Earth's Future

COMMENTARY
10.1029/2023EF003871

Key Points:

- Cryptocurrency mining has major but overlooked carbon, water, and land footprints
- China, USA, Kazakhstan, Russia, Canada, Malaysia, Germany, Ireland, Iran, Thailand, Sweden, Norway, Singapore, and the UK are among the top contributors to the environmental footprints of the global Bitcoin mining network
- Urgent regulatory intervention and technological breakthroughs are needed to mitigate the environmental impacts of the digital currency sector which is rapidly growing

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Citation:
Chamanara, S., Ghaffarizadeh, S. A., & Madani, K. (2023). The environmental footprint of bitcoin mining across the globe: Call for urgent action. *Earth's Future*, *11*, e2023EF003871. https://doi.org/10.1029/2023EF003871

Received 13 JUN 2023
Accepted 5 SEP 2023

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The Environmental Footprint of Bitcoin Mining Across the Globe: Call for Urgent Action

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Abstract Based on a multi-attribute assessment of the environmental impacts and challenges associated with global Bitcoin (BTC) mining activities around the globe, we call for urgent action by the scientific, policy, and advocacy communities. The worldwide BTC mining network consumed 173.42 TWh of electricity during the 2020–2021 period, bigger than the electricity consumption of most nations. The mining process emitted over 85.89 Mt of CO_2eq in the same timeframe, equivalent to the emission caused by burning 84 billion pounds of coal or running 190 natural gas-fired power plants. The environmental footprint of BTC mining is not limited to greenhouse gas emissions. In 2020–2021, the global water footprint of BTC mining was about 1.65 km^3, more than the domestic water use of 300 million people in rural Sub-Saharan Africa. The land footprint of the global BTC mining network during this period was more than 1,870 square kilometers, 1.4 times the area of Los Angeles. These striking numbers highlight the heavy reliance of the BTC network on fossil fuels and natural resource-intensive energy sources, resulting in major but unmonitored and unregulated environmental footprints. To mitigate the environmental costs of BTC mining, immediate policy interventions, technological advancements, and scientific research are crucial. Proposed measures include enhanced transparency, economic and regulatory tools, developing energy-efficient alternative coins, and the adoption of greener blockchain validation protocols.

Plain Language Summary The cryptocurrency sector is increasingly integrated into the global financial system. The world's transition to a digital economy, facilitated by major technological breakthroughs, has several benefits. But as the demand for exchanging and investing in digital currencies is rapidly growing, the world must pay careful attention to the hidden and overlooked environmental impacts of this growth. The dramatic increase in the price of Bitcoin (BTC) over the last few years and the resulting global race for BTC mining is turning the cryptocurrency market into one of the world's leading polluting sectors. Yet, our knowledge about the environmental footprints of mining BTC is very limited. Here, we provide the first estimates of the carbon, water, and land footprints of BTC mining around the world to argue why urgent intervention and action to monitor, control, and mitigate the environmental impacts of the cryptocurrency market is necessary.

1. Main Text

Over the past decade, the prices of major cryptocurrencies have grown substantially. Respectively, their global trading volume and number of transactions have increased significantly. Not long ago, some major companies officially announced to turn parts of their assets into cryptocurrency, as the biggest market ticker, and would accept Bitcoin (BTC) or some other popular types of cryptocurrency as an acceptable form of payment, boosting the trust and global interest in the cryptocurrency market. With the increasing popularity of cryptocurrencies and their success in gaining the trust of people and markets around the world, even governments and many central banks around the world are now investing in launching digital currencies. The current era of cryptocurrency as the biggest market ticker is comparable to the meteoric gold price rise at the beginning of the 1970s, motivating the ongoing discussion on whether cryptocurrency can be a replacement of gold (Klein et al., 2018). However, unlike gold, which requires prior knowledge and access to a resource, cryptocurrency mining can be merely done through reasonable capital investment and reliable access to electricity and the internet. The low barriers to entry enable individuals to mine cryptocurrency even by using a residential electricity network. The analysis of the future trends and placement of cryptocurrencies within the financial system is not easy, if not impossible. Yet, undeniably, the technological breakthroughs of the Fourth Industrial Revolution (Industry 4.0) and the

Writing – review & editing: Kaveh Madani

resulting enhancements in terms of security, privacy, efficiency of data transfer, and automation will continue to have a profound impact on the global banking and financial systems. Thus, given the current trends and observations, it is realistic to predict that cryptocurrencies, digital currencies, Non-fungible tokens (NFTs), and other blockchain assets and products will have an inevitable social, financial, and cultural role in modern societies (Yarlagadda, 2018).

Processing cryptocurrency transactions requires a computational setup, which contributes to the network by solving the cryptographic puzzle. Subsequently, the contributor would receive a reward for this Proof-of-Work (PoW) operation which is known as mining. These computational units (miners) consume an intense amount of electrical power to operate. As the value of the received financial reward outweighs the costs of contribution, mining cryptocurrencies becomes economically viable, resulting in significant growth in electricity consumption. It is estimated that around 1 million BTC miners are currently operating around the world (Carter, 2023).

So far, more than 10,000 types of cryptocurrencies have been traded worldwide (Statista, 2022). The global crypto market cap is currently about $0.5 trillion (CoinMarketCap, 2023), with BTC being the main shareholder with about $525 billion as of March 2023. An average BTC miner requires about 1.5 kW of power, equivalent to 36 kWh per 24 hr of operation (Kemmerer, 2021). This is slightly bigger than the daily electricity use per capita in the United States, one of the world's top energy consumers. While miners are becoming more efficient in terms of energy use, the substantial increase of total hashrate (the total computing power used by a miner or network of miners for processing transactions on a PoW blockchain) over the past years indicates that more miners are being added into the BTC network. The cumulative power needed to satisfy the annual BTC mining electricity demand of the top 10 mining countries is sufficient to provide electricity to more than 10, 31, and 52 million households in the US, Germany, and Japan, respectively. This is more than 15% of Africa's total electricity consumption with 54 countries and a 1.2 billion population.

Regardless of the energy source, producing and transmitting electricity for cryptocurrency mining has numerous environmental impacts. This makes the growing digital currency market a potentially polluting sector with an environmental footprint level far more than some conventional methods of digital transactions. For example, each BTC transaction is believed to have an equivalent carbon footprint of more than one million VISA transactions (Digiconomist, 2021). It is projected that in less than three decades, the BTC usage alone can produce enough greenhouse gas emissions to push global warming beyond the Paris Agreement's goal of capping anthropogenic climate warming below 2 degrees Celsius (Mora et al., 2018). Despite these alarming expectations, the financial and technological motivations for mining cryptocurrencies have suppressed the conversation surrounding their environmental costs.

Evidently, the crypto sector is being increasingly integrated into the global financial system. The world's transition to a digital economy, facilitated by major technological breakthroughs, has several benefits. But as the demand for exchanging and investing in digital currencies is growing faster than ever, the world must pay careful attention to the hidden and overlooked environmental impacts of this growing sector. Although some studies have been recently conducted to analyze cryptocurrency's environmental costs, the uncertainties surrounding the extent of these costs remain considerable (Howson, 2019). Additionally, past studies heavily focused on the carbon emissions of cryptocurrencies (Stoll et al., 2019), not reflecting their other major environmental impacts such as water and land footprints (Obringer et al., 2021; Ristic et al., 2019) that contribute greatly to the overall environmental footprint of the cryptocurrency sector.

To highlight the need for taking serious regulatory action to monitor and mitigate the environmental impacts of digital currencies, one can evaluate the environmental footprints of BTC as the most well-known form of digital currency. So, let us use the 2-year Cambridge Bitcoin Electricity Consumption Index (CBECI) values (Cambridge Centre for Alternative Finance, 2023) here to provide the first global estimate of the carbon, water, and land footprints of BTC mining with respect to the variations in energy supply mixes around the world. To do so, we can first roughly estimate the monthly electricity use for BTC mining in the 76 BTC mining nations monitored by CBECI between January 2020 to December 2021 using the average monthly hashrate share of each country and the total monthly electricity use of the global BTC mining network. Following Obringer et al. (2021), we can then estimate the average carbon, water, and land footprint of electricity generation in each BTC mining nation based on its energy supply mix data as reported by the International Energy Agency (IEA) and the environmental footprints of electricity generation from different sources given in Ristic et al. (2019) and Obringer et al. (2021). Multiplying the BTC electricity use in each country (Figure 1) by its footprint values gives us the carbon, water,

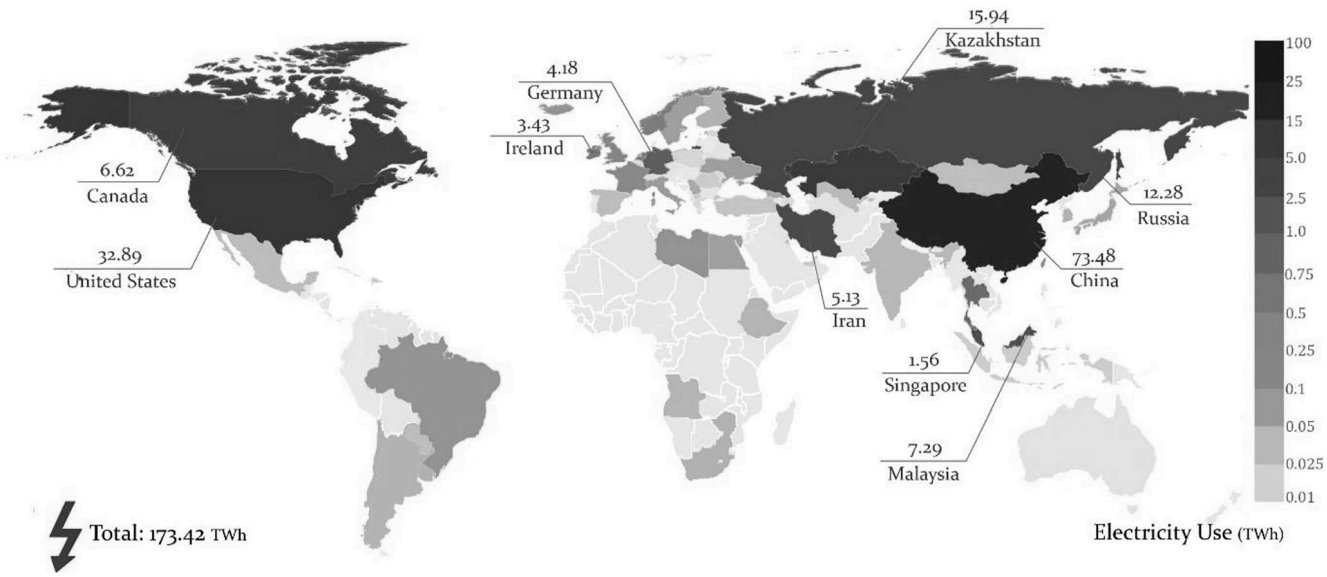

Figure 1. Electricity use of BTC mining across the world (2020–2021).

and land footprint of BTC mining for that country. Once the environmental footprints are revealed (Figure 2), we realize why the world should be concerned about the overlooked environmental footprints of the global BTC network. In the 2020–2021 period, the worldwide BTC mining network used 173 TWh of electricity, 60% more than its electricity use during the 2018–2019 period. Based on CBECI values, in 2021 and 2022, the annual electricity consumption for BTC mining across the globe exceeded 100 TWh per year. Currently (as of July 2023) the global electricity consumption for BTC mining in 2023 is expected to be above 135 TWh (Cambridge Centre for Alternative Finance, 2023). So, if BTC were a country, its energy consumption would have ranked it 27th in the world, ahead of a country like Pakistan with a population of over 230 million people.

The BTC network is highly dependent on fossil energies, constituting 67% of the BTC's global energy supply mix (Figure 3), with coal having a 45% share in this mix. Subsequently, global BTC mining emitted more than 85.89 Mt of CO_2eq from 2020 to 2021, equivalent to carbon emissions from 84 billion pounds of coal burned, 190 natural gas-fired power plants, or over 25 million tons of landfilled waste. To offset the CO_2 emissions of BTC mining in 2020 and 2021, about 3.9 billion trees should be planted, taking up an area almost equal to the area of countries like the Netherlands, Switzerland, or Denmark, or 7% of the Amazon rainforest. Hydropower, an energy source with a high water footprint due to evaporative losses and a land footprint higher than all renewables except for bioenergy, is the dominant renewable energy source of BTC operations, satisfying more than 16% of the global BTC network's electricity demand (Figure 3). In the 2020–2021 period, the global water footprint of BTC mining was about 1.65 km^3, equivalent to filling over 660,000 Olympic size swimming pools, and more than the current domestic water use of 300 million people in rural Sub-Saharan Africa. BTC is also intensive in terms of land footprint. The overall land footprint of the BTC mining network around the world in the 2020–2021 period was more than 1,870 square kilometers, 1.4 times the area of Los Angeles.

The landscape of BTC mining is very dynamic. For the past few years, China, by a large margin, has been the biggest BTC mining nation (Figure 4). Nevertheless, its share has dropped from 73% in 2020 to 21% in 2022. This can be attributed to the different government bans and actions against BTC mining (BBC, 2023). Some media reports suggest that China has been transferring some of its load to countries such as Kazakhstan and the United States (G Times, 2022) to reduce its carbon footprint and overcome the challenges of tracking fraud and illegal financial activities (BBC, 2023). This has resulted in an increase in the shares of the United States and Kazakhstan by 34% and 10% respectively based on the reported CBECI values in 2023. The reduction of China's BTC mining interest has resulted in a shift in the energy supply mix of BTC mining network. In 2020, 53% of the global BTC network's energy supply came from coal. This number was reduced to 46% in 2022, which is associated with 34% reduction in the carbon footprint, 32% decrease in the water footprint, and 25% decrease in the land footprint of the global BTC mining over a year. However, the global BTC mining network is still very dependent

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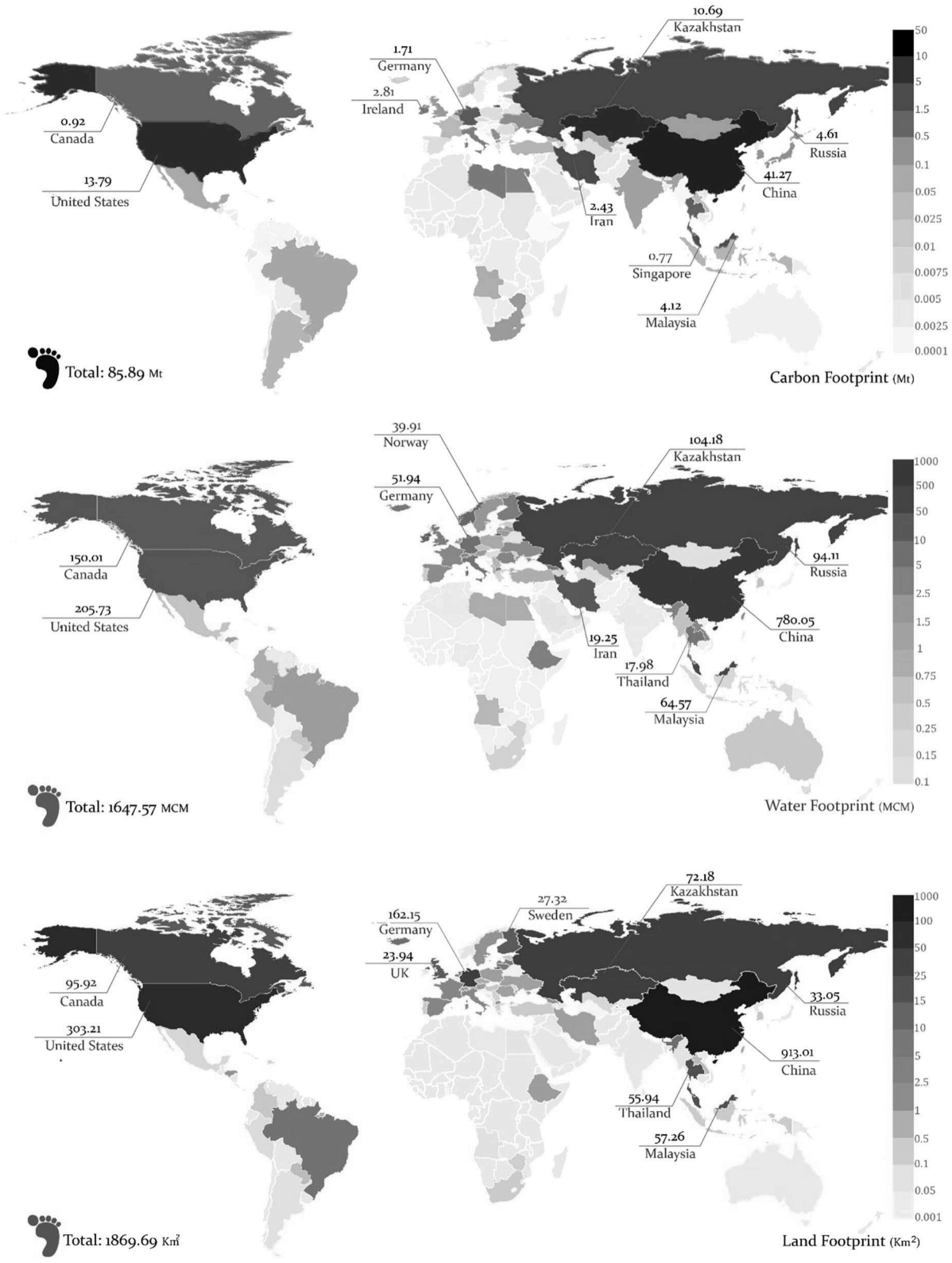

Figure 2. Environmental footprint of BTC mining across the world (2020–2021).

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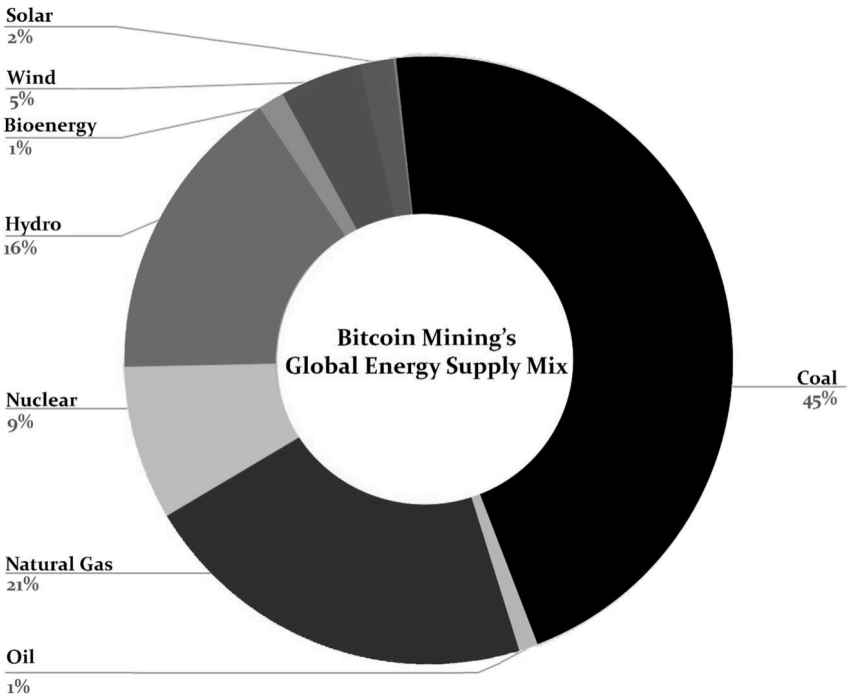

Figure 3. Contributions of different energy sources in supplying electricity to the global BTC mining network (2020–2021).

on fossil fuels. The share of natural gas in the global BTC energy mix has increased from 15% in 2021 to 21% in 2022. This increase is mainly due to the high dependency of electricity generation in some of the top BTC mining countries on natural gas. Currently, there are no federal laws prohibiting BTC mining in the second top BTC mining nation of the world, the United States. BTC mining regulations vary across the states in this country. Georgia, Kentucky, Texas, and New York are the top four hotspots for mining BTC, respectively responsible for 31%, 11%, 10.9%, and 9.8% of BTC mining in the U.S. (Cambridge Centre for Alternative Finance, 2023). Electricity cost in the fossil energy-dependent Kazakhstan—the third top BTC miner in the world—is three times cheaper than the U.S., motivating heavy investments in BTC mining in this country. BTC mining is also popular in Kazakhstan's neighbor, Russia, where electricity consumption for BTC mining is slightly less than Kazakhstan. The BTC mining's electricity use in Russia is 37% and 17% of electricity consumption for BTC mining in the U.S. and China, respectively. Malaysia, Canada, Iran, Germany, Ireland, and Singapore are the other six members of the world's top BTC miners list.

BTC mining in China and the U.S. also have the highest environmental footprint in the world, but the top BTC miners' ranking slightly changes when countries are ordered based on their BTC mining's carbon footprint, water footprint, and land footprint instead of their BTC mining's electricity use (Figure 4). This is because each country uses a unique mix of energy sources to produce electricity, having different water, carbon, and land footprints, making the relationship between BTC's electricity use and environmental footprints non-linear. For example, Ireland ranks ninth in terms of electricity use for BTC mining. But the BTC mining sector in this country has the sixth highest carbon footprint globally due to its high dependency on fossil sources of energy for electricity production. In addition to some ranking changes, one can notice that the differences (in terms of percentage) between the performance values of each country (electricity use, carbon footprint, water footprint, and land footprint) are not of the same magnitude (Figure 4). For example, Canada is the sixth BTC miner of the world in terms of electricity use but the ninth emitter of greenhouse gases for BTC mining thanks to the smaller role of coal and higher role of nuclear and natural gas in its energy supply portfolio in comparison to some other countries in the top BTC miners list. As a result, BTC mining's electricity use in Canada is 20% of that in the U.S. but the carbon footprint of BTC mining in Canada is less than 7% of that in the U.S. These values are 9% and 2%, respectively, when Canada is compared with the world's top BTC mining nation. China's coal-intensive BTC mining produced more than 41 Mt CO_2eq from January 2020 to December 2021. To offset this level of carbon emissions, about 2 billion trees should be planted which take up an area equivalent to the sum of Portugal and Ireland or 45,000 times

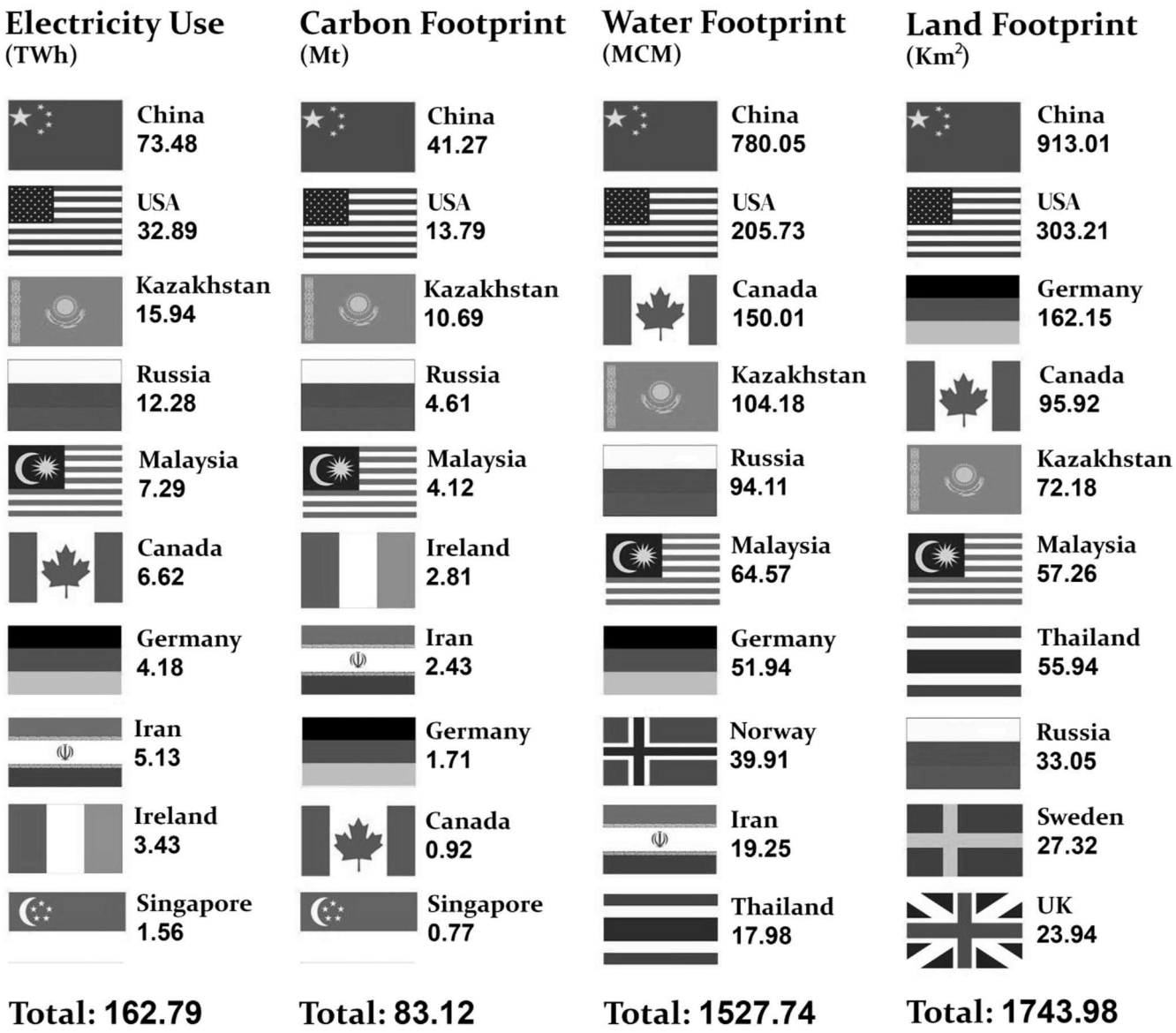

Figure 4. The World's top 10 BTC miners in terms of electricity consumption, carbon footprint, water footprint and land footprint (2020–2021).

the area of Central Park in New York City. Together, the top 10 BTC carbon emitters are responsible for 94% of the carbon footprint of the BTC sector.

The ranking based on the water footprint of BTC mining (Figure 4) is reflective of the water intensity of electricity production in each country. Iran, a country that is already dealing with "water bankruptcy" (Madani et al., 2016), is among the top 10 countries contributing to the global water footprint of BTC. Nonetheless, the high dependence of Iran's electricity generation on natural gas makes its BTC mining less water-intensive (but more carbon intensive) than countries like Canada and Norway that produce significant amounts of electricity from water-intensive renewable energies. Canada with about 60% dependency on hydroelectricity ranks third globally with respect to the impact of its BTC mining activities on water resources. Thailand with a high dependency on water-intensive bioenergy sources is another country that makes it to the list of top BTC mining nations in terms of water footprint. Together, the 10 countries in this list contribute to 92.5% of the global water footprint of BTC mining.

Thailand, Sweden, and UK are not in the list of top 10 BTC miners in terms of electricity use. But they are among the top 10 major contributors to the total land footprint of BTC mining due to the high contribution

of land-intensive energy sources (e.g., bioenergy) to their electricity sector. The 10 countries with the most land-intensive BTC operations are responsible for 93% of BTC's global land footprint.

Due to its nature, cryptocurrency mining activities are hard to track, creating barriers to the regulation of the crypto market and its imposed load on the power grid. In February 2021, German officials investigated a case of an individual who mined more than 1,700 BTC—worth $34 million at $20,000/BTC exchange rate - through others' computers without their awareness (Shalvey, 2021). The price of BTC is one of the important driving factors to determine BTC mining profitability (Gallersdörfer, et al., 2020; Houy, 2019; Vranken, 2017). Higher prices mean higher profitability, which motivates more BTC mining and therefore higher electricity consumption (Maiti, 2022). In August 2021, when the BTC price rose 400% compared to the previous year, the worldwide BTC network saw a 140% spike in electricity use. This price spike and the increased interest in BTC mining had social and political implications in different countries. For example, the Government of Iran blamed its major blackouts in 2021 on hidden BTC mining farms and "illegal" mining activities. Evidently, the growth of the BTC market is not purely motivated by financial incentives, this makes it difficult to explore the causal relationship between the average BTC price and energy consumption on a daily basis. Nonetheless, we see a 77% correlation between these two variables over the January 2020-December 2021 period. It still remains challenging to determine to what extent BTC price changes can affect energy consumption (Maiti, 2022). While the BTC price has an impact on the interest in BTC mining, the growth of the markets of BTC and other cryptocurrencies involves a range of financial, political, security, and even criminal incentives, that can motivate states along with large corporations and investors to invest in these markets. Undeniably, the digital currency sector is growing while its environmental impacts remain overlooked.

Our estimated environmental footprints of global BTC mining and its heterogeneous environmental impacts across the world unpack the concerning costs of the unchecked growth of an innovative but "ungreen" economy. This is especially concerning as some of the countries in the top 10 countries on the BTC miners in terms of electricity use have a GDP per capita of less than the global average and are already struggling with social and economic justice measures. Unregulated and untaxed mining activities exacerbate the inequality in these areas and have lasting environmental impacts. Thus, we advocate for immediate policy, technologic, and scientific interventions to mitigate these transboundary and transgenerational costs with major environmental injustice implications.

Policies must be enacted at the national and global levels to increase the transparency of cryptocurrency mining. These policies can be accompanied by a suite of economic and regulatory tools (e.g., increased cryptocurrency mining electricity price, taxes on cryptocurrency revenues and transactions, carbon offset mandates for blockchain tokens, ban on unclean energy-based crypto-mining, and environment-unfriendly digital currency divestment campaigns) to limit and compensate for the environmental costs of cryptocurrency market and reducing its reliance on "ungreen" energies, that is, those non-renewable and renewable energies that have high RAFs (Relative Aggregate Footprint is an index that normalizes the overall environmental footprint of energies according to local resource availability conditions (Mahlooji et al., 2020; Ristic et al., 2019)). Transition to a sustainable future requires taking advantage of different Industry 4.0 products without overlooking the need for a careful examination of their economic, environmental, and social trade-offs at the local and global levels.

The overall footprint of BTC and all other "alt-coins" networks depends both on the mining hardware and the blockchain validation protocol. Creating energy-efficient alt-coins and technological innovations that reduce the life-cycle impacts of all contributing elements of the crypto network are essential to reducing their environmental impacts of this global network. For example, developing and implementing blockchain validation protocols that are safe, but not as energy-consumptive as the PoW, such as the proof-of-stake (PoS) validation method, can reduce the cryptocurrencies' energy use per transaction and consequently slow down the global cryptocurrency energy demand growth.

Finally, we call for more research on the comprehensive evaluation of the transition to digital currency and its associated environmental impacts and various trade-offs. Future studies must go beyond carbon and BTC, as carbon footprint is not the only negative environmental impact of cryptocurrency mining and BTC is not the only popular, energy-consumptive cryptocurrency. High-resolution estimates of cryptocurrency mining footprints and future growth projections are required to enable a sustainable digital crypto market. The availability and knowledge of such estimates are vital for: (a) policymakers to enact change, and (b) individuals and companies to minimize the environmental footprints of their investments and protect their reputation and financial assets

against transition risks, resulting from market, legal, and policy changes as the world is fighting climate change, and physical risks, resulting from resource availability issues (e.g., water or energy shortage).

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

All the data used in this analysis are accessible. The BTC mining electricity consumption and hashrate data is based on CBECI values estimated by the Cambridge Centre for Alternative Finance and can be accessed at www.cbeci.org. Data on the energy supply mix of each country is available via the IEA website: https://www.iea.org/countries. The environmental footprint data for each type of energy was extracted from Obringer et al. (2021), https://doi.org/10.1016/j.resconrec.2020.105389 and Ristic et al. (2019), https://doi.org/10.1016/j.resconrec.2018.12.010.

Acknowledgments
Authors are thankful to the reviewers for their valuable comments.

References

BBC NEWS. (2023). US leads Bitcoin mining as China ban takes effect". [Online]. Retrieved from https://www.bbc.com/news/technology-58896545

Cambridge Centre for Alternative Finance. (2023). Cambridge bitcoin electricity consumption index [Dataset]. CBECI. Retrieved from www.cbeci.org

Carter, R. (2023). *How many bitcoins are there in 2023*. Banklesstimes, 16th Feb 2023. Retrieved from https://www.banklesstimes.com/how-many-bitcoins-are-there/

CoinMarketCap. (2023). *Cryptocurrency prices, charts and market capitalizations*. Retrieved from coinmarketcap.com

Digiconomist. (2021). *Bitcoin energy consumption index*. Retrieved from http://digiconomist.net/bitcoin-energy-consumption

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

Houy, N. (2019). Rational mining limits bitcoin emissions. *Nature Climate Change*, *9*(9), 655. https://doi.org/10.1038/s41558-019-0533-6

Howson, P. (2019). Tackling climate change with blockchain. *Nature Climate Change*, *9*(9), 644–645. https://doi.org/10.1038/s41558-019-0567-9

Kemmerer, D. (2021). *The 10 best bitcoin mining hardware machines 2021*. CryptoTrader.Tax. Retrieved from cryptotrader.tax

Klein, T., Thu, H. P., & 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

Madani, K., AghaKouchak, A., & Mirchi, A. (2016). Iran's socio-economic drought: Challenges of a water-bankrupt nation. *Iranian studies*, *49*(6), 997–1016. https://doi.org/10.1080/00210862.2016.1259286

Mahlooji, M., Gaudard, L., Ristic, B., & Madani, K. (2020). The importance of considering resource availability restrictions in energy planning: What is the footprint of electricity generation in the middle east and north Africa (MENA)? *Science of the Total Environment*, *717*, 135035. https://doi.org/10.1016/j.scitotenv.2019.135035

Maiti, M. (2022). Dynamics of bitcoin prices and energy consumption. *Chaos, Solitons & Fractals X*, *9*, 100086. https://doi.org/10.1016/j.csfx.2022.100086

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

Obringer, R., Rachunok, B., Maia-Silva, D., Arbabzadeh, M., Nateghi, R., & Madani, K. (2021). The overlooked environmental footprint of increasing Internet use [Dataset]. Resources, Conservation and Recycling, *167*, 105389. https://doi.org/10.1016/j.resconrec.2020.105389

Ristic, B., Mahlooji, M., Gaudard, L., & Madani, K. (2019). The relative aggregate footprint of electricity generation technologies in the European Union (EU): A system of systems approach [Datasets]. Resources, Conservation and Recycling, *143*, 282–290. https://doi.org/10.1016/j.resconrec.2018.12.010

Shalvey, K. (2021). A bitcoin stash worth $68 million was seized by German police but the owner has refused to give up his password. *Business Insider*, *15*.

Statista (2022). *GP Bullhound, and the motley fool, and Investing.com*. Statista, Statista Inc. Number of cryptocurrencies worldwide from 2013 to 2021 Retrieved from https://www.statista.com/statistics/863917/number-crypto-coins-tokens/

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

G. Times. (2022). *Chinese crypto miners in Kazakhstan use satellite networks, less hit by internet cut*. Global Times. Retrieved from https://www.globaltimes.cn/page/202201/1245305.shtml?id=11#:~:text=It%20is%20estimated%20that%2020,the%20Global%20Times%20on%20Thursday

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

Yarlagadda, R. T. (2018). Internet of things & artificial intelligence in modern society. In *International journal of creative research thoughts (IJCRT), ISSN* (pp. 2320–2882).