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# WHICH FACTORS CAN EXPLAIN THE CORRELATION BETWEEN CRYPTOMINING ACTIVITIES AND ENVIRONMENTAL IMPACT? A THEORETICAL ANALYSIS

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**Abstract.** In 2021, a massive relocation of cryptocurrency mining farms from China to Kazakhstan caused one of the largest energy crises in Asia and Europe. This work aims at an understanding of the current debate of cryptocurrency mining activities on the environment. The review highlights: 1. The existence of a positive relationship between cryptomining activities and the deterioration of environmental quality; 2. The contribution of renewable energies and blockchain algorithms to mitigate the above effects. Main results suggest the need for a supranational institution to monitor the current cryptocurrency production to complement current policies by the European Commission and United Nations.

**Keywords:** cryptocurrency, environmental impact, cryptomining activities, carbon footprints, blockchain technology.

**JEL Classification:** E02, F6, P18.

## Introduction

The main purpose of this theoretical analysis is to investigate the current debate of cryptocurrency mining activities on the environment. In addition, since the above activities rely on blockchain technology, the present paper also touches the endogenous effects of Blockchain technology on the environment through cryptocurrency mining production.

Energy consumption of cryptocurrencies is a growing concern (Lansky, 2019; An et al., 2020; De Vries, 2020; Badea & Mungiu-Papazan, 2021). The latest trend by the Cambridge Bitcoin Electric Consumption Index (Cambridge Centre for Alternative Finance [CBECI], n.d.-a) show that these activities require a significant amount of electricity. The data provided by the CBECI are supported, among others, by the analysis of Bondarev (2020), and the methodology to map Bitcoin mining has proved reliable despite its limitations.

The high energy consumption provides a significant impact on the environment, as cryptocurrency mining is often powered by non-renewable energy sources such as coal or natural gas (Wendl et al., 2023). Additionally, cryptocurrency mining requires the use of specialized hardware, which can be expensive and difficult to dispose of Bondarev (2020), De Vries et al. (2022).

At international level, there exists a lack of shared regulations and policies to limit the environmental impact caused by cryptomining activities (Wang et al., 2022). Such situation is fundamental for a rethinking of the role of international institutions able to guarantee the sustainability of the cryptocurrency mining (Truby, 2018; Lansky, 2019). The regulatory issue is widely debated for the significant impact caused on the environment, security, and stability of the cryptocurrency market (Baek & Elbeck, 2014; Goodkind et al., 2020; Yan et al., 2022).

Furthermore, beyond the purely juridical and economic-political sphere, blockchain technology is a core issue underlying the functioning of cryptocurrencies (Chaum, 1983; Crosby et al., 2016). The Proof of Work (PoW) was the first consensus algorithm used on blockchain other than ensuring the security of Bitcoin (Nakamoto, 2008). Therefore, current challenges from blockchain technologies for cryptocurrency mining production are also important aspects to deepen the investigation on the effects of cryptocurrency mining

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on the environment (Narayanan et al., 2016; Krause & Tolaymat, 2018; Lamba, 2022).

The remainder of the paper is structured as follows: Straightforward, we illustrate the methodology used for selecting the relevant literature; Section 1 delves into the literature on the environmental impact caused by the use of blockchain technology in cryptomining activities; Section 2 reports the main econometric models and indexes currently in the spotlight of the international debate; Section 3 describes main environmental impacts evidence with a focus on the massive relocation of cryptocurrency mining farms from China to Kazakhstan; finally, the last section concludes, illustrates some limitations and provides useful insights for further research.

## 1. Methodology

To set up the research, we used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology, so as to have a minimum amount of evidence to rely on during the analysis. Also, we used Mendeley software to identify and select the relevant literature and employed proper keywords to facilitate the screening process. In a subsequent step, we considered an in-depth reading of selected papers to better analyse the context of the debate.

We used the query "Cryptocurrency AND Environmental impact" and considered the following selection to retrieve relevant articles:

Identification: We reviewed Scopus and Mendeley as main databases and found 275 articles. We dropped 44 duplicated papers. In addition, we removed 121 records which were either not eligible, or not in line with the focus of this work. A total of 110 papers were then available for the subsequent phase.

Screening: At this stage we proceeded to remove all works considering local or national dynamics (n = 13), or that did not provide significant data according to the context of this literature review (n = 8). In doing so, the sample was reduced to 89 records.

Inclusion: After further revision, scientific articles providing methods, data and information already included in previously observed articles (n = 19), as well as articles reporting dubious or outdated evaluation methods (n = 10) and works related to different disciplinary fields (n = 19) were excluded from the analysis; all the remaining works related to the obtained database comprised 41 items. Finally, we also considered 10 additional records included in the reference section of the above remaining paperworks. The final sample contains 51 items.

## 2. Theoretical insights from the literature: the blockchain technology and its environmental impact

One of the main issues related to cryptomining activities are the algorithms employed by blockchain technology for energy savings. In particular, the transitioning from energy-intensive "Proof-of-Work" (PoW) algorithm to more efficient "Proof-of-Stake" technologies (Swan, 2015; Starceva & Cheklaukova, 2020).

When using PoW, users generally solve a complex mathematical puzzle to validate transactions and earn a cryptocurrency reward. This process requires a significant amount of power and electrical energy, as cryptominers compete against each other to solve the puzzle before other cryptominers. Bitcoin is the most well-known cryptocurrency that adopted the PoW algorithm. With the Proof of Stake (PoS), users "stake" their cryptocurrencies to earn the right to validate transactions and create new blocks. Therefore, those users holding a large amount of cryptocurrency have a greater chance of being selected to validate transactions and earn the cryptocurrency reward. Ethereum is a famous cryptocurrency adopting the PoS algorithm. One of the main differences between PoW and PoS is that the former is more energy intensive than the latter, since the process of selecting validators is randomly performed by PoS. Additionally, PoS is generally considered more efficient than PoW since it requires fewer hardware resources and a lower amount of electrical energy to operate. This means that cryptocurrencies using PoS have a lower environmental impact than those using PoW (Bach et al., 2018).

The work of Cao et al. (2020) compares the performance of PoW, PoS, and Directed Acyclic Graph (DAG) based blockchains. The analysis revealed that PoW-based blockchain is energy intensive compared to the others. Instead, DAG-based blockchains demonstrated high throughput and low energy consumption. In addition, the DAG technology is a consensus methodology based on the concept of "Tangle", where blocks are validated in a non-sequential and parallel way. This technique has been used by the IOTA cryptocurrency and presents several advantages, such as greater scalability and energy efficiency compared to PoW and PoS (Cao et al., 2020).

Wendl et al. (2023) examine the environmental impact of cryptocurrencies using PoW and PoS consensus algorithms. The authors identify several factors contributing to assess the differences between PoW and PoS consensus algorithms in terms of environmental impacts. These include the computing power required for mining, block creation time, block size, reward system, and network security. Main limitations and challenges associated with using PoS consensus algorithms, include the risk of centralization and the potential for network attacks. The authors suggest that PoS consensus algorithms may offer a more sustainable alternative to PoW in terms of energy consumption and carbon footprint. However, the authors also emphasize the need for further research to understand the implications of PoS consensus algorithms on security and decentralization of cryptocurrency networks (Wendl et al., 2023).

Košťál et al. (2018) examine the transition from PoW to PoS consensus algorithm. Their work took into account pros and cons of both consensus algorithms and assessed the implications of transitioning to PoS. For example, the transition process should be accurately managed to ensure no data loss or security breaches. Additionally, the transition could result in a change in the distribution of cryptocurrency ownership, which could impact market prices (Iwamura et al., 2019). The paper by Koštál et al. (2018) suggests that the transition from PoW to PoS should be gradually and predictably managed; in particular, network nodes should be informed in advance about the transitioning process and the possible changes that may occur during this process. Additionally, a clear roadmap should be provided specifying the timing and details of the transition.

Alahmad et al. (2018) compare PoW and PoS examining the differences in terms of security, efficiency, and sustainability. The results showed that PoS would not require as much processing power as PoW. Also, PoS is more scalable than PoW, as adding new nodes to the network would not require an excessive amount of resources. In terms of environmental sustainability, PoS is clearly more profitable than PoW, as it requires much less electricity for mining activities.

Lepore et al. (2020) conduct a review of blockchain-based consensus systems, examining various consensus algorithms such as PoW, PoS, and Pure PoS used by the "Algorand" blockchain. Their work examines the performance of these consensus algorithms in terms of transaction speed, security, and scalability. Main results showed that PoW is the most secure among the examined consensus algorithms; while it is the most expensive and least efficient in terms of transaction speed. PoS and Pure PoS, on the other hand, are more efficient and less expensive than PoW, but can be less secure due to lack of incentives for validators (Lepore et al., 2020).

Kohli et al. (2022) analyse the required energy consumption and carbon footprint of cryptocurrencies and proposed some solutions to address these issues such as the use of the DAG technology. Another proposed solution is the use of renewable energy such as solar or wind energy to provide power to cryptocurrency mining activities. However, the use of renewable energy can be costly and would require specific infrastructures (Kohli et al., 2022).

Lasla et al. (2022) propose Green-PoW, a PoW consensus algorithm for blockchain using a more energy-efficient approach. This would reduce energy consumption, without compromising security and decentralization of the network. The proposed Green-PoW algorithm uses a hybrid approach, combining traditional PoW technology with machine learning techniques to reduce energy consumption associated with the mining activity. In particular, this technology is based on the use of an artificial neural network (ANN) to predict the probability of mining success in order to limit the required computing power. The effectiveness of the proposed algorithm is assessed through simulations and comparisons with the traditional PoW protocol. Main results show that Green-PoW can reduce mining energy consumption up to 50% compared to the traditional PoW protocol. The advantage of this technology is that it can be used by existing PoW systems, without the need to switch to PoS or similar consensus (Lasla et al., 2022).

In terms of financial issues, Milunovich (2022) assesses the relationship between PoW and PoS in different cryptocurrencies and shows that these two modes of consensus are related but not interchangeable. The author analyse data related to cryptocurrency prices between 2013 and 2021. Main results show that PoW and PoS cryptocurrencies have a significant relationship, meaning that price variations across cryptocurrencies are correlated. In addition, the author argue that PoS cryptocurrencies have a stronger connection than PoW cryptocurrencies. To avoid price volatility, a portfolio differentiation is also advised (Klein et al., 2018; Pham et al., 2022).

Further innovation for implementing cryptocurrency technology is proposed by Xu et al. (2021) with the introduction of a new consensus mechanism called Proof of Engagement (PoE). This mechanism aims to overcome some of the limitations of existing solutions. PoS was originally designed to cope with the problem of energy consumption. PoE, on the other hand, reduces energy consumption and weakens the absolute control of full-time miners and mining pools over the blockchain network.

However, this leads to a negative secondary effect where the "rich" gets richer and earns more profits compared to the remaining investors. A non-competitive market can then be effectively realised, thus reducing the incentive of the system to attract new "miners" (Xu et al., 2021).

## 3. Environmental impact indexes from the literature

### 3.1. Most shared econometric models and indexes

Most of the recent literature (Vranken, 2017; Wang et al., 2022) is based on the econometric model used by Marc Bevand (2017), and subsequently developed by the Cambridge Centre for Alternative Finance (CBECI, n.d.-b). The developed index provides the possibility of carrying out inference related to the total emissions of Greenhouse Gas (GHG) due to the cryptomining activity – with reference to the Bitcoin currency only.

According to several studies (Stoll et al., 2019; De Vries, 2020; Gallersdörfer et al., 2020; Jiang et al., 2021) and in line with the CBECI methodology, local differences can be included in the carbon intensity of the power mix by differentiating among regions. Starting from this data, as well as from IP pool addresses, it is possible to define the shared quota per region based on the geographical distribution of the involved pools.

Furthermore, other studies (Kamal & Hassan, 2022; Ren & Lucey, 2022; Wang et al., 2022), proposed a cryptocurrency environmental attention index (ICEA) to capture the economic phenomenon in terms of cryptocurrency response to major related events (Baker et al., 2016; Corbet & Yarovaya, 2020; Ghosh & Kumar, 2021; Lucey et al., 2021). This index scales raw data from the observed total number of articles in the same publication source at the same time; ICEA is based on the vector error correction model (VECM) and structural VECM (SVECM) – impulse response function (IRF); forecast error variance decomposition (FEVD) and historical decomposition (HD) are useful for characterizing the dynamic relationships between ICEA and aggregate economic activities (Wang et al., 2022).

### 3.2. Limitations of models and indexes

The literature agrees in attributing certain limitations to the above models, as these depend on the analysis of proxy data and factors. As for the model developed by CBECI, this is generally validated through the identification of IP addresses and the distribution and intensity of the levels of distributed hash rates. The latter are necessary to map the mining activities.

The use of proxy data also affect the environmental component such as emissions, electricity demand and related GHG emissions. In addition, these factors limit the consequent approximation of historical intervals (e.g., countries adopting protectionist economic policies, such as China).

On the other hand, the robustness check carried out by Wang et al. (2022) for the UCRY model limits the econometric model to the use of Bitcoin only, whereas the impact of ICEA on IP is significantly positive in the short rather than the long term. However, this index does not allow inferences to be made regarding the correlation between the uncertainty of the price of cryptocurrencies and the environmental impact generated by the cryptomining activities. For these reasons it is a useful index for assessing the market trend, and the strategies and policies to be implemented (Corbet et al., 2021). In addition, the construction of the ICEA is based on data provided by a third-party database, other than presenting high volatility of the cryptocurrency in question.

## 4. Evidence of the environmental impact of cryptomining activities from the literature: a theoretical analysis

### 4.1. Carbon footprints of cryptomining activities

In general, the indexes mentioned in the previous section highlight a strong correlation between cryptomining activities and environmental pollution. Wendl et al. (2023) and several recent studies (Stoll et al., 2019; Li et al., 2019; An et al., 2020; Gallersdörfer et al., 2020; Chen & Xu, 2022; Badea & Mungiu-Papazan, 2021; De Vries et al., 2022), agree that cryptocurrency mining requires a significant amount of electricity from different sources.

Figure 1 shows that main electricity sources for Bitcoin generation derive from coal or natural gas (Digiconomist, n.d.); Below, similar results are observable in terms of carbon footprint (Figure 2).

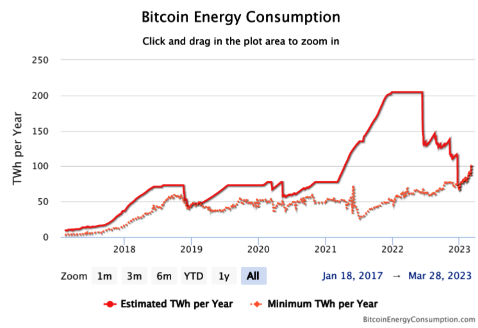


Figure 2. Bitcoin energy consumption (source: Digiconomist, n.d.)

Surprisingly, the carbon footprint and the consumption of electricity and waste from electronic equipment is the equivalent of 2,791,925 VISA transactions or 209,950 hours of viewing videos on YouTube,

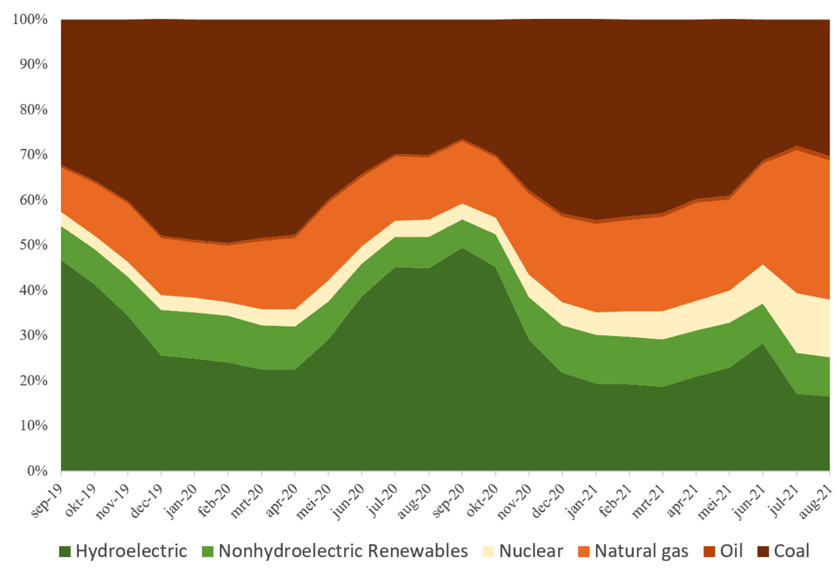


Figure 1. Electricity sources of the Bitcoin network over time (source: Digiconomist, n.d.)

respectively (De Vries et al., 2022). This is similar to the energy consumption of an average American family in 77.41 days or the weight of 2.17 iPhone 12s or 0.73 iPads (Digiconomist, n.d.).

This scenario allows us to highlight the technological environment in which cryptomining activities take place. An illustration is provided in the next section.

### 4.2. Empirical evidence from a case study: the relocation of Chinese mining farms to Kazakhstan

A previous research work (Basile, 2022) highlighted the relationship between macro-economic variables and cryptomining activities and their effects on GHG emissions. Whereas, other debate focused on regulatory aspects and cryptomining activities in Kazakhstan (Zakon, 1995, 2016, 2018; Ashimbayev & Tashenova, 2018; Cvetkova, 2018; Chudinovskikh & Sevryugin, 2019). As for the former, the analysis can refer to the Kazakh case where several Chinese cryptomining activities moved due to relocation.

On June 21, 2021, the People's Bank of China (PBOC), under pressure from the Beijing government, enforced repressive legislation against cryptocurrency mining activities. The aim was to reduce the risks of illegal cross-border transfers of illegal assets and activities such as money laundering – e.g., the PRC was the global leader of cryptomining activities (Syzdykova & Zhetibaev, 2020; Riley, 2021). In particular, the provinces of Sichuan and Xinjiang were the leaders in the sharing of the hashrate. Whatever the PRC government's goals, this event triggered the phenomenon described as the "great migration of mining" to countries where energy prices are among the lowest in the world, particularly in southern United States and Kazakhstan.

Now, let us consider the data computed from the CBECI through the econometric model cited in the previous section. Below, three tables depict the evolution of mining (e.g., hashrate levels) in Kazakhstan, the PRC, and the USA before and after the vetoes promoted by the PRC, starting from September 2019 until August 2021 (two months after the suppression of mining promoted by the PRC). We carry out this choice since the USA and Kazakhstan became major cryptomining producers after the repressive legislation adopted by the PRC.

The absolute hash level shown in Table 1, highlights a notable increase in Kazakhstan starting from June 2021. Table 2 highlights significant figures in terms of the average monthly share of hash rates by country; according to the CBECI, in August 2021, Kazakhstan is the second country worldside after the USA (USA = 35.40%; Kazakhstan = 18.10%).

Beyond bitcoins, recent 2021 data for the global distribution of mining energy is only partially available, but past figures (Table 3) show that 65% to 75% of the world's bitcoin mining has taken place in China, mainly in four Chinese provinces: Xinjiang, Inner Mongolia, Sichuan, and Yunnan. Hydropower in Sichuan and Yunnan can be considered as renewable energy pivot, while Xinjiang

Table 1. Evolution of the hashrate network (Eh/s) (source: CBECI database, n.d.-a, n.d.-b)

| | Evolution of network hashrate (Eh/s) | | |
|---|---|---|---|
| | PRC | USA | Kazakhstan |
| September 2019 | 66.8 | 3.6 | 1.3 |
| September 2020 | 91.1 | 9.6 | 5.5 |
| August 2021 | 0.0 | 42.7 | 21.9 |

Table 2. Evolution of country share (%) (source: CBECI database, n.d.-a, n.d.-b)

| | Evolution of country share (%) | | |
|---|---|---|---|
| | PRC | USA | Kazakhstan |
| September 2019 | 75.5 | 4.1 | 1.4 |
| September 2020 | 67.1 | 7.1 | 4.1 |
| August 2021 | 0.0 | 35.4 | 18.1 |

Table 3. Evolution of Chinese province production share on an annual basis (source: CBECI database, n.d.-a, n.d.-b)

| | Evolution of Chinese province shares (%) | | |
|---|---|---|---|
| | September2019 | September2020 | August 2021 |
| Sichuan | 49.5 | 61.1 | 0.0 |
| Xinjiang | 19.1 | 9.6 | 0.0 |
| Yunnan | 13.5 | 14.9 | 0.0 |

and Inner Mongolia are home to many of China's coal-fired power plants. In addition, data are unstable, as miners move from one Chinese region to another to benefit from abundant electricity at competitive or lower market prices.

Figure 3 shows the impact of mining farm relocation on real GDP in the service sector – which includes cryptomining activities (World Bank, n.d.).

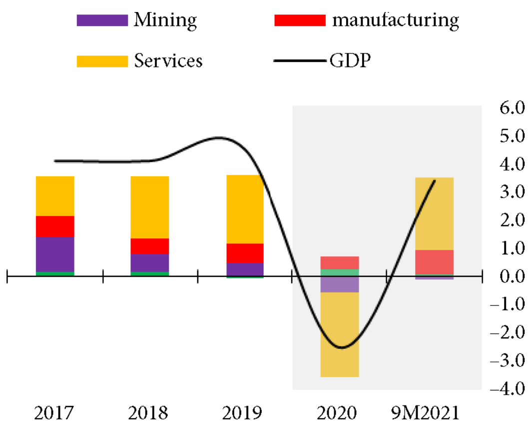


Figure 3. Kazakhstan main economic activities 2017–2021 (World Bank, n.d.)

Between the end of 2020 and the first nine months of 2021, an increase of 3 points in the service sector after the pandemic event was recorded (Figure 3). On the other hand, the most interesting data is that relating to real GDP.

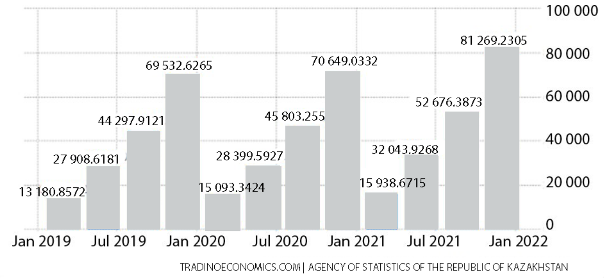


Figure 4. Kazakhstan's real GDP (Jan. 2019 – Jan. 2022) (source: World Bank, n.d.)

In terms of real GDP, this increased to 81269.23 KZT Billion in the fourth quarter of 2021, sharping from 52676.39 KZT Billion in the third quarter (Figure 4). The GDP deflator, on the other hand, decreased by 4 points in 2020 compared to the previous year (Trading economics, n.d.). Nonetheless, if we compare the above information with data provided by CBECI, we can argue that the recovery period was mainly due to an increase in the mining activity than the impact of the real economy in the country.

This result is also corroborated by the levels of GHG emissions, which show a substantial increase in the considered period. Kazakhstan is highly dependent on aging coal-fired electricity plants, which supply about 70% of the country's electricity compared to 37% globally (International Energy Agency [IEA], n.d.). According to the Global Petrol Prices database (n.d.), in June 2021, the average price of electricity in Kazakhstan was USD 0.049 per kWh. This is much lower compared to the world price of USD 0.137 per kWh which contributed to relocating cryptomining farms from the bordering Chinese provinces.

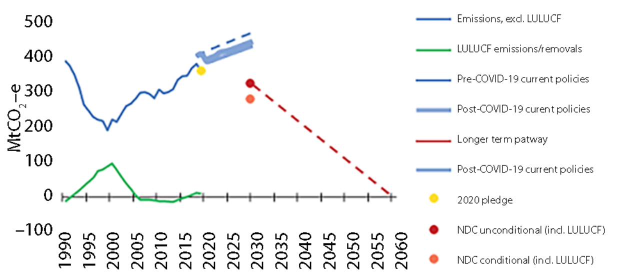


Figure 5. Kazakhstan's emissions forecast (1990–2060) (source: World Bank, n.d.)

As it can be observed in Figure 5, 2019 Kazakhstan's emissions (excl. LULUCF) were in the figure of 355 Mt $CO_2$-eq (World Bank, n.d.). This makes the country one of the highest emitters regionally and among the top-20 globally.

## 5. Discussion

### 5.1. Results

The present work provided a theoretical analysis for cryptomining activities and their environmental impacts in terms of GHG emissions and energy use. The investigation also provided evidence of main modelling approaches used in the literature, with particular reference to the Kazakh case.

The investigation allows us to reflect upon the following points: firstly, the use of inferential models is based on assumptions and error biases (Stoll et al., 2019; De Vries et al., 2022).

Secondly, several studies identified the absence of a supervisory governmental body – at state or international level – capable of guaranteeing a certain stability of exchange rates, environmental sustainability and energy safety (Mora et al., 2018; Lansky, 2019; Khan et al., 2020). The absence of supranational organizations monitoring cryptomining activities, might also cause the rise of further "Kazakh" cases worldwide (Financial Action Task Force, 2014; Cvetkova, 2018; Ashimbayev & Tashenova, 2018; Chudinovskikh & Sevryugin, 2019; Sagymbekov, 2020).

### 5.2. Limitations of the research

This research is not without limitations: firstly, we used only two international scientific databases such as Scopus and Mendeley. Nonetheless, since these belong to Elsevier, this guarantees an acceptable level of coverage. Secondly, the preliminary nature of the present work prevented us to include further studies in the considered sample, particularly the works showing potential closeness of contents among each other.

## Conclusions and further implications

The main results suggest the need for a supranational organization with the aim of codifying a common international legislation, to avoid the proliferation of energy and political crises such as the Kazakh one. Therefore, cryptocurrency mining activities, if not properly regulated in the long term, may present socio-economic and policy risks for real economies at national and/or international level. We argue about the need of a common international legislation, thus reinforcing the efforts already made by the international community to counterbalance potential energy price volatility and market competition.

In terms of actual cryptomining technologies, PoW and PoS may trace a path towards energy transition and energy democracy processes as advocated by the United Nations. Despite skepticism and limitations, the UN strategy converges on the need for implementing effective energy policies in the short and long term as highlighted in the 2030 Agenda for Sustainable Development and the latest COP 27. A similar view is also advocated by the European Union with regard to the adoption of the Green Deal strategy. Future research concerning the achievement of the proposed objectives in relation to the energy transition in cryptomining activities would provide useful insights to the current international debate on energy safety, regulation and cryptocurrencies.

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## Author contributions

GB designed the research methodology, data collection and description of the literature, conclusion and policy implications. AP contributed to data collection and description of the literature. PP and CDL provided revision and supervision to the manuscript.

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## Disclosure statement

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## References

Alahmad, M. A., Al-Saleh, A., & AlMasoud, F. A. (2018). Comparison between PoW and PoS systems of cryptocurrency. *Indonesian Journal of Electrical Engineering and Computer Science*, *10*(3), 1251–1256. https://doi.org/10.11591/ijeecs.v10.i3.pp1251-1256

An, J., Dorofeev, M., & Zhu, S. (2020). Development of energy cooperation between Russia and China. *International Journal of Energy Economics and Policy*, *10*(1), 134–139. https://doi.org/10.32479/ijeep.8509

Ashimbayev, T., & Tashenova, S. (2018). Prospects for using cryptocurrency in the economy of Kazakhstan and the attitude of the National Bank. *European Research Studies Journal*, *21*(4), 524–532. https://doi.org/10.35808/ersj/1140

Bach, L., Mihaljevic, B., & Zagar, M. (2018). Comparative analysis of blockchain consensus algorithms. In *41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*. IEEE. https://doi.org/10.23919/MIPRO.2018.8400278

Badea, L., & Mungiu-Pupazan, M. (2021). The economic and environmental impact of bitcoin Bitcoin. *IEEE Access*, *9*, 48091–48104. https://doi.org/10.1109/ACCESS.2021.3068636

Baek, C., & Elbeck, M. (2014). Bitcoins as an investment or speculative vehicle? A first look. *Applied Economics Letters*, *22*(1), 30–34. https://doi.org/10.1080/13504851.2014.916379

Baker, S. R., Bloom, N., & Davis, S. J. (2016), Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, *131*(4). https://doi.org/10.1093/qje/qjw024

Basile, G. (2022). A discussion on the Kazakh energy crisis of 2021: The role of cryptocurrency mining factories and the environmental implications. In *12th International Scientific Conference: Business and Management*, Vilnius, Lithuania. Article Number bm.2022.936. https://doi.org/10.3846/bm.2022.936

Bevand, M. (2017, February 1). Serious faults in Digiconomist's Bitcoin Energy Consumption Index. *Blog.* http://blog.zorinaq.com/serious-faults-in-beci/

Bondarev, M. (2020). Energy consumption of Bitcoin mining. *International Journal of Energy Economics and Policy*, *10*(4), 525–529. https://doi.org/10.32479/ijeep.9276

Cambridge Centre for Alternative Finance. (n.d.-a). *Cambridge Bitcoin Energy Consumption Index (CBECI). Methodology*. https://ccaf.io/cbeci/mining_map/methodology

Cambridge Centre for Alternative Finance (n.d.-b). *Cambridge Bitcoin Energy Consumption Index (CBECI) – CCAF Digital Tools.* https://ccaf.io/cbeci/mining_map/methodology

Cao, B., Zhang, Z., Feng, D., Zhang, S., Zhang, L., Peng, M., & Li, Y. (2020). Performance analysis and comparison of PoW, PoS and DAG based blockchains. *Digital Communications and Networks*, *6*(4), 480–485. https://doi.org/10.1016/j.dcan.2019.12.001

Chaum, D. (1983). Blind signatures for untraceable payments. In *Advances in Cryptology – CRYPTO'82* (pp. 199–203). Springer. https://doi.org/10.1007/978-1-4757-0602-4_18

Chen, H., & Xu, C. (2022). The impact of cryptocurrencies on China's carbon price variation during COVID-19: A quantile perspective. *Technological Forecasting and Social Change*, *183*, 121933. https://doi.org/10.1016/j.techfore.2022.121933

Chudinovskikh, M., & Sevryugin, V. (2019). Cryptocurrency regulation in the BRICS countries and the Eurasian Economic Union. *BRICS Law Journal*, *6*(1), 63–81. https://doi.org/10.21684/2412-2343-2019-6-1-63-81

Corbet, S., & Yarovaya, L. (2020). The environmental effects of cryptocurrencies. In *Cryptocurrency and blockchain technology*. De Gruyter. https://doi.org/10.1515/9783110660807-009

Corbet, S., Lucey, B., & Yarovaya, L. (2021). Bitcoin-energy markets interrelationships – New evidence. *Resources Policy*, *70*, 101916. https://doi.org/10.1016/j.resourpol.2020.101916

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation*, *2*(6–10).

Cvetkova, I. (2018). Cryptocurrencies legal regulation. *BRICS Law Journal*, *5*(2). https://doi.org/10.21684/2412-2343-2018-5-2-128-153

De Vries, A. (2020). Bitcoin's energy consumption is underestimated: A market dynamics approach. *Energy Research and Social Science*, *70*, 101721. https://doi.org/10.1016/j.erss.2020.101721

De Vries, A., Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2022). Revisiting Bitcoin's carbon footprints. *Joule*, *6*(3), 498–502. https://doi.org/10.1016/j.joule.2022.02.005

Digiconomist. (n.d.). *Bitcoin energy consumption index.* https://digiconomist.net/bitcoin-energy-consumption

Financial Action Task Force. (2014, June). *Virtual currencies – Key definitions and potential AML/CFT*. https://www.fatf-gafi.org/en/publications/Methodsandtrends/Virtual-currency-definitions-aml-cft-risk.html

Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2020). Energy consumption of cryptocurrencies beyond bitcoin. *Joule*, *4*(9), 1843–1846. https://doi.org/10.1016/j.joule.2020.07.013

Ghosh, T., & Kumar, S. (2021). The effectiveness of macro-prudential policies in the face of global uncertainty – the role of exchange-rate regimes. *Finance Research Letters*, *46*, 102358. https://doi.org/10.1016/j.frl.2021.102358

Global Petrol Prices. (n.d.). *Kazakhstan electricity prices*. https://it.globalpetrolprices.com/Kazakhstan/electricity_prices/

Goodkind, A. L., Jones, B. A., & Berrens, R. P. (2020). Cryptodamages: Monetary value estimates of the air pollution and human health impacts of cryptocurrency mining. *Energy Research and Social Science*, *59*, 101281.
https://doi.org/10.1016/j.erss.2019.101281

International Energy Agency. (s.d.). *Kazakhstan*. https://www.iea.org/countries/Kazakhstan

Iwamura, M., Kitamura, Y., Matsumoto, T., & Saito, K. (2019). Can we stabilize the price of a cryptocurrency? Understanding the design of Bitcoin and its potential to compete with Central Bank money. *Hitotsubashi Journal of Economics*, *60*(1), 41–60.

Jiang, S., Li, Y., Lu, Q., Hong, Y., Guan D., Xiong, Y., & Wang, S. (2021). Policy assessments for the carbon emission flows and sustainability of Bitcoin blockchain operation in China. *Nature Communications*, *12*, 1938.
https://doi.org/10.1038/s41467-021-22256-3

Khan, M. K., Khan, M. I., & Rehan, M. (2020). The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. *Financial Innovation*, *6*, 1. https://doi.org/10.1186/s40854-019-0162-0

Klein, T., Pham Thu, H., & Walther, T. (2018). Bitcoin is not the new gold – a comparison of volatility, correlation, and portfolio performance. *International Review of Financial Analysis*, *59*, 105–116. https://doi.org/10.1016/j.irfa.2018.07.010

Kamal, J. bin, & Hassan, M. K. (2022). Asymmetric connectedness between cryptocurrency environment attention index and green assets. *Journal of Economic Asymmetries*, *25*, e00240. https://doi.org/10.1016/j.jeca.2022.e00240

Kohli, V., Chakravarty, S., Chamola, V., Sangwan, K. S., & Zeadally, S. (2022). An analysis of energy consumption and carbon footprints of cryptocurrencies and possible solutions. *Digital Communications and Networks*, *9*(1), 79–89.
https://doi.org/10.1016/j.dcan.2022.06.017

Koštál, K., Krupa, T., Gembec, M., Vereš, I., Ries, M., & Kotuliak, I. (2018, September). On transition between PoW and PoS. In *Proceedings Elmar – International Symposium Electronics in Marine*. IEEE.
https://doi.org/10.23919/ELMAR.2018.8534642

Krause, M. J., & Tolaymat, T. (2018). Quantification of energy and carbon costs for mining cryptocurrencies. *Nature Sustainability*, *1*, 711–718.
https://doi.org/10.1038/s41893-018-0152-7

Lamba, A. (2022). Are carbon offsets the key to green cryptocurrencies? *PLOS Sustainability and Transformation*, *1*(3), e0000002. https://doi.org/10.1371/journal.pstr.0000002

Lansky, J. (2019). Possible state approaches to cryptocurrencies. *Journal of Systems Integration*, *98*(1).

Lasla, N., Al-Sahan, L., Abdallah, M., & Younis, M. (2022). Green-PoW: An energy-efficient blockchain Proof-of-Work consensus algorithm. *Computer Networks*, *214*, 109118.
https://doi.org/10.1016/j.comnet.2022.109118

Lepore, C., Ceria, M., Visconti, A., Rao, U. P., Shah, K. A., & Zanolini, L. (2020). A survey on blockchain consensus with a performance comparison of pow, pos and pure pos. *Mathematics*, *8*(10) 1782. https://doi.org/10.3390/math8101782

Li, J., Li, N., Peng, J., Cui, H., & Wu, Z. (2019). Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. *Energy*, *168*, 160–168. https://doi.org/10.1016/j.energy.2018.11.046

Lucey, B. M., Vigne, S. A., Yarovaya, L., & Wang, Y. (2021). The cryptocurrency uncertainty index. *Finance Research Letters*, *45*, 102147. https://doi.org/10.2139/ssrn.3805891

Milunovich, G. (2022). Assessing the connectedness between Proof of Work and Proof of Stake/Other digital coins. *Economics Letters*, *211*, 110243.
https://doi.org/10.1016/j.econlet.2021.110243

Mora, C., Rollins, R. L., Taladay, K., Kantar, M. B., Chock, M. K., Shimada, M., & Franklin, E. C. (2018). Bitcoin emissions alone could push global warming above 2 °C. *Nature Climate Change*, *8*(11), 931–933.
https://doi.org/10.1038/s41558-018-0321-8

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. https://bitcoin.org/bitcoin.pdf

Narayanan, A., Bonneau, J., Felten, E., Miller, A., & Goldfeder, S. (2016). *Bitcoin and cryptocurrency technologies: A comprehensive introduction*. Princeton University Press.

Pham, L., Karim, S., Naeem, M. A., & Long, C. (2022). A tale of two tails among carbon prices, green and non-green cryptocurrencies. *International Review of Financial Analysis*, *82*, 102139. https://doi.org/10.1016/j.irfa.2022.102139

Ren, B., & Lucey, B. (2022). Do clean and dirty cryptocurrency markets herd differently? *Finance Research Letters*, *47*, 102795. https://doi.org/10.1016/j.frl.2022.102795

Riley, J. (2021). The current status of cryptocurrency regulation in China and its effect around the world. *China and WTO Review*, *7*(1), 135–152.
https://doi.org/10.14330/cwr.2021.7.1.06

Sagymbekov, B. Z. (2020). On the definition of crypto- currency in the legislation of the Republic of Kazakhstan. *Law Series Bulletin of the L.N. Gumilyov Eurasian National University*, *2*(131).
https://doi.org/10.32523/2616-6844-2020-131-2-37-43

Starceva, N., & Cheklaukova, E. (2020). Cryptocurrencies: History and types. *Scientific Papers Collection of the Angarsk State Technical University*, *2018*(1).
https://doi.org/10.36629/2686-7788-2020-302-309

Stoll, C., Klaaßen, L., & Gallersdörfer, U. (2019). The carbon footprint of bitcoin. *Joule*, *3*(7), 1647–1661.
https://doi.org/10.1016/j.joule.2019.05.012

Swan, M. (2015). *Blockchain: Blueprint for a new economy.* O'Reilly Media, Inc.

Syzdykova, A., & Zhetibaev, Z. (2020). An attitude of the world countries to the use of cryptocurrency and analysis of the situation in Kazakhstan. *Economic Bulletin of the L. N. Gumilyov Eurasian National University*, (*3*), 147–156.
https://doi.org/10.32523/2079-620X-2020-3-147-156

Trading economics. (n.d.). *Kazakhstan GDP*. https://tradingeconomics.com/kazakhstan/gdp

Truby, J. (2018). Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies. *Energy Research and Social Science*, *44*, 399–410. https://doi.org/10.1016/j.erss.2018.06.009

Vranken, H. (2017). Sustainability of bitcoin and blockchains. *Current Opinion in Environmental Sustainability*, *28*, 1–9. https://doi.org/10.1016/j.cosust.2017.04.011

Wang, Y., Lucey, B., Vigne, S. A., & Yarovaya, L. (2022). An index of cryptocurrency environmental attention (ICEA).

*China Finance Review International*, *12*(3), 378–414. https://doi.org/10.1108/CFRI-09-2021-0191

Wendl, M., Doan, M. H., & Sassen, R. (2023). The environmental impact of cryptocurrencies using proof of work and proof of stake consensus algorithms: A systematic review. *Journal of Environmental Management*, *326*, 116530. https://doi.org/10.1016/j.jenvman.2022.116530

World Bank. (n.d.). *Kazakhstan overview*. https://www.worldbank.org/en/country/kazakhstan/overview

Xu, Y., Yang, X., Zhang, J., Zhu, J., Sun, M., & Chen, B. (2021). Proof of engagement: A flexible blockchain consensus mechanism. *Wireless Communications and Mobile Computing*, *2021*, 6185910. https://doi.org/10.1155/2021/6185910

Yan, L., Mirza, N., & Umar, M. (2022). The cryptocurrency uncertainties and investment transitions: Evidence from high and low carbon energy funds in China. *Technological Forecasting and Social Change*, *175*, 121326. https://doi.org/10.1016/j.techfore.2021.121326

Zakon. (1995). *The Law of the Republic of Kazakhstan dated August 31, 1995, No. 2444 "On banks and banking activities in the Republic of Kazakhstan"*. https://online.zakon.kz/document/?doc_ id=1003931

Zakon. (2016). *The Law of the Republic of Kazakhstan dated July 26, 2016, No. 11-VI "On payments and payment systems"*. https://online.zakon.kz/document/?doc_id=38213728

Zakon. (2018). *The Law of the Republic of Kazakhstan dated July 2, 2018, No. 167-VI "On currency regulation and currency Control.* https://online.zakon.kz/document/?doc_ id=33740496#pos=67;-26