THE IMPACT OF CRYPTOCURRENCY PRODUCTION ON ENVIRONMENTAL SUSTAINABILITY

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Abstract

This paper explores the environmental implications and energy consumption associated with cryptocurrency mining, with a particular focus on Bitcoin and Ethereum. As digital currencies grow in popularity and adoption, their ecological footprint — especially in Proof-of-Work (PoW) systems — has become a significant global concern. The study reviews existing literature and statistical data to compare the energy use, carbon emissions, and environmental externalities of major cryptocurrencies. Key findings reveal that Bitcoin mining consumes over 120 terawatt-hours of electricity annually, contributing to more than 65 million tons of CO_2 emissions, while also generating substantial electronic waste. In contrast, Ethereum's transition to Proof-of-Stake (PoS) has led to a 99.95% reduction in its energy demand, offering a model for more sustainable blockchain operations. The paper further examines the geographic distribution of mining activities, identifying policy gaps and regulatory responses in countries such as the United States, China, and Kazakhstan. The conclusion underscores the urgent need for coordinated international regulation, environmental taxation, and green innovation to mitigate the hidden costs of crypto mining and align digital finance with sustainable development goals.

Keywords: Bitcoin, Ethereum, mining, cryptocurrency, transaction

Introduction

In recent years, the rapid development of cryptocurrencies—particularly Bitcoin and Ethereum—has sparked intense debates not only within financial and technological circles but also among environmental experts and policymakers. While the decentralized and borderless nature of digital currencies offers several noteworthy benefits, including financial inclusion and transactional efficiency, their environmental impact has become a matter of global concern.

Cryptocurrency mining—particularly systems based on the Proof-of-Work (PoW) consensus mechanism—requires enormous amounts of electricity, which is most often derived from non-renewable energy sources. According to recent estimates, Bitcoin mining alone consumes more energy annually than some smaller nations, such as Argentina or the Netherlands. Such large-scale energy consumption significantly contributes to increased carbon dioxide emissions, thereby exacerbating climate change. This, in turn, is regarded as one of the foremost global challenges of the modern era.

Moreover, the rapid proliferation of digital assets across various industries and investor circles has significantly expanded the scale of mining operations, further intensifying environmental externalities. These impacts include not only greenhouse gas emissions but also electronic waste and water consumption—especially in regions where environmental regulations are weak or nonexistent. In light of the urgent need for global decarbonization and sustainable development, it is essential to critically assess the ecological cost of digital mining.

The aim of this paper is to analyze the environmental consequences of digital mining, determine the amount of energy consumed in the process, and assess the resulting ecological externalities along with potential strategies for their mitigation.

The object of the research is the energy consumption and environmental impact resulting from cryptocurrency mining, with a particular focus on systems based on the Proof-of-Work (PoW) mechanism.

Main Text

In recent years, there has been a significant increase in both academic and practical interest in studying the energy consumption of cryptocurrencies and their impact on the environment. Several studies [1],[2], indicate that Bitcoin mining consumes more energy annually than some developed countries. According to assessments by various experts, Proof-of-Work (PoW) systems are inherently energy-intensive, and their large-scale use substantially increases carbon emissions into the environment.

Nevertheless, the issue remains controversial: some researchers argue that the energy consumption associated with mining may be a temporary phenomenon and that the transition to new technologies—such as Proof-of-Stake—will reduce its ecological impact [3, p399]. Other scholarly works emphasize the localization of mining, particularly the extent to which it depends on a region's energy sources and regulatory environment.

The existing scientific literature remains partial and often fails to provide a comprehensive analysis of environmental externalities, including aspects such as electronic waste, water consumption, and the impact on local ecosystems. Against this backdrop, the need for

in-depth, interdisciplinary analysis becomes increasingly evident.

The exponential growth of digital mining—particularly of cryptocurrencies based on the Proof-of-Work (PoW) mechanism, such as Bitcoin—has led to an unprecedented increase in energy consumption and, consequently, to negative environmental impacts. Although there are competent scientific studies addressing the parameters of energy use, the more complex ecological consequences of this process—such as greenhouse gas emissions, electronic waste, and excessive consumption of natural resources—remain underexplored. This issue is further complicated by the fact that mining activities are often geographically concentrated in regions with weak or ineffective environmental regulations. As a result, the problem lies not only in the high energy demand but also in the absence of sustainable state policies capable of mitigating or even partially restraining such environmental impacts.

In recent years, the energy consumption of cryptocurrencies has become one of the central topics in international academic and practical discourses. One of the most influential sources in this regard is the data provided by the Cambridge Centre for Alternative Finance, which indicates that Bitcoin's annual energy consumption exceeds 100 terawatt-hours (TWh)—a figure higher than the total yearly energy usage of several countries, such as Argentina or Sweden. [4]

Krause and Tolaymat (2018) place particular emphasis on the fact that Bitcoin mining requires extreme computational resources and, as a result, consumes large amounts of non-renewable energy sources—an outcome that directly contributes to climate change trends. [5]

The Digiconomist platform also serves as one of the primary non-commercial sources that continuously tracks Bitcoin's energy efficiency indexes. It highlights the consistently high energy consumption generated by PoW systems, despite ongoing technological advancements.

It is noteworthy that in the case of Ethereum, the transition from a Proof-of-Work to a Proof-of-Stake system—known as "The Merge"—resulted in a significant reduction in energy consumption (by approximately 99%), positioning it as a potential model for sustainable transition. This shift is frequently cited in studies such as Truby (2018). [5] where the author discusses the necessity of regulating blockchain technology in accordance with environmental standards.

Moreover, some scientific studies point out that the methodology for measuring energy consumption remains contentious in many respects, as most assessments are based on estimation models rather than precise, validated data.

The environmental impact of digital mining is highly multifaceted, encompassing not only excessive energy consumption but also greenhouse gas emissions, electronic waste, excessive water usage, and noise pollution. Recent studies and case examples demonstrate that such effects are real and exert significant influence both on the natural environment and on the social conditions of affected communities.

The above-mentioned concerns are supported by concrete data. Specifically, as of 2023, Bitcoin's annual energy consumption was approximately 169.7 terawatt-hours (TWh), exceeding the total yearly energy consumption of the country of Poland.

It is also noteworthy that each Bitcoin transaction generates carbon emissions equivalent to those produced by a gasoline-powered vehicle traveling between 1,600 and 2,600 kilometers.[6]

In 2023, carbon emissions resulting from Bitcoin mining amounted to approximately 65.4 million tons of CO_2, which is comparable to the annual emissions of Singapore.[7]

Moreover, the specialized equipment used for mining—such as ASIC chips—often becomes obsolete prematurely due to rapid technological advancement and continuous high-intensity usage. This contributes to the growing volume of electronic waste and has a negative impact on the environment.

Electronic waste encompasses a broad spectrum of obsolete battery-powered devices, including computers, mobile phones, household appliances, medical instruments, and other equipment. These devices often contain hazardous and toxic substances that pose significant risks to human health, thereby necessitating proper recycling procedures and incurring additional financial and environmental costs.

Obsolete electrical devices, if not properly disposed of, often end up in landfills, where they begin to interact with the surrounding environment. The toxic substances contained in such waste—such as lead, mercury, cadmium, nickel, and many others—can leach into the soil and water, leading to environmental contamination. These toxic pollutants have the capacity to travel significant distances from the original point of pollution, thereby dispersing harmful substances over wide areas and posing serious risks to human health.[8]

Bitcoin mining also requires colossal amounts of water resources for cooling the hardware. According to scientific studies, during the years 2020–2021, the water consumption associated with Bitcoin mining was equivalent to the volume of approximately 660,000 Olympic-sized swimming pools.[9]

Another noteworthy aspect is the negative impact of noise generated during cryptocurrency mining on the social environment and human well-being. For instance, residents of Granbury, Texas, in the United States, were exposed to constant noise from Bitcoin mining farms, which led to various health problems, including insomnia, stress, psychological tension, anxiety, and other related conditions.[10]

Different countries exhibit varying approaches toward cryptocurrency mining. For example:

Today, the United States serves as a global hub for Bitcoin mining. The primary reasons for this include relatively low electricity costs and favorable government regulations. For instance, mining farms in the state of Texas benefit from access to cheap electricity, which is at times significantly lower than residential energy rates.[10]

In 2025, President Trump signed an executive order titled *"Strengthening American Leadership in Dig-*

ital Financial Technology", aimed at promoting cryptocurrency mining and reinforcing the United States' leadership in the field of digital financial technologies..

In addition, the Trump administration established a strategic Bitcoin reserve aimed at strengthening the role of cryptocurrency within the U.S. financial system

Kazakhstan has become the second-largest country in Bitcoin mining. Similar to other major mining hubs, it benefits from relatively cheap electricity, which is primarily generated from coal. However, the increasing energy consumption has led to power shortages, prompting the government to tighten regulations periodically. For instance, in 2024, authorities shut down 36 unlicensed cryptocurrency exchange platforms in an effort to reduce energy usage and improve sectoral transparency. Since 2023, the *Law on Digital Assets* has been in force, establishing licensing requirements for cryptocurrency mining and exchange activities. Mining companies are now obligated to comply with customer identification procedures and adhere to anti–money laundering (AML) and counter–terrorism financing (CTF) standards..[11]

Since 2023, the Kazakhstani government has begun offering subsidies to mining farms that transition to renewable energy sources or adopt energy-efficient practices. These incentives are provided through tax reductions as well as co-financing of technological investments, such as energy-efficient cooling systems.

In 2021, China banned cryptocurrency mining and trading, citing financial risks and environmental concerns. In 2024, the country's monetary regulator issued new regulations requiring banks to strengthen the monitoring of cryptocurrency-related transactions and to block operations deemed high-risk.

In Russia, cryptocurrency mining is primarily concentrated in certain regions of Siberia, where hydropower resources are relatively abundant. However, during the winter months, increased energy consumption leads to electricity shortages, prompting local authorities to impose temporary bans on mining activities during these periods.

In Kuwait, where electricity is heavily subsidized by the state, cryptocurrency mining operations have led to a sharp increase in energy consumption. As a result, the government initiated a crackdown on illegal mining activities, leading to a 55% reduction in electricity usage in the city of Al-Wafra..[12]

As in many countries around the world, digital economy is becoming increasingly popular in Georgia as well. According to data from the end of 2025, the cryptocurrency mining sector in the country has reached unprecedented levels, with its energy consumption surpassing that of major industries such as steel production and Georgian Railways.

This trend is closely linked to the rising price of Bitcoin, which has currently reached a historic high—hovering around $100,000—and continues to exhibit an upward trajectory. In 2024, Georgia recorded server hardware imports totaling $115 million, nearly four times higher than in previous years.

In the first quarter of 2025, mining companies operating in Georgia consumed a total of 187 million kilowatt-hours of electricity. For comparison, this figure is 7.5 times higher than that of the same period in the previous year, indicating exponential growth within the sector. It is also noteworthy that the majority of mining equipment is concentrated in the country's free industrial zones, which exempts their owners from most tax obligations.[13]

Conclusion

- Mining operators are constantly seeking regions with relatively low energy costs and favorable regulatory environments. However, as energy consumption increases, governments tend to tighten regulations, prompting miners to either relocate to other regions or adopt new sources of renewable energy—particularly green energy projects, such as those utilizing volcanic power.
- Despite the fact that some countries have adopted strict measures to regulate digital mining, there is still no unified approach at the global level. Therefore, it is essential to develop international standards that enhance transparency, enable accurate assessment of environmental impacts, and promote the advancement of environmentally sustainable technologies.
- In order to encourage the transition to renewable energy sources, high-emission mining farms should be subject to substantial carbon taxes—effectively enforcing the "polluter pays" principle in practice.
- With its low energy tariffs, tax incentives, and geostrategic location, Georgia presents an attractive platform for the global crypto industry. However, in the long term, it is essential to maintain an optimal balance between economic benefits and energy stability.
- Future research should focus on a comprehensive analysis of the environmental impact of mining, the evaluation of new technological alternatives, and the development of strategies that align the growth of the digital economy with environmental sustainability.

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