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Commentary

The true costs of digital currencies: Exploring impact beyond energy use

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The digital currency Bitcoin is known for its energy hunger and associated carbon footprint. Investors, however, must not neglect further environmental, social, and governance issues related to digital currencies. Therefore, we urge the adoption of a more comprehensive view in assessing the externalities of investments in Bitcoin and other cryptocurrencies.

Introduction

In January 2021, electric car manufacturer Tesla became the first company listed on the S&P 500 stock market index to buy the digital currency Bitcoin.[1] Tesla's purchase of the equivalent of $1.5 billion in Bitcoin surprised many stakeholders and concerned responsible investors, as environmental, social, and governance (ESG) issues have become a pivotal factor in financial markets.

Investors' concerns are primarily driven by Bitcoin's high energy demand and associated carbon emissions. In our earlier work, we estimated that the Bitcoin network could consume nearly as much electricity as all global data centers combined and cause a level of carbon emissions comparable to those produced by the city of London.[2] Emissions, however, only comprise one of the three ESG factors of responsible investment practices. Social and governance factors have received limited attention in previous academic literature on cryptocurrencies.

To explore the social and governance factors of the Bitcoin network, a holistic, ESG-driven examination of Bitcoin is required. Figure 1 summarizes and defines the elements covered in this commentary. Insights related to Bitcoin can be applied to the hundreds of other digital currencies that exist.

Environmental impact

The high energy requirements and the associated carbon footprint of Bitcoin are well documented. Bitcoin's energy consumption results from a process known as "mining." Bitcoin miners update the underlying digital ledger, known as blockchain, by validating transactions and adding them in new blocks. Because the Bitcoin network is an open network, anyone can join this process if they have suitable computer hardware. The Bitcoin protocol provides an incentive to participate, because the creators of new blocks receive a reward in bitcoins. Creating a new block is, however, intentionally computationally expensive. Blocks can only be created through a process that resembles a number-guessing game, wherein a correct guess is required to complete a block. As of May 2021, the Bitcoin network was generating 180 quintillion such guesses every second of the day, with miners competing against each other to correctly guess first and reap the rewards. Even so, a new Bitcoin block is only created once every 10 min, and the protocol continuously adjusts the difficulty of mining to maintain this rate. The more valuable a single bitcoin becomes, the higher the incentive is to participate, and the more Bitcoin miners will spend on hardware and electricity to compete in the block creation process. The recent growth in Bitcoin price is therefore increasing the network's power requirements. Our earlier work estimates that global Bitcoin-mining activity can generate about 90.2 million metric tons of CO_2 (Mt CO_2) annually.[2]

Until now, there has been no guidance on how to allocate the carbon footprint of Bitcoin among investors. One option would be to adapt the Greenhouse Gas (GHG) Protocol, which is the world's most widely used standard to account for corporate emissions. For equity investments where the reporting company has no financial control or significant influence over the emitting entity, the GHG Protocol prescribes an equity-share approach that proportionally allocates emissions to investors. Although Bitcoin does not represent an equity investment, most people buy bitcoin for its investment value. Because Bitcoin is a decentralized system, investors have neither control nor influence over Bitcoin; they only control their obtained share.

Therefore, the total carbon footprint of Bitcoin could be allocated proportionally among investors. Tesla, for instance, invested $1.5 billion over an unknown period.[1] Assuming that Tesla paid the average price in January 2021 of $34,534.02 per bitcoin, the company acquired 43,435 bitcoins. Tesla then announced that it had sold 10% of its bitcoins in April 2021, leaving the company with around 39,092 bitcoins, or 0.21% of all bitcoins currently in circulation (18,713,700). According to a proportional emissions approach, Tesla should receive a share of 0.19 Mt CO_2 annually (0.21% times 90.2 Mt CO_2). Factoring in that approximately a fifth of all bitcoins might be permanently inaccessible, Tesla's

Figure 1. ESG aspects to consider for cryptocurrency investments
This framework was developed by the authors and is based on Global Reporting Initiative Standards.

annual share of emissions shifts to 0.24 Mt CO_2. This value is equivalent to 1.43% of the total emissions saved by Tesla vehicles up until May 2021, and the total Bitcoin carbon footprint exceeds the total GHG emission reductions of electric vehicles (51.9 Mt CO_2 in 2020) as reported by the International Energy Agency's EV Outlook 2021. To illustrate the absolute size, Figure 2 puts Bitcoin's carbon footprint and the share of Tesla's investment into perspective with country-level emissions.

Carbon emissions are not the only environmental impact of Bitcoin. Bitcoin miners use considerable quantities of highly specialized and short-lived mining hardware that cannot be repurposed. The entire network generates as much electronic waste as a country like Luxembourg does annually, which results in an electronic waste footprint of almost 135 g of equipment (equivalent to the weight of an iPhone 12 mini) per transaction processed on the Bitcoin network.[6] This equipment is primarily made of aluminum, copper, iron, and rare earths. Low waste collection and recycling rates in countries with high mining activity create the risk of toxic chemicals and heavy metals leaching into soils and causing air and water pollution. Unlike Bitcoin, other cryptocurrencies rely on mining mechanisms that require general-purpose hardware such as CPUs or GPUs that can be repurposed once it cannot be profitably run.[7]

Social impact

Although leading investment banks currently only consider the environmental factors of Bitcoin in their ESG assessments of this digital currency,[8] recent research has examined the social impact of Bitcoin. Relevant aspects include societal security, labor practices, equality, and health impacts.

Recent events have drawn attention to how Bitcoin could affect societal security. For instance, Bitcoin mining could enable countries such as Iran or Russia to circumvent economic sanctions imposed to increase international safety.[2] Additionally, the soaring demand for mining hardware is exacerbating the global shortage of computer chips. This shortage could prevent automakers from manufacturing more electric cars, because electric vehicles require far more chips than do traditional combustion engine vehicles. The chip shortage also constrains the supply of laptops, mobile phones, and other electronic devices.[2] If this situation continues, it could impact the availability of equipment required to work from home. Remote work has become a vital strategy in preventing the spread of the coronavirus disease 2019 pandemic,[9] reducing the need for heating and cooling commercial properties and reducing gasoline used for transportation.

Bitcoin mining could also significantly affect societal security due to its impact on electrical-grid stability. Power outages in Tehran and Sukhumi have illustrated how local communities might suffer due to the popularity of Bitcoin mining.[10,11] Bitcoin miners typically operate 24/7, year-round, but higher baseload demand will reduce grid stability during periods of peak demand.

Bitcoin could also be linked to illegal financial activities. Although criminal use of the network for money laundering or other illicit transactions is limited and comprises only 0.3% of the overall transaction volume,[8] Bitcoin is characterized by an absence of trusted third parties, a central issuing authority, or proper regulation. As such, Bitcoin offers no comprehensive nor clear legal protection for its users. Critics argue that Bitcoin offers "significant opportunities" for theft and fraud[12] and that cryptocurrency markets are prone to price manipulation.[13] Recently, Bitcoin has been associated with ransomware used for cyber-extortion, which can be linked to terrorist activities.[14]

When examining the social impact of Bitcoin, labor practices should be considered, because Bitcoin mining might occur in locations that violate international working condition standards. A significant number of Bitcoin miners are found in the Chinese province of Xinjiang because of its abundance of cheap coal-based power. In April 2021, an incident in a local Xinjiang coal mine interrupted one-third of the entire Bitcoin network's computational power.[15] ESG-compliant investors should therefore consider potential conflicts of interest, because coal mines in Xinjiang have been mentioned in the context of forced labor. Xinjiang has repeatedly been criticized for hosting detention camps for Muslim minorities such as Uighurs.

Of all the social aspects discussed in this section, Bitcoin's effect on a healthy lifestyle is less concrete. However, the production of electricity required to run the Bitcoin network has been linked to air pollution, which directly impacts human health.[16]

Governance considerations

Governance might seem like the least-relevant ESG factor that concerns Bitcoin, because by design Bitcoin is not controlled by any entity. However, multiple parties have a significant influence on Bitcoin and its surrounding ecosystem. Governance includes aspects such as transparency, competitive behavior, indirect economic impacts, and taxation.

First and foremost, the Bitcoin network is based on open-source software. Anyone can run, change, fork, or develop code that enables participation in the

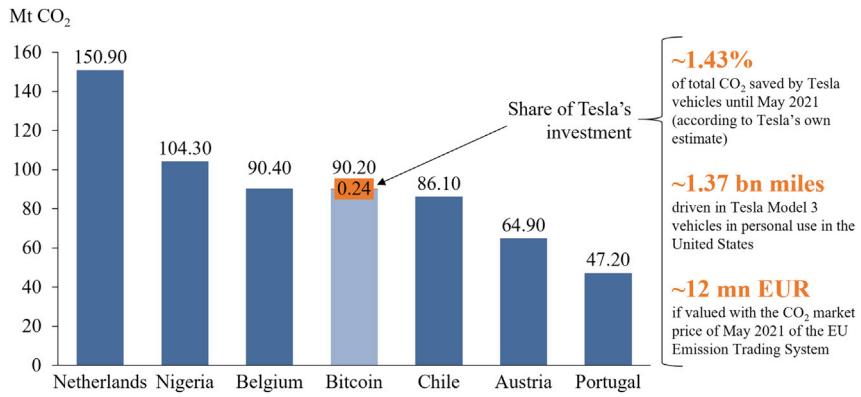

Figure 2. Comparison of Bitcoin's carbon footprint to national annual CO_2 emissions

Country-level emissions are obtained from the International Energy Agency.[3] Tesla's share in the total Bitcoin carbon footprint[2] is compared to the lifetime CO_2 savings of Tesla vehicles per May 2021, according to Tesla's own estimate.[4] Tesla's impact report shows that the life-cycle emissions for a Model 3 (personal use) amount to 175 g of CO_2 per mile.[4] 0.24 million metric tons of CO_2 is therefore equivalent to 1.37 billion miles in a Model 3. The carbon price of around EUR 50 per ton of CO_2 in May 2021 is based on the EU Emission Trading System carbon market price.[5]

Bitcoin network. Although several different implementations exist, 95% of all publicly available nodes in the network run "Bitcoin-core," the original software written by Satoshi Nakamoto. A small group of developers manages the corresponding GitHub repository, and potential updates are discussed via Bitcoin improvement proposals (BIPs). However, because Bitcoin-core has no automatic updates, network participants decide which code they run on their node.

A small number of privately owned mining pools control the majority of computational power in the Bitcoin network,[17] which endangers competitive behavior. This concentration of control enables large actors to form new points of control within the blockchain infrastructure, because these parties have the power to accept or reject BIPs. Other actors in the ecosystem, such as exchanges, managers of fiduciary funds, or influencers with huge numbers of followers, can easily alter beliefs and investment behavior, which could lead to abuse of market power. Such actions affect the network's reliability and integrity and threaten the confidentiality of information about network users.

Further, Bitcoin might enable tax evasion. Depending on the jurisdiction, capital gains on Bitcoin or other cryptocurrencies might be subject to taxes. Because of Bitcoin's decentralized nature and because a single bitcoin cannot be attributed to a country, the owner of Bitcoin assets has the autonomy to decide where and how to file any related capital gains.

Conclusion

Tesla was the first company listed on the S&P 500 stock market index to buy Bitcoin assets, and other large institutions have started to recognize digital currencies as a means to diversify their portfolios. In parallel, a growing number of investment products such as cryptocurrency exchange-traded funds facilitate trading in cryptocurrencies for the general public. However, Tesla suspended the purchase of vehicles using Bitcoin over environmental concerns just 50 days after first enabling this practice, which highlights an increased public awareness of ESG issues.

The trend toward more focus on ESG-compliant investments could gain more momentum as the threat of climate change compels global populations to work toward net-zero emissions. As investors place more emphasis on ESG, all types of assets will be challenged to comply with new transparency standards. For example, in addition to crypto mining, the gold-mining industry encounters challenges in its alignment to ESG standards.[18] The ESG concept is, however, not limited to environmental externalities. In this commentary, we have indicated that Bitcoin investments and exposure to cryptocurrency in general could be associated with significant ESG issues. Relevant social aspects include societal security, labor practices, equality, and health impacts. Governance aspects must also be considered, because investors could face risks from untransparent mining activities, concentration of power, negative indirect economic impacts, and issues of tax evasion. Therefore, both investors and academics should adopt a broad and comprehensive perspective when considering the external impacts of cryptocurrency investments.

AUTHOR CONTRIBUTIONS

All authors contributed equally.

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