The Environmental Costs of Mining Bitcoin

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Abstract

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 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 year and the resulting global race for BTC mining is turning the cryptocurrency market turning into one of the world's leading polluting sectors. Yet, our knowledge about the environmental footprints of mining BTC is very limited. To address this hap, this study provides the first estimates of the carbon, water and land footprints of BTC mining around the world.

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Over the last year, the prices of major cryptocurrencies have grown substantially. Respectively, their global trading volume and number of transactions have increased significantly [1]. Several major companies have officially announced to turn parts of their assets into BTC, as the biggest market ticker, and accept BTC or some other popular types of cryptocurrency as an acceptable form of payment, boosting the trust and global interest in the cryptocurrency market.

The current era of BTC as the biggest market ticker is comparable to the meteoric gold price rise at the beginning of 1970s, motivating the ongoing discussion on whether BTC can be a replacement of gold [2]. However, unlike gold, which requires prior knowledge and access to a resource, BTC mining can be merely done through a reasonable capital investment and a reliable access to electricity and the internet. The low barriers to entry enable individuals to mine BTC even by using a residential electricity network. So far, more than 4500 types of cryptocurrencies have been traded worldwide [3]. The global crypto market cap is currently about $1.72T and is growing steadily, with BTC being the main shareholder with about $750 billion [4].

Processing cryptocurrency transactions requires a computational set up, which contributes to the network by solving the cryptographic puzzle. Subsequently, the contributor would receive 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 a significant growth in electricity consumption. According to estimations, there are currently 1 million miners operating around the world [5].

Regardless of the energy source, producing and transmitting electricity for cryptocurrency mining have numerous environmental impacts.

To offset global BTC mining carbon emission, about 2.8 billion trees should be planted, taking up an area almost equal to the area of the UK or 4% of the Amazon rainforest.

The global water footprint of BTC mining is about half a million Olympic size swimming pools, and more than the current domestic water use of 300 million people in rural Sub-Saharan Africa.

BTC's global land footprint is more than 1200 square kilometers, slightly smaller than the area of Los Angeles.

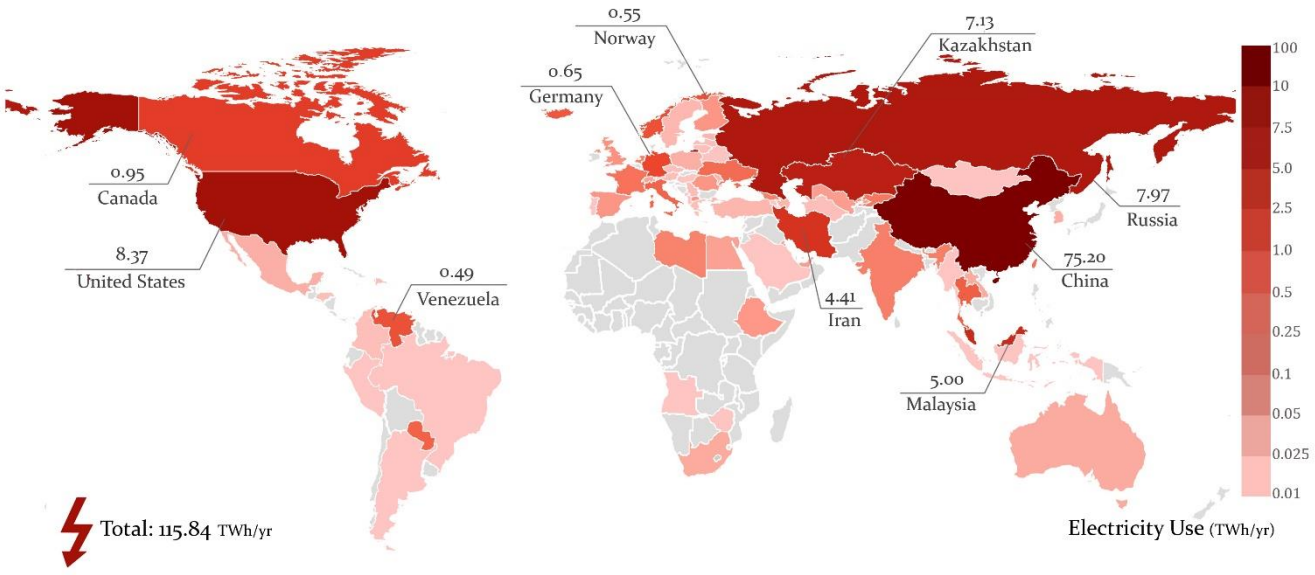
An average BTC miner requires about 1.5kW of power, equivalent to 36 kWh per 24 hours of operation [6]. This is slightly bigger than the daily electricity use per capita in the United States, one of the world's top energy consumers. While miners are becoming more efficient in terms of energy use, the substantial increase of total Hash Rate over the past year 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 ten mining countries is sufficient to provide electricity to more than 10 and 30 million households in the US and Germany, respectively. This is about 17% of Africa's total electricity demand with 54 countries and 1.2 billion population.

Regardless of the energy source, producing and transmitting electricity for cryptocurrency mining have 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 [7]. 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 [8]. Despite these alarming expectations, the financial and technological motivations of cryptocurrencies have suppressed the conversation surrounding their environmental costs.

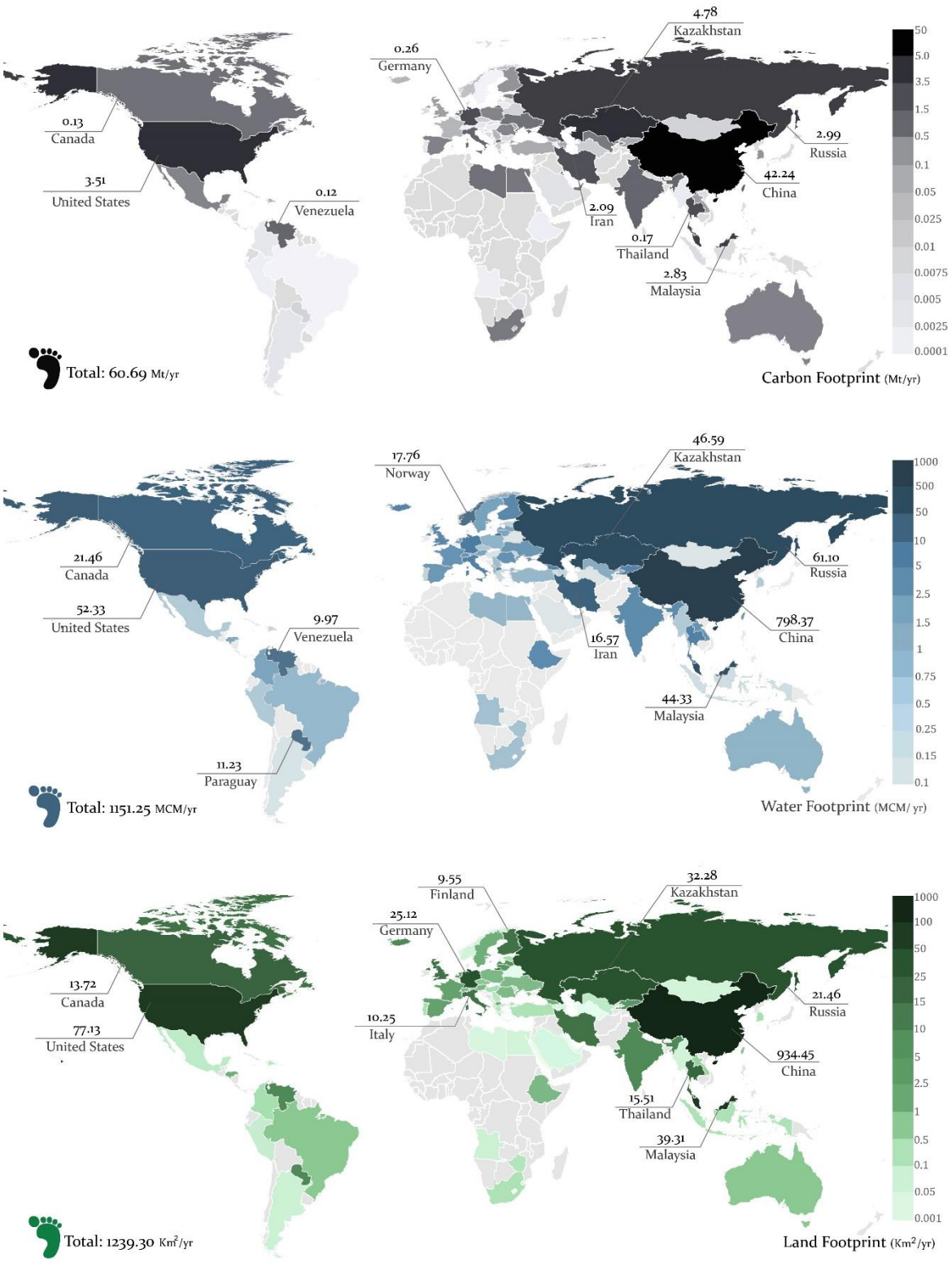
The crypto sector is increasingly integrated into the global financial system. "The world's transition to a digital economy facilitated" by major technological breakthroughs, has several benefits. But as the demand for exchanging and investing in digital currencies is growing faster than ever, the world 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 remains considerable [9]. Additionally, past studies have been only focused on the carbon emissions of BTC mining [10], not reflecting its other major environmental impacts such as water and land footprints [11,12] that contribute greatly to the total environmental footprint of the cryptocurrency sector.

To address this knowledge gap, we used the most recent Cambridge Bitcoin Electricity Consumption Index (CBCEI) values [13] 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. The last set of data available at the time of this analysis are from May 2021.



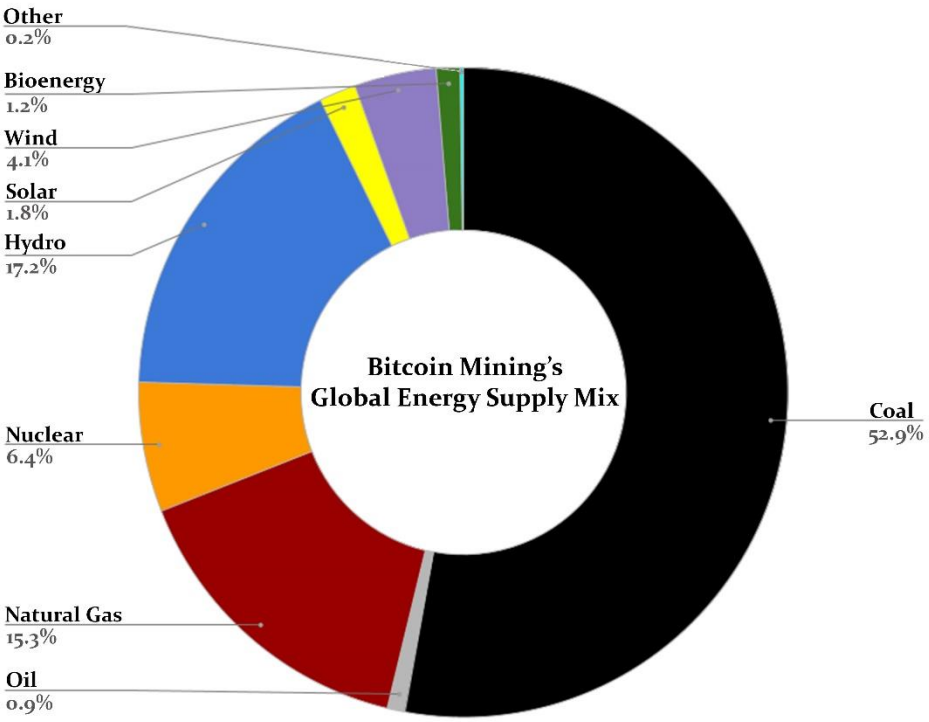
Annual electricity use of BTC mining across the world, as of May 2021



Annual environmental footprint of BTC mining across the world, as of May 2021

CBCEI reports the electricity consumption of the BTC network on the global and regional scales and its breakdown for the world's 76 BTC mining nations. We used these values together with our estimates of the carbon, water, and land footprints of producing an average unit of electricity in different countries to calculate the environmental footprints of the BTC network across the world. As of May 2021, the worldwide BTC mining network is using 116 TWh of electricity per year, 128% of more than its electricity use in June 2020, and about 14% less than its electricity use in April 2021. If this network were a country, it would be the 33th largest electricity consumer, above countries such as the Netherlands, Belgium, and Finland [13]. This network is highly dependent on fossil energies, constituting 69% of the BTC's global energy supply mix, with coal having a 53% share in this mix.

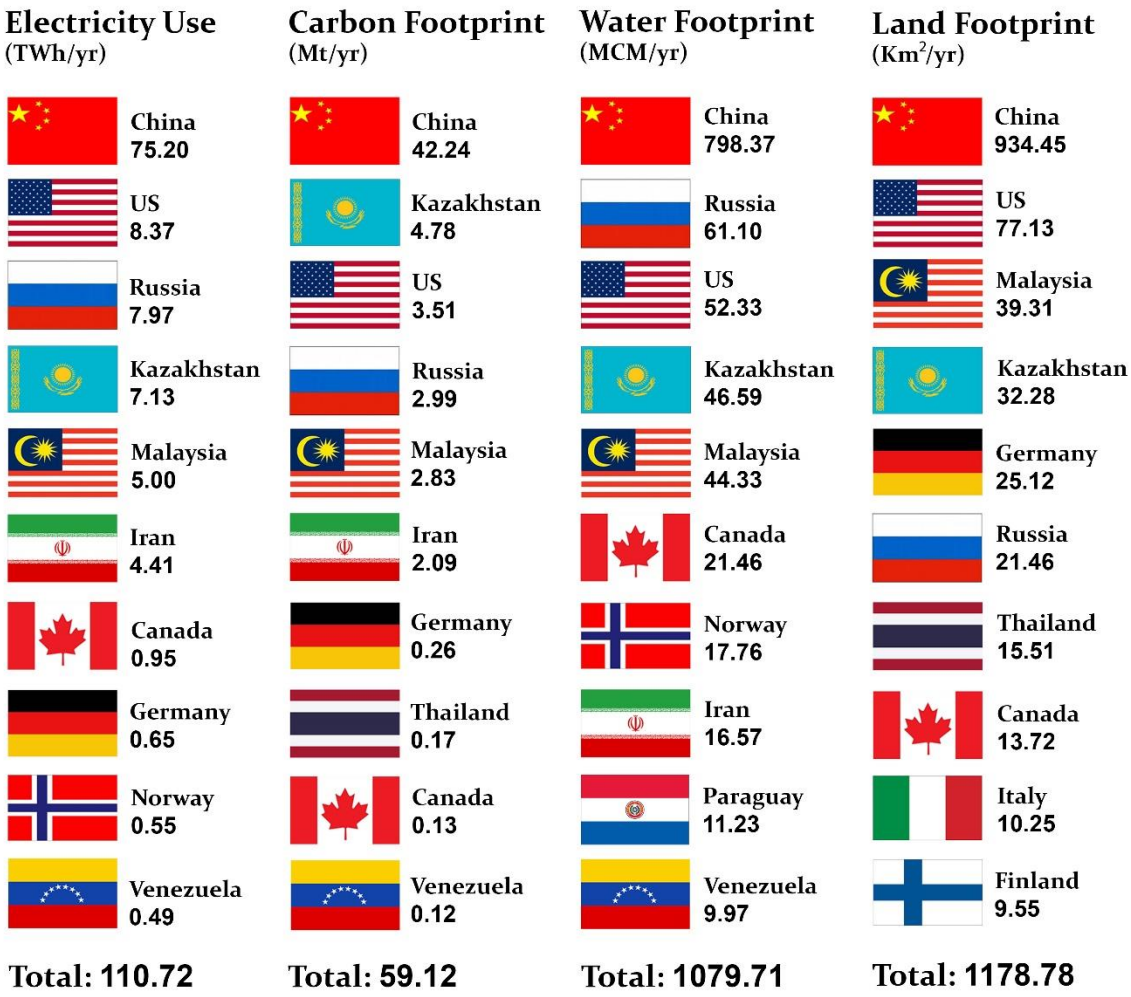
Subsequently, global BTC mining is currently emitting more than 60.69 Mt of CO2eq per year. To offset this amount, about 2.8 billion trees should be planted, taking up an area almost equal to the area of the UK or 4% of the Amazon rainforest. Hydropower, an energy source with a high water footprint due 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 17% of the global BTC network's electricity demand.



Contributions of different energy sources in supplying electricity to the global BTC mining network, as of May 2021

The global water footprint of BTC mining, about 1.15 km^3, is equivalent to filling about half a million Olympic size swimming pools, and more than the current domestic water use of 300 million people in rural Sub-Saharan Africa. BTC's global land footprint is more than 1200 square kilometers, about the area of Los Angeles.

A significant gap exists between China, as the world's largest energy consumer and BTC miner, responsible for 65% of the global BTC mining electricity use, and the rest of the world's top ten BTC miners. China's BTC mining electricity consumption, which stands for almost 1% of its total electricity use [14], is more than twice the sum of the BTC mining electricity use of the rest of the top ten miners.



The world's top ten BTC miners in terms of electricity consumption, carbon footprint, water footprint, and land footprint, as of May 2021

This is about the annual electricity consumption of 150 million people in Sub-Saharan Africa. The world's top ten BTC miners list includes some developing, oil-rich countries such as Kazakhstan, Iran, and Venezuela where cheap and subsidized electricity makes cryptocurrency mining highly profitable.

The top miners ranking changes when countries are ordered based on their BTC mining's carbon footprint, water footprint, and land footprint instead of its electricity use. This is because each country uses a unique mix of energy sources to produce electricity, having different water, carbon, and land footprints. China's coal-intensive BTC mining is producing more than 42 Mt CO_2eq per year. To offset this level of emissions, about 2 billion trees should be planted which take up an area equivalent to the sum of Portugal and Ireland or more than 40,000 times the area of Central Park in New York City.

Kazakhstan, the world's fourth BTC miner in terms of electricity use, is the world's second BTC carbon emitter because of its very fossil energy-intensive electricity production. Electricity cost in Kazakhstan is three times cheaper than the US and the country has passed federal laws encouraging investors to set up large BTC mining farms. With more than 84% dependence on fossil fuels for electricity generation, Thailand is among the top ten countries contributing to the global BTC carbon footprint, although it is not among the top ten miners in terms of mining electricity use. Together, the top ten BTC carbon emitters are responsible for 97% of the carbon footprint of the BTC sector.

The ranking based on the water footprint of BTC mining is reflective of the water intensity of electricity production in each country. Canada with about 60% dependency on hydroelectricity ranks 6th globally with respect to the impact of its BTC mining activities on water resources. Iran, a country that is already dealing with water bankruptcy, is among the top ten 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 mostly produce electricity from water-intensive renewable energies. Paraguay is another country with a water-intensive energy sector that appears in the list of top ten countries in terms of BTC mining's water impact. On the other hand, Germany, the world's 8th BTC miner and 7th BTC carbon emitter, does not make it to this list, given the low shares of water-intensive sources in its national energy mix. Together, the ten countries in this list contribute to 94% of the global water footprint of BTC mining.

Thailand, Italy, and Finland are not in the list of top ten BTC miners in terms of electricity use. But they are among the top ten 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 ten countries with the most land-intensive BTC operations are responsible for 95% of BTC's global land footprint.

The 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 the majority of the top ten 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, purely driven by financial incentives, 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 justice implications.

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. Iran's government blamed a countrywide blackout in January 2021 on hidden BTC mining farms and "illegal" mining activities. In February 2021, German officials investigated a case of an individual who mined more than 1,700 BTC - worth $85 million at $50,000/BTC exchange rate - through others' computers without their awareness [15].

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 cryptomining, and environmental unfriendly cryptocurrency divestment campaigns) to limit and compensate for the environmental costs of cryptocurrency market and reducing its reliance on "ungreen" energies (including both the non-renewables with high carbon emissions and the renewables with high water/land footprint).

We advocate for immediate policy, technologic, and scientific interventions to mitigate these transboundary and transgenerational costs with major environmental justice implications.

The total footprint of BTC and all other 'alt-coins' networks depend 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. 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: 1) policymakers to enact change; and 2) 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).

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