on the inherent system of blocks and chains, where each block contains financial assets linked together through chains of verification and encryption, which are simply methods of protecting information from unwanted parties. As a result of blockchain's increasing popularity and productivity in the financial market, the creation of cryptocurrencies has opened up a new financial asset class besides stocks, bonds, and mutual funds to name a few. Essentially encrypted blocks of data under the name of a digital currency, cryptocurrency's decentralized foundation allows transaction party members to forego an intermediary institution (i.e. a bank) and work on peer-to-peer networks. As of 9:19 a.m., July 31, 2023, the market cap of Bitcoin (BTC), the most mainstream and established cryptocurrency, is approximately $572.48 billion, while trading at a price of $29,443.65 since its near-zero dollar price at its start-up in 2009.

However, the emergence of cryptocurrency has sparked some controversy, particularly in the form of concerns around its impact on the environment. Since cryptocurrencies are decentralized, crypto mining is one way that users validate transactions on ledgers and gain more crypto assets. The competitive nature of crypto mining encourages the creation of extensive data mining servers that require megawatts of electricity. As cryptocurrencies and other blockchain technologies continue to expand, so does the sustainability risk of maintaining blockchain-based platforms. While there are very real concerns about the current eco-destructive factors of cryptocurrency, the increasing awareness and support for instituting potential solutions and sustainability measures in crypto-related fields is a promising future for the balance between cryptocurrency and the natural world.

Environmental Concerns

The crux of cryptocurrency's negative environmental impact lies within the blockchain system itself. Because cryptocurrency is a finite resource, there's largely an increasing trend in demand for crypto mining before the supply runs out, which in turn fuels a rising sustainability problem regarding the eco-friendliness of cryptocurrency. One of the greatest concerns is climate change. Crypto mining is an energy-intensive process. It is estimated that Bitcoin-mining server farms consume 150 terawatt-hours (TWh) of electricity annually, an amount that surpasses the energy outputs from countries as large as Norway and Argentina (1). Some argue that the stigma around crypto mining may be exaggerated given that the world's annual energy consumption is 176 thousand TWh, and Bitcoin uses less than 0.1 percent of that energy (2). While the amount may seem small, reducing the energy consumption from crypto mining and verification protocols is an easily achievable possibility. As a result of cryptocurrencies' substantial usage of fossil fuels like coal, oil, and gas in order to generate the electricity needed to run their mining servers, greenhouse

gas emissions have become a prevalent issue with crypto mining, as these gases (i.e. carbon dioxide) enter the earth's atmosphere, trap the sun's heat, and alter ecosystems that play essential roles in sustaining the planet's temperature and vitality for living and nonliving things. Therefore, it should still be paramount to reduce the energy consumption of current cryptocurrencies, particularly Bitcoin, by establishing networks on more eco-friendly platforms discussed later in the "Cryptocurrency Innovations for Environmental Sustainability" subsection.

Another concern regarding cryptocurrency is the electronic waste that is produced from mining hardware. As the crypto market continues to grow, so does the innovation of mining hardware in order for mining companies to maintain an edge over their competitors. However, an underlying issue is the disposal of hardware that becomes obsolete. Electronic waste, or e-waste, contains toxic chemicals, particularly heavy metals like lead that decrease biodiversity regeneration of living organisms, and can subsequently be harmful to the environment if disposed of improperly (3). This waste includes computer chips that require the physical process of mining of finite resources for manufacturing just to become an obsolete technology thrown into the landfills (4).

Figure 1: Approximate annual amount of e-waste generated by Bitcoin in 2023 (source: *Digiconomist*)

Consequently, the demand for cutting-edge technology to explore the cryptocurrency market has led to an exploitation of computing resources in certain areas of the world. China and Kazakhstan, two of the largest coal-yielding and consuming nations, have become the leading countries for crypto mining as a result of both their abundance in fossil fuels and lack of government restriction over energy use. Coupled together, these two factors have been exploited in other similar-minded nations; Iran, for example, has invested so much into crypto mining to the extent that its inhabitants suffer from frequent electricity outages and resource depletion (5).

Government Policies and Industry Initiatives

In 2016, the Paris Climate Accord was officially implemented as an international

treaty by 196 countries that essentially established world leaders' efforts to reduce the causes and effects of climate change as well as limiting global warming to below 2° C (6). Now that the rise of cryptocurrency and blockchain technology has become a looming threat to the treaty, many governments are enforcing greener policies than before upon large corporations. Over 70 countries have created their own policies to reduce carbon emissions, and this has spurred a chain reaction in the business world, where 21 percent of the largest 2 thousand public corporations have instituted net-zero policies as both a sustainability measure and pro-green business strategy (7).

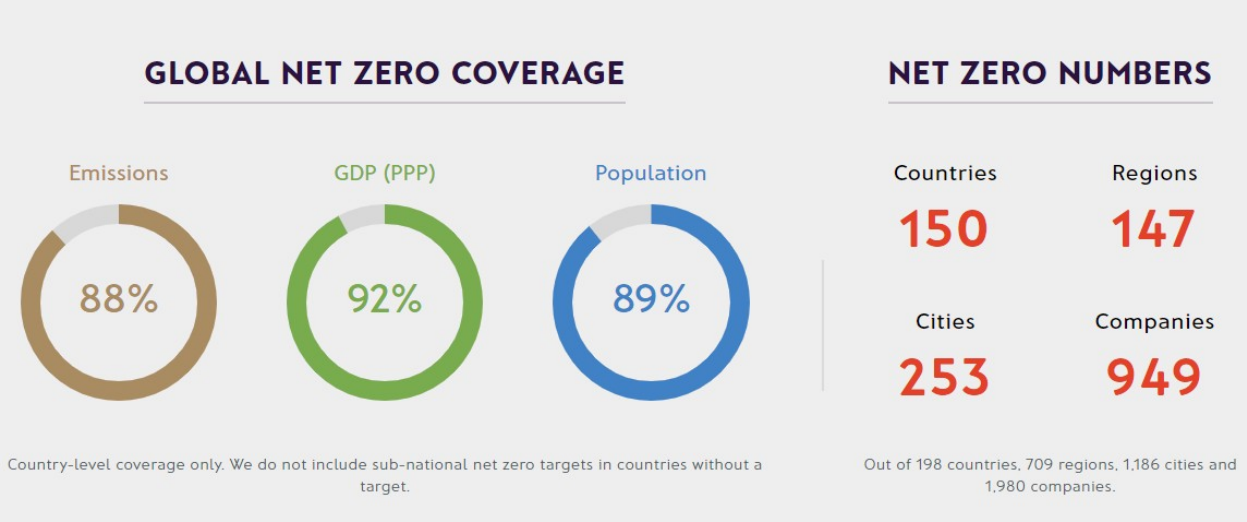

Figure 2: Net-Zero Data Visualization for Coverage and Numbers Worldwide (source: *Net Zero Tracker*)

Although not exactly a green policy, the Chinese government curtailed the private ownership of Bitcoins and Altcoins (cryptocurrencies other than BTC) in late 2021 in preparation for China's digital yuan, and this "crypto ban" has subsequently sent destructive shockwaves in Chinese crypto mining locations (5). The U.S. has since become the leading nation for crypto mining, accounting for 37.8% of all Bitcoin mining activities approximately a year after China's switch to the digital yuan (8), and its leading states include the likes of New York, Kentucky, Georgia, and Texas, which possess abundant fossil fuels, cheap electricity, or both. Under U.S. President Joseph Biden's administration, reducing climate change, and therefore limiting the non-eco-friendly side effects of cryptocurrency, has become a pressing issue. The U.S. government is committed to cutting greenhouse gas emissions by 50 percent by 2030 and an electricity grid free of carbon pollutants by 2035. On March 9, 2022, President Biden signed an executive order on Ensuring the Responsible Development of Digital Assets, which officially formulated a team of scientists

and analysts to produce reports concerning the ecological and energy-related implications of cryptocurrency and crypto mining. This team has since come to the conclusion that distributed ledger technologies (DLT) could potentially mitigate the effects of climate change. DLT would provide the backbone to other blockchains to undergo eco-friendly changes without the use of external operations as well as working with other U.S. federal agencies like the Environmental Protection Agency and Department of Energy to further facilitate eco-friendly, crypto-related policies (9).

Cryptocurrency Innovations for Environmental Sustainability

Although the demand for crypto mining is increasing, the most recent sustainability measures in the cryptocurrency field have proven to be potential solutions to environmental concerns. Since cryptocurrency is generally designated as a transparent form of currency, carbon credits, or carbon offsets, are tokens that represent measurable amounts for reducing greenhouse gas emissions that governments and large organizations use to promote the carbon-related transparency in their actions forward. Since cryptocurrencies already account for verification and security of financial transactions, implementing a carbon-credit system as a cryptocurrency combines the best of both worlds. As an example, Carboncoin is an established cryptocurrency that forgoes competitive crypto mining in order to reduce the demand for mining servers and thus create a popular, decentralized financial asset that also serves as a carbon credit-based ledger. The competitive cryptocurrency systems, also known as "Proof of Work" (PoW) systems, are energy-inefficient since they encourage a zero sum approach to crypto mining, whereas Carboncoin supports a more energy-efficient "Proof of Stake" (PoS) system, in which miners rely on market incentives in order for validators to invest a stake in the cryptocurrency. Ethereum, the second-largest cryptocurrency after Bitcoin, switched from a PoW system to a PoS system and now reportedly uses 99.9% less energy than before (1).

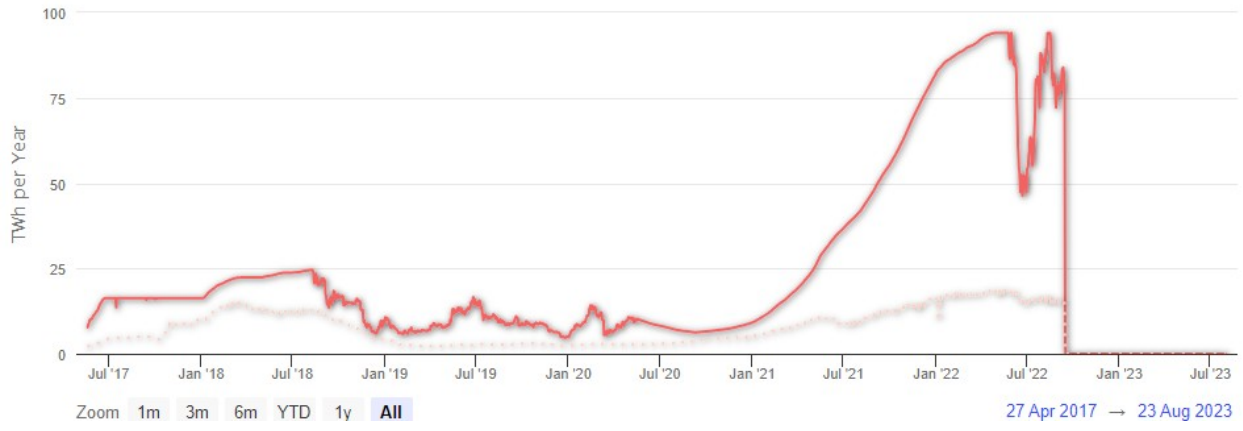

Figure 3: Ethereum Energy Consumption from April 2017 to August 2023 (source: *Digiconomist*)

However, Bitcoin's continued dominance in the digital asset market has been largely fueled by its PoW system. As a result, there are debates over the rationality of converting Bitcoin into a more energy-efficient mechanism like PoS. Fundamentally, PoW systems are simpler than PoS and other energy-efficient systems since PoWs are facilitated by competition between miners to build onto blockchains and verify transactions, while PoS systems add a degree of complexity in that they select validators to vote in a "stake" in the cryptocurrency to create new blocks. These concerns make non-PoW cryptocurrencies' prone to theft and hacking. A direct effect of public misuse and invalidation of stakes in PoS systems are looming threats of cryptocurrencies' centralization and censorship. By requiring validators to own stakes in cryptocurrency instead of mining it, PoS systems can be readily exploited by big stack players who can censor the voting with their stakes and essentially infinitely increase their stakes, as there is minimal risk of losing the vote (2). As a result, PoS cryptocurrencies may discourage public interest due to the fear of being manipulated and censored by dominant asset pooling.

One way to reduce Bitcoin's energy consumption while maintaining its secure, decentralized public ledger is by modifying the current PoW protocols. This could potentially be achieved by implementing Green-PoW, a "qualification" system in which miners that fail to mine their block first would still be rewarded with a preferred admittance into another round of mining. Normally, only the quickest miner receives the spoils (a block and the associated coin(s)) in PoW systems. Green-PoW's incentivized exclusivity of each round is an attractive option for "losing" miners to repurpose their spent efforts and energy on the upcoming rounds, and the dwindling pool of miners over the course of a few rounds would also reduce both the number of competitors, fork occurrences, and total energy consumption (10).

Another modified version of PoWs is merged mining. Merged mining, or auxiliary PoW, is an energy-efficient algorithm that enables miners to submit previous PoWs on the parent network to validate blocks on the auxiliary network simultaneously (11). Particularly targeted towards Bitcoin mining, merged mining would forgo energy expenditures on the auxiliary networks by reusing the proof from the original Bitcoin network concurrently without hindering mining performance efficiency.

While a modified PoW mechanism might be the best outlook for Bitcoin, other cryptocurrencies are finding success with other validation methods. The energy-efficient cryptocurrency Gridcoin harnesses the power from idle computers connected to its network for scientific research through the Berkeley Open Infrastructure for Network Computing (BOINC). This proof-of-research algorithm rewards users for making scientific and computational contributions. Since Gridcoin's creation in 2013, some projects currently using power from its network include mapping the Milky Way galaxy through the incentives of the MilkyWay@Home project (12).

Additionally, Carboncoin implements a system where its currency is based on the authentication of energy producers emitting carbon to use their carbon assets in investing into greener sources of energy like hydroelectric power (13). Because cryptocurrencies are not limited to a source location (though most current crypto mining locations reside near areas rich in fossil fuels), there are several renewable energy sources that can serve as alternatives. One such example, hydroelectric power, is a dominant renewable energy source in South Mainland China during the wet season, and using it as a source of electricity would drastically reduce the greenhouse gas emissions from crypto mining, as China's flourishing underground cryptocurrency network still boasts the second largest percentage of crypto mining in the world (14). Funneling the generated hydroelectricity into mining cryptocurrency is also desirably energy-efficient if the generated amount is more than what the regional power grid can hold. Instead of letting the unusable leftover energy go to waste, it can be efficiently used in mining cryptocurrency (15). Similarly, the Icelandic crypto mining company Genesis Mining exclusively uses renewable energy and has jumpstarted eco-friendly business models for other crypto mining companies. Another incentivizing route for mining cryptocurrencies is powering the blockchain with real-time renewable energy. SolarCoin is a cryptocurrency that converts each MWh of solar-generated power into one new token, and while its mission to make cryptocurrency a greener asset is desirable, the demand for SolarCoin, and thus the amount of renewable solar energy consumption, could be maximized if there is a limited number of SolarCoins available to crypto owners. This is because its value would appreciate as its supply decreases. Hence, one potential method to encourage renewable energy use to mine cryptocurrencies is to make the 'coin burn' rate directly proportional to the percentage renewable energy used for mining. If power generating resources are finite in some nations, then flared natural gas could be a more reasonable approach. In a "recycling-shaped" way, the natural gas byproducts from oil extraction can be used to generate electricity, or even combusted to further reduce greenhouse gas emissions, and the transformed energy can subsequently be used to mine cryptocurrency (14). This transparency in the origin of cryptocurrency's raw resources is another carbon-reducing solution: targeting the eco-friendliness of supply chain management.

Future Outlook and Conclusion

It is clear that there are several environmental concerns regarding cryptocurrency. New innovations continue to mitigate cryptocurrency's negative environmental impact and progress toward a net-zero carbon outlook. Recently, it has been theorized that quantum computing could reduce crypto mining's electricity usage by as much as ninety percent. Gavin Brennen at al. at Macquarie University have proposed an innovative, more energy-efficient verification of crypto transactions by going quantum. By locating two quantum computers at a close range of photon wavelengths and using boson sampling for measurement, quantum-encrypted cryptocurrency would streamline financial security and energy efficiency between users

on cryptocurrency networks. Quantum computers could be capable of saving an estimated 127 TWh of energy while performing algorithms and computations (16). In a similar dual-purpose proposition, along with Ethereum, Gridcoin, and other new cryptocurrencies like Chia are implementing PoS and proof-of-research-effective protocols to combat the competitive, non-eco-friendly PoW systems, the expansion of carbon credit markets served by cryptocurrencies such as Carboncoin is an area of desirable growth, as it makes governments and companies accountable in reducing their carbon footprints. Tying into accountability, an increased transparency in supply chain management is another eco-friendly factor that could be applied to cryptocurrencies in order to reduce environmental degradation and increase awareness regarding sustainability measures. As cryptocurrency continues to play a more impactful role in our world, the measures to maintain an eco-friendly business outlook serve an even more vital position to save the planet.

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