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# Blockchain, climate damage, and death: Policy interventions to reduce the carbon emissions, mortality, and net-zero implications of non-fungible tokens and Bitcoin

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ABSTRACT

The art industry has commercialised and popularised non-fungible tokens (NFTs), with the volume and value of NFT transactions rapidly growing to US$ 10.7 billion in Q3 2021. The increase in NFT transactions has drawn the attention of the art market to the consequent carbon emissions resulting from verifying transactions in proof-of-work blockchains supporting NFT transactions. With $CO_2$-related deaths attributable to NFT transactions, social pressure from the art market has helped to progress the switch away from the deliberately polluting proof-of-work blockchains to more sustainable consensus protocols.

Nonetheless, many popular types of blockchain have resisted the pressure to decrease their environmental impact, including Bitcoin, whose attributed 2021 annual emissions will produce emissions responsible for around 19,000 future deaths. In response, recent global policy interventions have employed legal and fiscal tools to reduce the carbon impact of some or all types of blockchains. Linking the damage caused by proof-of-work blockchains to climate change and human mortality, this study examines the recent policy interventions designed to motivate a shift in blockchain consensus protocols and promote miners' energy efficiency to mitigate environmental damage. This article further explores available policy intervention options that are currently not utilised.

## 1. Introduction

### 1.1. NFTs: a new way to cause pollution

This article initially highlights the problem related to energy consumption and emissions caused by NFTs and other types of blockchain activity, linking the damage to the Paris Agreement goals and human mortality. It explains how social pressure resulting from the use of NFTs in the art market has impacted the NFT platform's choice of blockchain, and ultimately affected the developer's choice of consensus protocol. For example, social pressure has helped to motivate a planned switch in Ethereum, the largest NFT platform, away from the polluting proof-of-work consensus protocol. The article then explores policy intervention options designed to encourage the use and development of more sustainable blockchain, in the case that the industry does not respond to social pressure.

Non-fungible tokens (NFTs) are yet another example of how technology is reshaping the concept of property ownership, where NFTs offer solutions for new types of ownership, while limiting possession and control.[1] Notably, NFTs offer important security and ownership verification advantages, as well as ease of transacting and offering benefits beyond the art world [1].[1] The rapidly increasing uptake of NFT transactions has increased social attention towards the level of emissions from proof-of-work blockchain networks that support NFT transactions (Section 3.1.1 below identifies why this type of blockchain is damaging and unsustainable). Artists and the art market have been faced with dangerous and widely acknowledged levels of emissions caused by the existing high-energy consuming proof-of-work blockchain networks that

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[1] NFTs, for example, may be a solution for determining the possession and control over a digital property, especially when such possession and control may arguably rest in a non-human AI or an algorithmic entity managed solely by an algorithm. For a general discussion on AI ownership of property, see Rafael Dean Brown (2021) Property ownership and the legal personhood of artificial intelligence, Information & Communications Technology Law, 30:2, 208–234, DOI: 10.1080/13600834.2020.1861714.

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support most NFT transactions.[2] Ethereum, the most popular network for NFT transactions, is switching its consensus protocols away from proof-of-work[3] and a roadmap has set out the context for such change which focuses on sustainability.[4] This is a sign of progress resulting partially from a combination of the social pressure from the environmentally aware NFT art market, the need to lower energy costs and the looming threats of proof-of-work targeted policy intervention.[5] Less popular and newer platforms supporting NFTs have also advertised their environmental credentials, avoiding proof-of-work in favour of energy-efficient consensus protocols. Palm[6] uses Ethereum blockchain to trade NFTs claiming to consume 99% less energy than proof-of-work blockchain, while Cardano[7] and Flow[8] offer alternative models for NFT trading.

Nevertheless, a deliberately high energy-intensive proof-of-work blockchain remains the most popular choice for blockchain consensus protocols [2].[2] Where social pressure fails to persuade developers to switch to more sustainable blockchain, there are a range of available options for policy-makers that can be considered.

The article explores the impact of social awareness in encouraging a shift away from proof-of-work consensus protocols, using the examples of NFTs. Namely, the article details how the environmental awareness raised by the recent NFT phenomenon has progressed the shift away from polluting proof-of-work for Ethereum, the most popular blockchain network supporting NFT transactions. It has also encouraged the choice in the design of new NFT-platforms away from proof-of-work consensus protocols. With a view towards encouraging a shift away from proof-of-work blockchains outside of only NFTs, this study explores tools for policymakers when social pressure is insufficient. The article examines recent global policy intervention options and suggests other available methods.

### 1.2. Differentiating sustainable and unsustainable blockchains

The ambition of COP26[9] to secure global net-zero carbon emissions by 2050 is threatened by the alarming rise in the carbon footprint of the most popular blockchain networks, which are resisting technological modifications that would reduce their energy consumption. The emissions caused by proof-of-work consensus protocols not only pollute the planet but also cause unnecessary human deaths. The article finds that carbon emissions as a result of NFT transactions in October 2021 alone are expected to kill 18 people, and such social costs are severely discouraging for artists and art traders. This is only a fraction of the 8326 unnecessary future deaths caused by Ethereum's annual emissions and the 18,818 unnecessary future deaths Bitcoin's blockchain will cause resulting from its 2021 emissions (see Section 2.3: Why are NFTs bad for the environment?). Bitcoin is resistant to change and not a platform for NFTs transactions (though may be used for payments), which has limited impact from socially conscious art collectors and artists.

Not all blockchains pollute, and more sustainable alternatives do exist. Some require significantly lower levels of energy consumption, which would have a negligible impact on global emissions and not result in a vast number of deaths. Given the importance of blockchain to the economy and society, it is vital to differentiate between types of blockchains based on their consensus protocols to determine how to encourage sustainable choices. It is also necessary to consider how to motivate more efficient device mining hardware (such as application-specific integrated circuit (ASIC) devices) to increase the energy efficiency of proof-of-work miners.

### 1.3. Structure

Previous research has explored regulatory and fiscal tools available to policymakers to reduce emissions from blockchain-related activities. This study explores the recent developments to evaluate how theoretical possibilities have worked in practice. The article also provides alternative suggestions, such as taxation of ASIC devices dependent upon emissions and tax tools, to influence the platform's choice of the underlying blockchain based on the consensus protocol. It identifies how the polluting costs of NFT trading and other types of blockchain activity are passed onto society,[10] while the commercial benefits are retained privately [3].[3] The extent of the polluting activity threatens the progress being made towards achieving climate targets in the UN Sustainable Development Goals (SDGs).[11] This article references legal and economic theories based on the 'polluter pays' principle and carbon pricing to internalise negative environmental externalities [4][4] in order to motivate a switch to a more environmentally efficient blockchain.[12]

This article explains the recent progress in improving blockchain energy consumption efficiency and explores recent developments resulting from the legal tools used by policymakers to mitigate environmental problems. This article overviews key tools used to encourage a more sustainable design of blockchains that are resistant to voluntary redesign, from the social pressure to regulatory developments and fiscal tools. This overview will help policymakers to understand the impact of such market interventions and options available, while considering their disruptive effects. It concludes with an understanding of the measures needed to mitigate negative externalities.

## 2. NFT phenomenon

NFTs are unique and non-replicable digital assets recorded as cryptographic tokens on the blockchain. The technical term of 'ERC20 Standard'[13] tokens is given to fungible tokens of the same value that can be interchanged like-for-like, such as two identical Bitcoins. This is different from 'ERC721' tokens[14] which are non-interchangeable as they are a unique digital assets with their own values, making them non-fungible tokens. NFTs provide a secure and innovative means of certifying ownership of either physical or digital assets, which can then be traded. Ethereum allows both fungible and non-fungible tokens on its

[2] How bad are NFTs for the environment? The Independent, 22 April 2021, https://www.independent.co.uk/climate-change/sustainable-living/nft-environment-climate-change-crypto-b1835220.html, accessed 18 October 2021.

[3] Ethereum, Proof of Stake, https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/ accessed 27 December 2021.

[4] Endgame https://vitalik.ca/general/2021/12/06/endgame.html, accessed 27 December 2021.

[5] Ethereum Closes In on Long-Sought Fix to Cut Energy Use Over 99%, Bloomberg, 23 May 2021, https://www.bloomberg.com/news/articles/2021-05-23/ethereum-closes-in-on-long-sought-fix-to-cut-energy-use-over-99 accessed 27 December 2021.

[6] https://palm.io/, accessed 1 January 2022.

[7] https://cnft.io/, accessed 1 January 2022.

[8] https://www.onflow.org/, accessed 1 January 2022.

[9] UN Climate Change Conference UK 2021 https://ukcop26.org/, accessed 24 August 2021.

[10] Contrary to the polluter pays principle which recommends de-socialising external environmental costs, 1974 OECD Recommendation on the Implementation of the Polluter-Pays Principle[C(74)223]: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(92)81&docLanguage = En (accessed 27 May 2018).

[11] UNDP, Sustainable Development Goals, https://www.undp.org/sustainable-development-goals#:~:text=The%20Sustainable%20Development%20Goals%20(SDGs)%2C%20also%20known%20as%20the,people%20enjoy%20peace%20and%20prosperity, accessed 24 August 2021.

[12] The OECD refer to this as "…continuous incentive for pollution abatement and technical innovation." OECD, Environmental Taxes Recent Developments in China and Developing Countries (Paris, OECD, 1999) 52.

[13] https://eips.ethereum.org/EIPS/eip-20, accessed 1 January 2022.

[14] https://eips.ethereum.org/EIPS/eip-721, accessed 1 January 2022.

ERC1155 multi-token standard.[15] Bitcoin however only allows fungible trading of Bitcoins.

### 2.1. NFT uses

While NFTs offer possibilities for certifying ownership of various assets, such as real estate, it is the art market where NFTs have proven to be the most popular to date. Tokenising physical or digital art via NFTs has enabled ownership to be both indisputably verified using blockchain technology and provided a simplified means of buying and selling such art. Artist Damien Hurst has offered tradeable NFTs that verify the ownership of digital art,[16] while some digital assets, such as YouTube clips and social media posts, have themselves been tokenised, thereby creating a tradeable asset and a store of value.[17] Such content may not have been traditionally thought of as art, but rather part of the digital commons.[18] As such, traders have found a novel means of capitalising on hitherto free content, by creating ownership and selling it as a unique digital asset. The digital signature of each unique NFT makes it a collectible item, proving ownership of a unique piece of art or music, for example.

In addition to practical and financial uses, some NFTs have been created as part of a cultural blockchain phenomenon, where people seek to own a digital version of an image, song, or video. While the unique properties can easily be replicated, holding an NFT is similar to owning a certified original version of a popular image or an autographed print. Many NFTs that are playful or irreverent have been created as part of a meme culture, whereas some have attracted significant attention as cultural artefacts. For example, the first tweet by Twitter's founder, Jack Dorsey, was sold for approximately US$ 3 million at an auctions.[19] Notwithstanding the public availability of the tweet (see Fig. 1), the authentic rights to the tweet became a collectible part of Internet history, in the same way that an autographed original copy of a famous book may be valuable. The rights to the NFT for the YouTube sensation video, 'Charlie bit my finger', sold for GBP 538,000, while the image connected with meme-based digital currency, 'Dogecoin', sold as an NFT

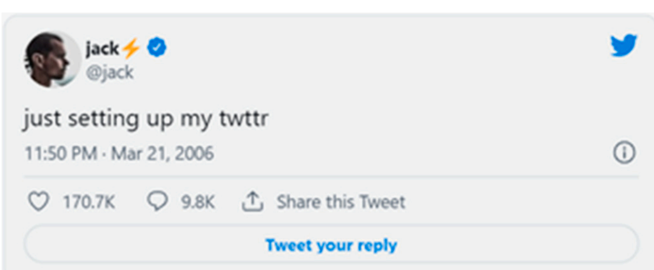


**Fig. 1.** Jack Dorsey's first tweet.
twitter.com/jack/status/20.

for US$ 4 million[20] (see Fig. 2). This novel and emergent usage differs from that of tradeable digital currencies.

As the technology supporting NFTs depends on smart contracts [5],[5] NFTs offer significant uses beyond collecting valuable assets. Contractual rights can be endowed through an NFT, such as the rights to the royalties of a music track and offering significant opportunities for commercial and financial markets. Furthermore, there is the potential to utilise the technology to tokenise the ownership of vehicles or real estate, for example, which could simplify the administrative procedures involved in buying and selling vehicles and homes. This enhances the security of transactions by preventing disputes from fraudulent or incorrect claims to ownership of property, since ownership is immutably verified, and the record is publicly available on the blockchain. The substantial value of NFT transactions combined with the potential utilities of its technologies means that their use is expected to grow.

### 2.2. NFTs and blockchain

Notably, NFTs are supported by the same blockchain technology utilised for digital currencies, such as Bitcoin. Extensive literature[21] is devoted to applications of blockchain beyond digital currencies [6],[6] such as in smart contracts, and emergent uses, including NFTs and gaming. For example, the Ethereum blockchain is being used to trade the digital currency Ether, but the open-source design of Ethereum means it is used for a variety of other uses, including decentralised finance [7],[7] peer-to-peer lending or trading [8][8], alternative digital currencies, decentralised autonomous organisations, smart contracts, and NFT trading.[22]

All such blockchain technology applications collectively cause emissions, and the scale of emissions is dependent upon the design of the blockchain being used for that application [9,10].[9,10] For example, Ethereum is the prevailing choice of blockchain for NFTs, but there may be alternative blockchains available to trade NFTs that may be more or less polluting than Ethereum depending upon their design. Moreover, NFT transactions do not yet cause the scale of emissions attributed to Bitcoin and other leading digital currency transactions. Nevertheless, the growing usage of NFTs is concerning, given that it contributes to the collective emissions caused by the underlying blockchain technologies supporting NFT transactions. For example, NFT sales increased eightfold to US$ 10.7 billion in Q3 2021 from the previous quarter (see Fig. 3). With the rapid pace of growth, the extent of the pollution problem raised by environmentally conscious users can no longer be ignored by blockchain developers. Artists and art traders have actively sought to avoid proof-of-work blockchains and favoured energy-efficient alternatives,[23] a recognition of the social impact of the art market.

[15] https://ethereum.org/en/developers/docs/standards/tokens/erc-1155/, accessed 1 January 2022.

[16] Damien Hirst launches his own NFT 'Currency', Financial Times, 14 July 2021, https://www.ft.com/content/9a29c9e1-5990-4fc9-b021-20e4aef5f6fd, last accessed 20 July 2021.

[17] What you need to know about non-fungible tokens (NFTs), Forbes, 24 May 2021, https://www.forbes.com/uk/advisor/investing/nft-non-fungible-token/ last accessed 20 July 2021.

[18] Raúl Tabarés Gutiérrez, Understanding the role of digital commons in the web; The making of HTML5, Telematics and Informatics, Volume 35, Issue 5, 2018, pp. 1438–1449, doi:10.1016/j.tele.2018.03.013.

[19] Reuters, Twitter boss Jack Dorsey's first tweet sold for $2.9 million as an NFT, 22 March 2021. https://www.reuters.com/article/us-twitter-dorsey-nft-idUSKBN2BE2KJ.

[20] NFTs and me: meet the people trying to sell their memes for millions, The Guardian, 23 June 2021, https://www.theguardian.com/technology/2021/jun/23/nfts-and-me-meet-the-people-trying-to-sell-their-memes-for-millions.

[21] See for example the devoted journals Frontiers in Blockchain https://www.frontiersin.org/journals/blockchain, as well as Blockchain: Research and Applications https://www.journals.elsevier.com/blockchain-research-and-applications; and publications such as Mohd Javaid, Abid Haleem, Ravi Pratap Singh, Shahbaz Khan, Rajiv Suman, Blockchain technology applications for Industry 4.0: A literature-based review,Blockchain: Research and Applications, 2021, doi:10.1016/j.bcra.2021.100027.

[22] Key use cases for Ethereum and Blockchain, https://www.gemini.com/cryptopedia/ethereum-smart-contracts-tokens-use-cases, accessed 11 October 2021.

[23] NFTs are shaking up the art world. They may be warming the planet, too. New York Times, https://www.nytimes.com/2021/04/13/climate/nft-climate-change.html.

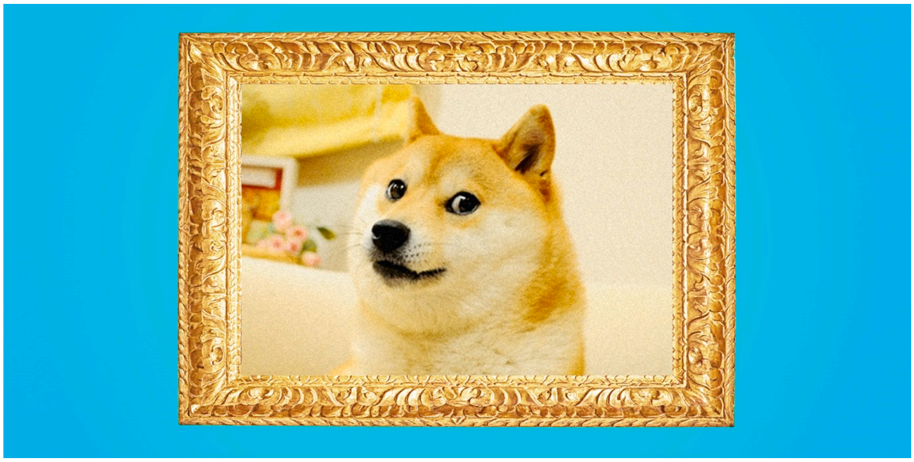

**Fig. 2.** Record-breaking NFT sale of meme-based digital currency Dogecoin.
Source: NBC News; Getty Images https://www.nbcnews.com/pop-culture/pop-culture-news/iconic-doge-meme-nft-breaks-records-selling-roughly-4-million-n1270161.

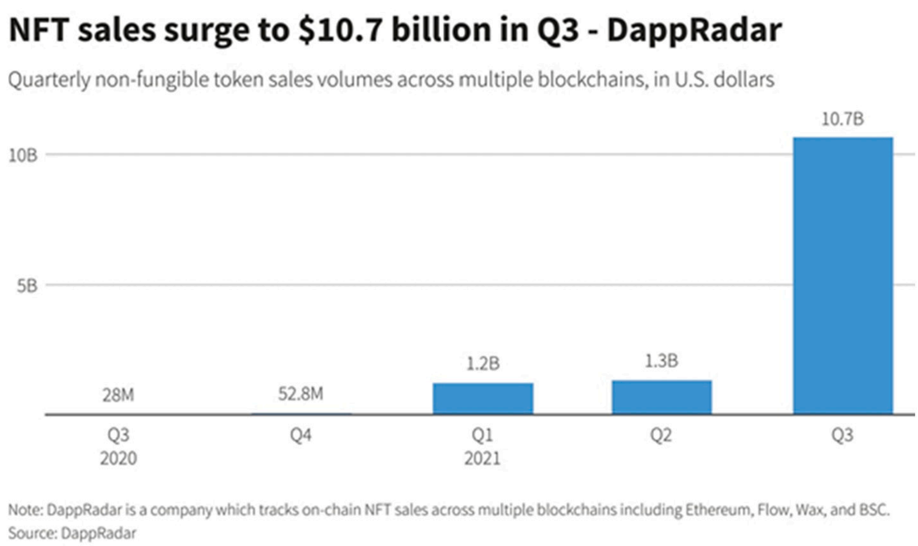


**Fig. 3.** NFT sales Q3 2021.
NFT sales surge to $10.7 bln in Q3 as crypto asset frenzy hits new highs, Reuters, 4 October 2021, https://www.reuters.com/technology/nft-sales-surge-107-bln-q3-crypto-asset-frenzy-hits-new-highs-2021-10-04/.

### *2.3. Why are NFTs and some types of blockchain bad for the environment?*

Notably, NFT transactions have significant commercial and financial potential within and beyond the art market, thereby enabling digital transactions to become more secure and efficient. However, NFTs' dependence on purposefully energy-intensive blockchain technologies means that buying or selling an NFT asset comes at an environmental cost.

Furthermore, NFT transactions rely on smart contracts and take place through blockchain, with transactions verified through peer-to-peer mining akin to digital currencies. Ethereum, which is also used for transacting the Ether[24] digital currency, has become the choice venue for NFT art transactions. The growth of NFT transactions poses a major problem because of the energy-intensive transaction verification process, requiring multiple mining devices to verify a blockchain transaction. The greater the number of transactions, the greater the demand on the network and the more such mining devices are demanded and operated. In the Bitcoin network for example, this can require seven mining devices each plugged in and consuming energy 24 h a day. As Bitcoin mining devices are only rewarded when there is a verification of a transaction, the number of mining devices plugged in and operating depends upon the level of demand for transaction.

Ethereum's overall mining processes to verify transactions consume a similar amount of energy to the Republic of Ireland,[25] and it is only one of the thousands of platforms available. Thus, NFT trade contributes to global problems because it increases demand for verification devices and ultimately how many devices are operating at any one time. (NFT transacting parties may have been unaware of the carbon-intensive nature of their purchase or sale, although news coverage has created awareness of the problem and resulting design choice changes.) Buying

[24] https://ethereum.org/en/.

[25] Digital NFT art is booming—But at what cost? Time, 18 March 2021, https://time.com/5947911/nft-environmental-toll/, last accessed 20 July 2021.

an NFT artwork has been reported to entail the same energy consumption as the average EU household uses in a month.[26] The energy-intensive design of Ethereum and other types of blockchains means that the growing usage of NFTs in their current form threatens global efforts to retain global temperatures below 2 °C.[27]

Furthermore, current emissions from mining devices supporting NFTs transactions are expected to kill people at some time in the future. Bressler estimates that the average lifetime carbon emissions of 3.5 Americans (4434 metric tons or 4,434,000 $kgCO_2$) will kill one person between 2020 and 2100 who would not otherwise have died.[28] Death rates from Blockchain transactions can then be estimated based on Bressler's calculations, by calculating the estimated emissions caused by a Blockchain network and dividing the number of transactions to calculate an estimated emissions transaction cost. This will differ by Blockchain network since each type of Blockchain consumes a different rate of energy, but this is helpful to compare the relative emissions and consequently the relative predicted death rate.

Each single Ethereum transaction is estimated to cause 85.47 $kgCO_2$[29] resulting from the mining devices involved in verifying the transaction, and there were 942,812 NFT sales in the month preceding October 10, 2021.[30] Assuming that NFT transactions on the Ethereum blockchain have the same carbon footprint as other transactions on the Ethereum blockchain, and based on the assumption that 4434 metric tonnes could kill a person unnecessarily, the mining devices needed to verify 51,877 transactions would produce enough emissions to kill a person between 2020 and 2100. Hypothetically, the mining devices verifying NFT sales in one month in 2021 would be responsible for approximately 18 unnecessary future deaths from carbon emissions. This is on the assumption that all such NFT transactions took place on blockchains equal to Ethereum's carbon footprint, which may be inaccurate but a useful guidance point. With every NFT transaction contributing to the death of a person, there is an urgent need to reduce emissions and mortality rates. The significant rise in NFT transactions has been partially responsible for the increase in Ethereum's carbon emissions (as well as alternative blockchain networks used for NFTs).

What is troubling with NFTs is the pace at which transactions are rising. NFT sales rose from approximately US$ 1 billion in Q2 2021 to over US$ 10 billion in Q3. This rapid increase in the number of months has considerably worsened the overall environmental impact of NFTs.[31] The scale of the problem is increased when the entirety of all Ethereum transactions are considered, not only NFTs. The entire Ethereum network is estimated to produce 36.92 Mt. of $CO_2$[32] (36,920,000,000 $kgCO_2$). At Bressler's same estimated rate of 4434 metric tonnes, this projects an unnecessary future death rate of 8326 people caused by one year of Ethereum's network operation alone. Ethereum is only one type of blockchain, meaning that the total blockchain future mortality rate is likely to be much higher. The social backlash against the artist's carbon impact was partially responsible for pushing Ethereum to upgrade its network away from its polluting proof-of-work model.

Digital currencies still are responsible for many times more emissions than NFTs. When compared with Bitcoin, which is approximately 10 times more polluting than Ethereum per transaction (a single transaction causes 842.51 $kgCO_2$ compared to Ethereum's 85.47 $kgCO_2$), Bitcoin will cause significantly more deaths for a much lower use rate. With an estimated annual carbon footprint of 83.44 $MtCO_2$[33] (83,440,000,000 $kgCO_2$), Bitcoin is responsible for an estimated 18,818 unnecessary future deaths per annum as of October 2021. This is particularly notable as Bitcoin does not have the multiple use versatility of the Ethereum network, as it only is only available for trading fungible tokens. However, Bitcoin's decentralised network relies upon its original White Paper that does not envision changing its consensus protocol regardless of its emissions levels.[34]

Scholars have warned about the growing negative impact of blockchain-related pollution, especially that caused by digital currency transactions [11].[11] Recently, blockchain energy efficiency has rather improved, but the increase in blockchain transactions worldwide has increased the overall energy consumption and resulting emissions. Unfortunately, NFTs are now adding to this problem (see Fig. 4), and the increasing scale of the blockchain's energy consumption has become a major global problem. There are also concerns of how PoW blockchains disproportionately impact vulnerable communities.[35]

There are alternative blockchain networks available to host NFT platforms that are significantly less energy intensive because they have adopted alternative consensus protocols, such as Tezos[36] and VeChain.[37] Such consensus protocols ought to be encouraged over the more polluting versions on environmental grounds. Blockchain developers are, however, cautious to move away from a tried-and-tested blockchain model with its security advantages [12][12] and acceptable ability to maintain Byzantine fault tolerance [13].[13] There are also concerns about centralising what is supposed to be a decentralised network by selecting the verifying nodes. As such, proof-of-work consensus protocols remain the most popular type of blockchain.

Given the extent of the risk to the environment of continuing to allow the free market [14][14] to operate without internalising the polluting costs, policymakers are seeing a need for policy intervention to correct this market failure before it is too late. Some mining operators are realising this possibility and taking proactive measures to avoid regulatory intervention, but the overall behaviour [15][15] of the mining community is insufficiently changing at present.

The impact of digital currencies dwarf that of NFTs, and the latter are likely to reduce in their impact due to Ethereum's upgrade. The objective of the next section is to evaluate available policy measures designed to reduce the emissions rate and consequent expected mortality rate related to blockchain transactions. The scale of damage caused by transactions of NFTs and digital currencies all depends upon the design of the supporting blockchain. Where the developers refuse to adapt the technology to minimise environmental damage and human mortality,

[26] 'How bad are NFTs for the environment?' The Independent, Thursday 22 April 2021 https://www.independent.co.uk/climate-change/sustainable-living/nft-environment-climate-change-crypto-b1835220.html, last accessed 20 July 2021.

[27] United Nations Framework Convention on Climate Change, Paris Agreement, Conference of the Parties Twenty-first session Paris, 30 November to 11 December 2015, FCCC/CP/2015/L.9/Rev.1.

[28] "Our central estimate 2020 MCC also implies that reducing (adding) 4434 metric tons of carbon dioxide in 2020 saves one life (causes one excess death) in expectation globally between 2020 and 2100. In all, 4434 metric tons is equivalent to the lifetime emissions of 3.5 average Americans…" Bressler, R.D. The mortality cost of carbon. Nat Commun 12, 4467 (2021). doi:10.1038/s41467-021-24487-w.

[29] Digiconomist, Ethereum Energy Consumption Index, https://digiconomist.net/ethereum-energy-consumption, accessed 12 October 2021.

[30] https://nonfungible.com/market/history, accessed 18 October 2021.

[31] NFT sales surge to $10.7 bln in Q3 as crypto asset frenzy hits new highs, Reuters, 4 October 2021 https://www.reuters.com/technology/nft-sales-surge-107-bln-q3-crypto-asset-frenzy-hits-new-highs-2021-10-04/.

[32] Digiconomist, Ethereum Energy Consumption Index, https://digiconomist.net/ethereum-energy-consumption, accessed 13 October 2021.

[33] Digiconomist, Ethereum Energy Consumption Index, https://digiconomist.net/bitcoin-energy-consumption/, accessed 17 October 2021.

[34] https://bitcoin.org/bitcoin.pdf, accessed 1 January 2022.

[35] Peter Howson, Alex de Vries, Preying on the poor? Opportunities and challenges for tackling the social and environmental threats of cryptocurrencies for vulnerable and low-income communities,Energy Research & Social Science, Volume 84, 2022, 102394, doi:10.1016/j.erss.2021.102394.

[36] https://tezos.com/nftgallery/.

[37] The crypto world is getting greener. Is it too little too late? Rolling Stone, 9 July 2021, https://www.rollingstone.com/culture/culture-features/nfts-crypto-environmental-global-warming-proof-of-stake-blockchain-1194402/.

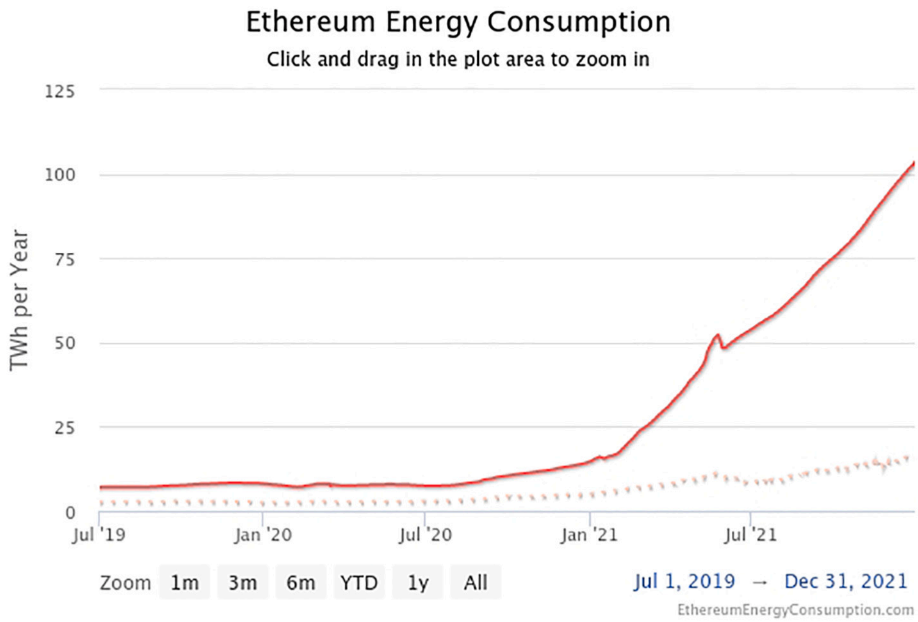


**Fig. 4.** Ethereum energy consumption.
Digiconomist, Ethereum Energy Consumption Index, https://digiconomist.net/ethereum-energy-consumption, accessed 1 January 2022.

policy intervention may be necessitated to affect the market's choice of blockchain or otherwise force technological adaptation through a number of policy options. The objective of evaluating such policy intervention options is to advance the need for sustainable blockchain transactions, to enable its potential without risking overkill market intervention that could eliminate the benefits of blockchain and stifle technological innovation.

## 3. Policy interventions

Previous literature has proposed policy intervention as a theoretical solution: for example Truby proposed multiple policy intervention options in 2018 [11]. Several years on, there are now real-world examples of experimentation with some of the available policy intervention choices from various jurisdictions. The purpose of this section is to evaluate such contemporary examples as available policy tools, as well as to propose alternatives.

### *3.1. Design-side policy interventions: facing the problem of proof-of-work*

#### *3.1.1. Design changes: proof-of-work problem*

Any examination of policy intervention will consider how to motivate a switch away from proof-of-work blockchain. It is impossible to separate the pollution resulting from NFT trading from the underlying problem of inefficiencies in blockchain design. The energy-intensive process of 'mining' to verify a digital currency trade or execute an NFT trade is a result of the design choices of blockchain developers. Mining devices are rewarded for verifying transactions on the blockchain, provide for the security of the transaction, and create a competitive market. The NFT phenomenon has only highlighted the underlying problem with the blockchain's energy consumption.

There are, however, less energy-intensive models available that ought to be encouraged over the more polluting choices, depending on the developer's consensus mechanism choice. The US Congressional Research Service proposes proof-of-stake and proof-of-authority as more sustainable consensus mechanism alternatives to proof-of-work.[38] Proof-of-work uses so much energy because there are multiple validating device developers competing to be rewarded with a digital token. In proof-of-stake consensus protocols, one validator is selected by the blockchain algorithm to complete the verification of a given transaction, which means that far less energy is required to validate a transaction. Proof-of-stake blockchain transactions are verified in a different way, corresponding to the quantity of tokens owned by the miner. Miners use their own digital tokens as collateral and are granted authority over the token proportionate to the sum staked. Thus, the more tokens owned by the miner, the greater is the extent of their mining power. de Vries explains how a proof-of-stake validation blockchain is less energy-intensive, "...participating machines do not have to use their computing power. This prevents both extreme energy use as well as the incentive to develop specialised (singular purpose) hardware and showcases that blockchain technology does not necessarily have a significant environmental impact." [16][16] There is scope through a combination of legal, fiscal, and policy tools to encourage a shift in use towards more energy-efficient blockchain, which would also encourage more efficient design of future blockchain platforms.

Most platforms are reluctant to change and prefer proof-of-work because it is tried-and-tested, industry standard and has more proven security [17].[17] However, developers should be discouraged from path dependence [18],[18] where it causes such significant environmental harm and requires encouragement to focus efforts on innovating efficiencies. When they fail, regulatory intervention may be required [19].[19] The key is balance; regulators must weigh the individual interest in the innovation with the potential risk to the public and the environment, keeping in mind more environmentally sound alternatives [20].[20] Similarly, NFT traders could significantly reduce their carbon impact by avoiding proof-of-work platforms. Regulations could require traders to avoid proof-of-work platforms, or traders could be taxed at the point of transaction based on the energy consumption or emission levels of the type of platform utilised for the transaction. This would be aligned with the polluter pays principle, as accepted in environmental law and policy-making.

#### *3.1.2. Voluntary re-design of proof-of-work*

As developers frequently favour proof-of-work blockchain due to its perceived advantages, policy intervention can also consider how to

[38] Bitcoin, blockchain, and the energy sector, 9 August 2019, https://fas.org/sgp/crs/misc/R45863.pdf, Accessed 30 July 2021.

motivate industry to switch to a more sustainable version. Highlighting the social cost of proof-of-work blockchain designs has encouraged some innovation in designing alternatives to proof-of-work blockchains, as well as improving the problems with the proof-of-work blockchain itself. El-Masri et al. propose an alternative proof-of-work design that does not waste computing resources, as in other proof-of-work designs [21].[21] Instead, the paper's 'proof-of-useful-work' design utilises the computational power used to validate a blockchain transaction to add benefits to the users. It provides an example of how the 'squandered computing resources' can be recycled to provide solutions, in this case, saving costs for the blockchain participants. This novel redesign of proof-of-work has come about because of the pressure on industry to abandon the classic proof-of-work blockchain, while recognising that developers prefer the security benefits encompassed within proof-of-work compared to alternative designs. However, it still requires developers to switch consensus protocols from proof-of-work which is problematic in itself.

### 3.1.3. *Voluntary re-design away from proof-of-work*

Time will tell how effective industry's voluntarily changes are in reducing emissions and energy consumption, and whether policy intervention is actually needed to require developers to go further than industry choices. Mining device operators can be pushed to rely more on clean energy for their machines, while developers can switch their blockchain design so the mining devices require less energy [22].[22] Ethereum transactions are estimated to have a significantly lower carbon footprint than Bitcoin,[39] but the levels remain disproportionately high relative to their use. The capacity of Ethereum to host multiple different types of applications and its open-source design has made it an increasingly popular platform. Ethereum's energy consumption has risen considerably recently, and the transaction rates of NFTs have increased (see Fig. 4). With Ethereum, the platform of choice for the NFT market, there has been pressure on developers to reduce Ethereum's carbon impact. Pressure from scholars and regulators, as well as a social outcry against the carbon impact, has had some impact in motivating developers to adapt to less polluting alternatives to proof-of-work such as proof-of-stake [23].[23]

Ethereum's planned switch to a proof of stake algorithm, Casper, is expected to be less energy intensive[40] and reduce its emissions a thousand-fold, which is enormously significant.[41] Ethereum has detailed the plans[42] as part of its upgrade to reduce the level of computational power used in verifying transactions, in order to reduce the consequent energy use to become more sustainable.[43] This would considerably reduce the NFT-linked mortality rate and overall mortality rate caused by the Ethereum network. Ethereum further claims that upgrading to proof-of-stake will actually make its planned blockchain more secure, negating the reason given by other blockchain developers that security is lower than proof-of-stake. The upgrade may largely make mining devices unnecessary and redundant, which would explain the predicted significant decrease in Ethereum's carbon footprint. Essentially, there will be no need for the current levels of electricity consumption because there will be less need for mining Ether owing to a reduction in the need for solving mathematical puzzles to verify transactions. Ethereum users will "…leverage their existing cache of ether as a means to verify transactions and mint new tokens. This will still limit the amount of new coin created but without requiring the energy used to run massive banks of computers to solve math equations."[44] This would inevitably render the bulk of ASIC mining devices redundant, as they will not be needed to randomly verify transactions since the network will choose the device itself.[45]

Given that the switch happens, this will be a ground-breaking precedent and may encourage other blockchain platforms to switch. This is of crucial importance given that the switch can significantly lower emissions levels for all types of Ethereum transactions, including NFTs. The timing of the Ethereum upgrade is dependent on certain technical prerequisites. The mining community is against this as it affects their business model because fewer mining devices are needed and rewarded for validating transactions.[46] If Ethereum, as one of the major blockchain players, can prove the success of this blockchain over proof-of-work consensus protocols, it can break the cycle of path dependence and security fears of developers and networks. This could push other developers to upgrade to this cleaner version, including NFT transactors, and reduce the overall levels of emissions. If it fails, the risk is that the industry will double down on proof-of-work.

### 3.1.4. *Regulating against proof-of-work*

Where social and environmental concerns fail to motivate a switch away from proof-of-work, policy intervention has been utilised to achieve the desired results and this remains an option for future policy makers. Some jurisdictions are actively recognising the need to specifically discourage proof-of-work designs, given their high energy use. New York State Senate has passed a bill specifically halting proof-of-work blockchain verification methods until an environmental impact assessment takes place. This would severely delay approvals for new proof-of-work miners. Bill S6486 would require an environmental impact assessment to ensure that such mining would not hinder the State's obligations under the Paris Agreement (required by the Climate Leadership and Community Protection Act 2019). It "[e]stablishes a moratorium on consolidated operations that use proof-of-work authentication methods to validate blockchain transactions; provides that such operations shall be subject to a full generic environmental impact statement review."[47] This should encourage a shift to more efficient designs, away from the Bitcoin-style design, and other jurisdictions following suit would have greater impacts.

### 3.1.5. *Fiscal tools to discourage proof-of-work*

An alternative policy intervention to regulation is to introduce varied transaction sales tax or income tax rates depending on the energy consumption level in the transaction type. For example, a tax on the sale of a proof-of-work transaction could be introduced and charged at a higher rate than other types of verification proofs. This would require energy consumption and/or emissions to be correctly estimated by the revenue authorities.

Alternatively, any capital gains tax or income tax resulting from profits on NFT or digital currency transactions could be charged at a premium rate if proof-of-work verification is used. From the profits

[39] Digiconomist, Ethereum Energy Consumption Index, https://digiconomist.net/ethereum-energy-consumption, accessed 29 July 2021.

[40] NFTs are hot. So is their effect on the earth's climate | WIRED, 3 July 2021, https://www.wired.com/story/nfts-hot-effect-earth-climate/, accessed 29 July 2021.

[41] Ethereum cryptocurrency to slash carbon emissions, The Guardian, 19 May 2021, https://www.theguardian.com/technology/2021/may/19/ethereum-cryptocurrency-to-slash-carbon-emissions, accessed 29 July 2021.

[42] https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/.

[43] https://ethereum.org/en/eth2/.

[44] Ethereum mining will soon be obsolete, as 'London' update moves key deadline to December, CNBC 5 August 2021, https://www.cnbc.com/2021/08/05/ethereums-mining-cliff-moved-up-from-summer-2022-to-december-2021.html.

[45] CoinTelegraph, ETH Miners Will Have Little Choice Once Ethereum 2.0 Launches With PoS, 13 June 2020 https://cointelegraph.com/news/eth-miners-will-have-little-choice-once-ethereum-20-launches-with-pos, accessed 27 December 2021.

[46] Ethereum mining will soon be obsolete, as 'London' update moves key deadline to December, CNBC 5 August 2021, https://www.cnbc.com/2021/08/05/ethereums-mining-cliff-moved-up-from-summer-2022-to-december-2021.html.

[47] New York State Senate Bill S6486 https://www.nysenate.gov/legislation/bills/2021/S6486.

gained from the blockchain-adopting alternatives, more sustainable consensus protocols could be subject to reduced rates of tax. In the UK, Her Majesty's Revenue and Customs introduced a 'Tax on cryptoassets' policy paper, which recognises the various proof types but does not distinguish tax rates based on carbon emissions or energy consumption.[48] This is a missed opportunity to incentivise low-emissions blockchain choices as part of the UK's Green Industrial Strategy.[49]

### 3.2. Industry-focussed policy interventions

Blockchain miners and digital currency interests are commonly drawn to accommodating environments. These are usually in the form of jurisdictions with an inexpensive and reliable energy supply combined with a relaxed regulator or limited regulations. Policymakers seeking to limit the environmental or social impact of blockchain miners in such jurisdictions have adopted various responsive strategies. The responses have focussed on different symptoms of hosting blockchain miners, such as the increased demand for energy supply or increased emissions levels within the jurisdiction. Energy price [24][24] fluctuations do not seemingly discourage major mining interests from continuing to operate, and some US-based miners have bought disused coal power plants to guarantee their energy supply.[50] Such behaviour, while not universal (others have invested in renewable energy plants or guaranteed renewable energy supply), is a significant setback towards environmental goals and the continuing increase in need for energy is concerning either way.

This section draws syntheses between the responses of different jurisdictions' policy interventions and analyses their impact. Policy interventions have commonly focussed on various points of incidence designed to reduce the extent to which energy is consumed in the mining process, particularly non-renewable energy. Notable interventions include increasing energy prices for miners, incentivising miners to switch to renewables, incentivising miners to use more efficient mining devices, prohibiting the mining operation altogether, and restricting financial institutions' dealings with digital currencies. All these strategies are directly focussed on the miners themselves, except the latter, which has an indirect effect on reducing the demand for mining. Such interventions have occurred through a combination of regulatory and fiscal tools. These are detailed below.

#### 3.2.1. Prohibitive regulations on miners and financial institutions

Regulatory responses aimed at restricting mining operations have occurred in China, Canada, and the US. In China, regulators have restricted both mining and the ability of financial institutions to deal with digital currencies, the latter having an indirect chilling effect on the demand for blockchain mining. In the US, several instances have also been cited of localised restrictions on mining operations.

China's measures first began in May 2021 by prohibiting "financial institutions and payment companies from providing services related to cryptocurrency transactions".[51] This included '…account openings, registration, trading, clearing, settlement, and insurance…',[52] accepting virtual currencies as a form of payment or providing foreign exchange services.[53] The idea may have partially been to reduce the need for miners to operate if the digital currency could not be traded, and thus, no transactions require verification. As digital currencies have continued to flourish globally despite China's measures, the business imperative to perform mining operations in China will not have diminished, and there may be cases of illegal mining operations.

Cash explains the '…most successful examples of clean energy economic growth, innovation, and deployment in areas where smart government regulation has provided clarity and certainty and rules that incentivise a robust market. In these areas, the right market signals create the right landscape for investment, adoption of technologies, and clean energy job growth' [25].[25] In 2021, China lost patience with alternative market signalling methods and clamped down on digital currency mining,[54] resulting in approximately half of global miners going offline with immediate effect.[55]

This considerably reduced the total emissions of miners with immediate effect,[56] a crude regulatory response to a national and global problem centred in China. The Financial Stability and Development Committee of China's State Council called for a crackdown of cryptocurrency miners,[57] resulting in thousands of miners being taken offline and the collapse of the Bitcoin hashrate (see Fig. 2). China's objective[58] to become a carbon-neutral economy [26][26] was hindered by the scale of cryptocurrency mining in the country, and may be responsible for the cryptocurrency mining crackdown.[59]

The Chinese method has been blunt but effective in its objective to reduce energy consumption and pollution caused by blockchain mining devices, within its own borders, though not globally. The Chinese prohibition resulted in carbon leakage as many miners relocated their revenue-generating mining devices to neighbouring countries, such as Kazakhstan, but also further to the USA and Canada[60] (see Figs. 3 and 5). The mining levels and hashrate[61] have subsequently recovered as described below (See also Figs. 5 and 6). By October 2021, the USA became the primary destination for Bitcoin mining, hosting over 30% of the global hashrate.[62] The problem has been relocated to other jurisdictions offering cheap and reliable supplies of energy and limited regulations. China can, however, claim that it has made progress towards its national climate objectives and removed an unwanted burden on its energy network.

[48] HMRC, Policy paper, Tax on cryptoassets, https://www.gov.uk/government/publications/tax-on-cryptoassets accessed 4 August 2021.

[49] HM Government, The Ten Point Plan for a Green Industrial Revolution, November 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf.

[50] https://www.nbcnews.com/tech/tech-news/bitcoin-miners-align-fossil-fuel-firms-alarming-environmentalists-n1280060 accessed 14 October 2021.

[51] China bans financial, payment institutions from cryptocurrency business, Reuters, 18 May 2021, https://www.reuters.com/technology/chinese-financial-payment-bodies-barred-cryptocurrency-business-2021-05-18/ accessed 30 July 2021.

[52] Explainer: What Beijing's new crackdown means for crypto in China, Reuters. 19 May 2021, https://www.reuters.com/world/china/what-beijings-new-crackdown-means-crypto-china-2021-05-19/, accessed 30 July 2021.

[53] Business Management Department of the People's Bank of China, 7/6, Risk reminder on preventing virtual currency trading activities, https://mp.weixin.qq.com/s/jJbuBjDYMxvbZdR71jBKlQ.

[54] China's cryptocurrency-mining crackdown spreads to Sichuan, Reuters, June 19, 2021, https://www.reuters.com/technology/chinas-cryptocurrency-mining-crackdown-spreads-sichuan-2021-06-19/, accessed 29 July 2021.

[55] https://www.blockchain.com/charts/hash-rate.

[56] Bitcoin mining isn't nearly as bad for the environment as it used to be, new data shows CNBC, 20 July 2021, https://www.cnbc.com/2021/07/20/bitcoin-mining-environmental-impact-new-study.html, Accessed 29 July 2021.

[57] The State Council People's Republic of China, China's central bank summons financial institutions for harder cryptocurrency crackdown, 21 June 2021, http://english.www.gov.cn/statecouncil/ministries/202106/21/content_WS60d08c69c6d0df57f98db96b.html Accessed 30 July 2021.

[58] Government of China, 减碳，中国设定硬指标 30 September 2020 人民日报 http://www.gov.cn/xinwen/2020-09/30/content_5548478.htm.

[59] Why China's Ban on Crypto Mining Is More Serious Than Before, Nasdaq 9 July 2021, https://www.nasdaq.com/articles/why-chinas-ban-on-crypto-mining-is-more-serious-than-before-2021-07-09 accessed 30 July 2021; Peter Howson, Bitcoin: Why China's crackdown isn't enough, The Independent 7 June 2021 https://www.independent.co.uk/voices/bitcoin-china-crackdown-energy-environment-b1861123.html accessed 24 August 2021.

[60] Cambridge Bitcoin Electricity Consumptions Index, https://cbeci.org/mining_map, accessed 29 July 2021.

[61] https://www.blockchain.com/charts/hash-rate.

[62] America is the big winner of China's crypto crackdown, The Economist, 22 October 2021 https://www.economist.com/graphic-detail/2021/10/22/america-is-the-big-winner-of-chinas-crypto-crackdown.

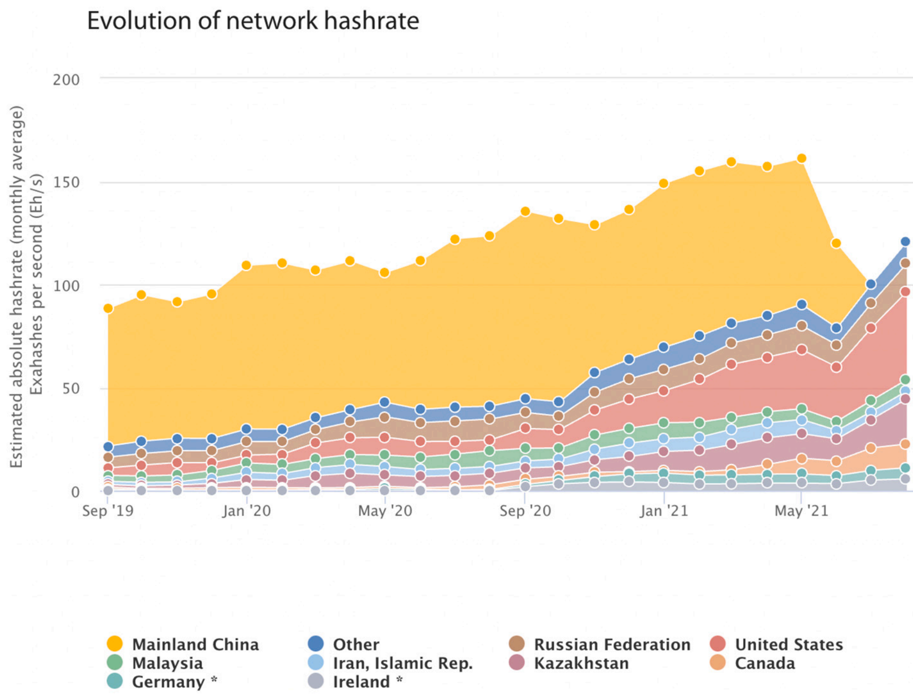


**Fig. 5.** Evolution of Global Bitcoin network hashrate map as of August 2021.
Cambridge Bitcoin Energy Consumption Index https://cbeci.org/, accessed 1 January 2022.

However, relocating operations to cheap-energy locations does not always last. With many Chinese miners relocating to Quebec, Canada, the demand for power supplies was too high for energy providers to deal with, especially in the winter. Quebec's sole energy authority issued a decision in 2018 to refuse the supply of energy to new mining operators.[63] Energy costs also increased.[64] Some miners relocated from the region, while others stayed, and some looked to expand to other countries to ensure sound and diverse supplies.[65] Miners, although lucrative customers for energy companies, are increasingly considered a problem for power suppliers and energy authorities. Where national governments are silent, localised measures have been taken to restrict the operations of miners.

The Common Council of Plattsburgh, New York, also elected to regulate and issue a moratorium on new cryptocurrency mining operations in the city,[66] although this did not affect the city's existing operator.[67] Some public utility districts in Washington State, where inexpensive hydroelectricity has attracted mining operators, have issued moratoria on new applications for mining operations.[68]

China's measures have shown, first, how a nation can take unilateral action to reduce its own national emissions output. The impact was severe and rapid, but from a national perspective, China has managed to both reduce overdependence on its energy grid, as well as maintain its commitment towards its emissions reduction objectives. This is similar to the case in New York, where residents suffer from premium energy prices owing to the high energy demand from miners.

Second, it has shown the macro global effects of introducing such measures unilaterally, resulting in an initial reduction, but heralded by the relocation of mining devices to friendlier alternative jurisdictions. The relative ease of relocating even older, more polluting devices has meant that the problem has simply been shifted elsewhere, and polluting mining activities would continue. From a global perspective, such carbon leakage may mean that any net decrease in emissions and energy consumption [27][27] is limited [28].[28] Thus, international cooperation may be required to coordinate a more globally effective response. For example, to maximise impact, China could have prohibited the export of the most polluting mining devices, and mining device destination nations could have prohibited, taxed, or regulated their own imports and the subsequent usage of mining devices.

### 3.3. Energy consumption

An alternative type of policy intervention has been less focussed on prohibiting mining activities through regulation, but instead, utilising fiscal tools and legal requirements to affect the business model of miners. Such market-driven tools can compel miners to factor in the high cost of energy or mandate a switch to renewables. Miners need the certainty of market signals based on smart government intervention to determine which technologies and energy to invest in [29].[29] Ultimately, the purpose is to require a switch to a more sustainable business model, either renewable energy, or more efficient mining hardware.

#### 3.3.1. Premium charges for energy use

Both New York and China have examples of increasing charges on

[63] The Régie de l'énergie rendered decision D-2021-007: https://www.newswire.ca/fr/news-releases/cryptomonnaies-la-regie-de-l-energie-rend-une-decision-809387001.html accessed 14 October 2021.

[64] Quebec asks crypto miners how much they'll pay for electricity, Bloomberg, 21 June 2018 https://www.bloomberg.com/news/articles/2018-06-21/how-much-will-you-pay-for-electricity-quebec-asks-crypto-miners accessed 14 October 2021.

[65] Bitcoin mining in Canada is thriving despite stringent regulations, Nasdaq, 30 August 2021, https://www.nasdaq.com/articles/bitcoin-mining-in-canada-is-thriving-despite-stringent-regulations-2021-08-30.

[66] Local Law P-7 of 2018.

[67] WAMC Radio, Plattsburgh Passes Cryptocurrency Regs, Maintains Moratorium, 26 October 2018, www.wamc.org/post/plattsburgh-passes-cryptocurrency-regs-maintains-moratorium, Accessed 3 August 2021.

[68] Bitcoin, Blockchain, and the Energy Sector, 9 August 2019, https://fas.org/sgp/crs/misc/R45863.pdf, Accessed 30 July 2021, at 13.

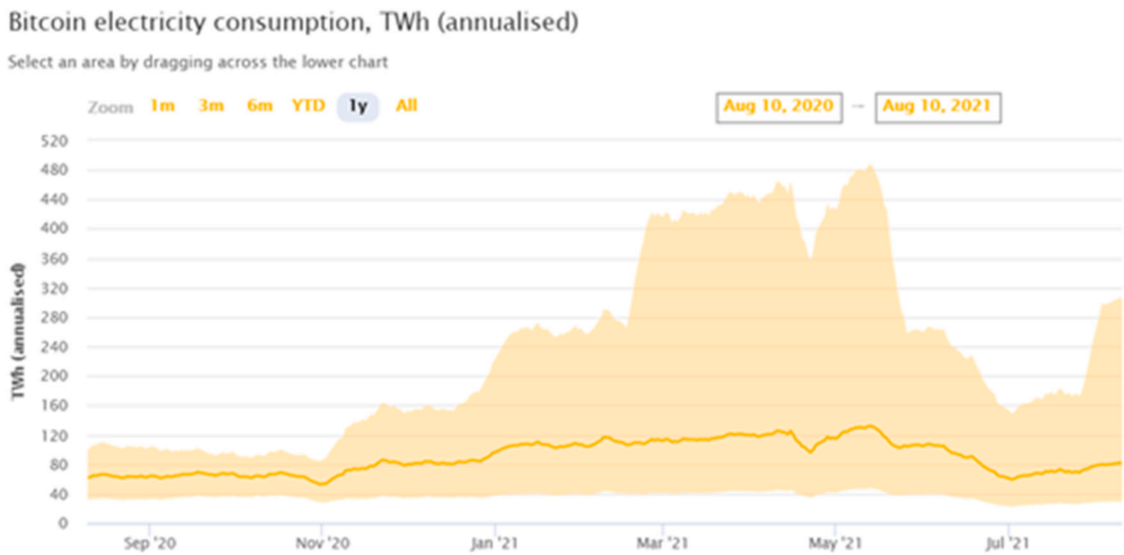


**Fig. 6.** Bitcoin hashrate and energy consumption resulting from Chinese regulations.
Cambridge Bitcoin Energy Consumption Index https://cbeci.org/, accessed 11 August 2021.

miners to internalise environmental costs,[69] as well as to reduce pressure on the electricity network. The additional costs are also in line with the 'polluter pays' principle.[70] Stiglitz makes the case that negative externalities are not required to be factored into such a business model; this is actually a de facto subsidy [30].[30] Charging high-volume energy users a premium on the basis that they are making private profits without any social benefit helps to de-socialise both the environmental negative externality as well as the additional cost to residential energy users [31,32].[3132] In this case, the subsidy would be because the society would become responsible for the environmental costs, and in New York, it would also mean that regular residential energy users have to foot the bill for higher electricity prices due to the high demand caused by a private mining operations in their network.

New York has pressed to internalise costs through market-based price instruments, while China has focussed on a taxation strategy. This very targeted measure has a clear objective to reduce the attraction of mining. A ruling by the New York Public Service Commission allowed municipal power authorities to issue tariffs on high-density-load energy customers.[71] This allows power companies to charge premium prices for the electricity consumed by digital currency mining companies, making it less affordable to mine and particularly to operate high-energy consumption mining devices.

Similarly, China's Leading Group of Internet Financial Risks Remediation in 2018 requested that local governments regulated cryptocurrency miners' electricity usage and introduced related taxation towards limiting the extent of mining nationwide [33].[33] Charging more for electricity consumption through taxation or charges can help internalise the negative externalities caused by mining operations by factoring them into business costs. This may make mining unprofitable unless more efficient devices are employed. These additional costs decrease the demand for working with proof-of-work blockchains and are intended to have the supply-side effect of lowering energy consumption.

#### 3.3.2. *Energy-focussed intervention: clean energy and carbon offset*

Reliance on cleaner energy would reduce the environmental impact of NFTs and other applications of mining operations. Owing to social concerns and increased awareness of the environmental impact of blockchain-related mining, there is a looming threat of the regulation of mining operations, as emphasised by examples of policy intervention. Being keen to avoid the need for such interventions, some miners have switched to renewable energy. Others have sought to offset their emissions.

Partly due to the high-profile pressure from environmental groups, the use of renewable energy in mining increased, but in 2020, renewable energy only accounted for 39% of the total electricity used by proof-of-work miners [34].[34] Electricity is estimated to account for 80% of miners' business costs,[72] and miners' key priority is to utilise the cheapest available electricity.[33] Nevertheless, hydrocarbon energy appears to be the default option for miners to ensure a guaranteed supply of energy [35].[35] Redundant coal mines have reopened to supply energy to digital currency miners,[73] indicating a significant setback for the SDGs and global climate objectives.

Responding to social pressure and regulatory interest, blockchain companies have voluntarily elected to offset their carbon emissions which is a positive move. Voluntary initiatives in the blockchain sector, such as the Crypto Climate Accord, have sought to decarbonise the cryptocurrency and blockchain industry through private industry-led means.[74] However, such initiatives do not represent the entire

[69] Principle 16 of the Rio Declaration endorses the polluter-pays principle. UN Conference on Environment and Development 1992, UN Doc. A/CONF151/26/Rev. (Accessed 27 May 2018).

[70] 1974 OECD Recommendation on the implementation of the Polluter-Pays Principle[C(74)223]: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(92)81&docLanguage=En (accessed 27 May 2018).

[71] New York State Public Services Commission, 18052/18-E-0211 PSC approves new cryptocurrency electricity rates for upstate utility, 07/12/18. https://www3.dps.ny.gov/pscweb/webfileroom.nsf/ArticlesByCategory/BB3E5C36350EFF3A852582C8005D1D79/$File/pr18052.pdf?OpenElement.

[72] Bitcoin miners navigate extreme world of crypto power-hunting, Bloomberg July 13, 2021, https://www.bloomberg.com/news/features/2021-07-13/bitcoin-miners-building-rigs-must-navigate-world-of-crypto-power-hunting Accessed 29 July 2021.

[73] Bitcoin miners are giving new life to fossil-fuel power plants, Wall Street Journal 21 May 2021, https://www.wsj.com/articles/bitcoin-miners-are-giving-new-life-to-old-fossil-fuel-power-plants-11621594803, accessed 24 August 2021.

[74] https://cryptoclimate.org/ Accessed 24 August 2021.

industry, and decarbonisation measures cannot be guaranteed for the industry as a whole without regulatory intervention.[75] Thus, mandating renewable energy or carbon offsets consequently remains a potentially useful regulatory option for policymakers.

Regulatory intervention to persuade mining operations to utilise renewable energy has to date focussed on either mandating the need for renewable energy or requiring a carbon offset. Seeking to achieve 100% clean energy by 2030, the county of Missoula, Montana, USA, became wary of digital currency mining operations using approximately a third of its county's energy supply. Digital currency miners had been attracted to the county because of its inexpensive hydropower energy, but this put pressure on the grid and increased electricity prices for residents. The county, also concerned with emissions, reacted with a resolution requiring any new mining operations to offset their energy consumption in the county by purchasing 100% clean energy, and funding or constructing new renewable projects.[76]

#### 3.3.3. *Tackling carbon leakage through mining location-based differentiations*

Mining operations taking place in destinations with cleaner energy production would produce less of an environmental impact. Differences in the uptake of renewable energy vary depending on the mining location. In Iceland, 100% of the electricity for mining ensues from renewable sources, whereas in China, where up to 70% [36][36] of Bitcoin was mined in 2020, coal is used to generate two thirds of its electricity.[77] It may be feasible for certain types of blockchain mining operations to be classified based on their mining destinations. For example, if the majority of the Ethereum network's mining occurs in Iceland, it may be possible to incentivise this blockchain over alternative blockchains where mining takes place predominantly in non-renewable energy-dependent locations. This could be through taxation rate differentiation, for example, as described herein.

An environmental setback has been the recent relocation of mining devices from China to Iran, where hydrocarbon energy is inexpensive because of government subsidies. In 2020, Iranian hydrocarbon-produced electricity subsidies were valued by the International Energy Agency at US$ 12.5 billion.[78] Kazakhstan, another destination of China's exodus of miners, subsidised electricity produced from hydrocarbons to US$ 800 million in 2020.[79] The recovery of the Ethereum and Bitcoin hashrate since the Chinese prohibition is a sign that the miners have successfully relocated and are back online.[80] Allowing miners to benefit from such subsidies with limited social benefits and severe environmental costs is a perverse incentive. This could be reversed through the model employed in New York that charges higher rates of electricity consumption to blockchain miners. Concerned jurisdictions could also differentiate taxation or charge rates depending on the predominant location of miners.

Proposals have also made for differing rates of taxes on polluting mining device sales or importation, as well as border tax adjustments to prevent carbon leakage and tax competition [37].[37] Georgia, for example, has sought to attract cryptocurrency miners by exploiting their cheap energy through tax competition. This includes the exemption of value-added tax (VAT) for nationally registered mining companies. It has also sought to attract traders by guaranteeing exemptions from VAT and income tax in transactions between Georgia's fiat currency and digital currencies.[81] For any jurisdiction wishing to introduce its own version of a carbon tax [38][38] on miners, traders or developers, and prevent carbon leakage of blockchain miners relocating to more tax-friendly destinations, border tax adjustments provide an option [39].[39] International tax cooperation, similar to the global minimum tax rate agreed by the OECD, can also prevent environmentally detrimental tax competition.[82]

#### 3.3.4. *Reducing energy consumption via enhanced mining device efficiency*

Cryptocurrency mining machines themselves can be [40],[40] and have increasingly been, designed to require less electricity and reduce emissions [41].[41] Application-specific integrated circuits have replaced less efficient technologies, for example. While the industry has made improvements in the energy efficiency of such hardware without policy intervention, regulations could force all operators to upgrade to more efficient energy standards. Policymakers can also signal the type of technologies to invest in to the market [42].[42]

Energy-efficient standards, such as the EU's Ecodesign Directive,[83] have been proposed, but regulatory inertia has prevailed. The US federal energy efficiency standards[84] are not applicable to computer products. Instead, individual states have the choice to introduce such standards, including California that has introduced energy efficiency standards for computers and monitors.[85] Indeed, limited regulations or fiscal tools have been introduced globally to incentivise a switch to investment in more efficient cryptocurrency mining devices. Taxation based on the energy efficiency of the mining devices would at least incentivise a switch to more efficient mining hardware.

A switch away from proof-of-work blockchains would also minimise the need for high-energy consumption devices. Therefore, a switch to alternative designs would go a long way towards solving the energy consumption problem of mining devices.

### 3.4. *Tax measures*

#### 3.4.1. *Taxes to improve miners' energy efficiency*

It may be practical to shift demand away from high-energy consuming mining devices by targeting taxes on users. Environmental cost internalisation to incentivise behavioural change in miners' choice of mining devices can be targeted at different points of 'incidence' [43].[43]

The point of taxation can be on any of the mining device

[75] Gemini to offset bitcoin carbon emissions (finextra.com) 24 June 2021. https://www.finextra.com/newsarticle/38335/gemini-to-offset-bitcoin-carbon-emissions?via=indexdotco accessed 4 August 2021.

[76] Resolution No. 2019-026, A resolution establishing a county-wide cryptocurrency mining interim zoning overlay district in Missoula county, Montana, to be effective immediately for a period of one year.

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manufacturers, on the sale of the mining device, upon the import of a mining device, or upon use of the mining device. All such points of incidence replicate similar carbon taxes or carbon pricing efforts from interventions on household appliances, such as refrigerators.

Domestic sales of mining device hardware can be subject to various taxes, such as a sales tax or VAT, and allowances to subtract such hardware from business profits can be disallowed. However, it may be prudent to make allowances for the upgrade to more efficient mining devices when less efficient models are retired and recycled, similar to the capital allowances available to businesses when upgrading other types of machinery. For imported device hardware, import or excise taxes are commonplace, and taxes can be differentiated based on the efficiency of the device as long as nationally manufactured devices are subject to equivalent tax treatment.[86] Nevertheless, ASIC devices imported to the US from China are liable for an additional 27.6% tariff as a result of measures taken to reduce the US–China trade deficit.[87] This significantly impacts the purchasing decisions of major mining operators in the US.

An alternative tool is for all types of mining devices to be registered with national tax authorities and for an annual fee to be charged based on the efficiency of the device. This would follow how some authorities charge for certain types of polluting machinery used in industry[88] or how vehicles are subject to varying annual emission-based charges in Great Britain.[89]

A further available tax tool would be to introduce a special corporation or income tax regime for mining operators based on the sustainability of their business practices, with premiums charged for the most polluting operators based on their inventory of mining devices. Alternatively, such a tax could be focussed on the device manufacturer, although this would pose a problem where the devices are manufactured outside the jurisdiction. Verifying the efficiency of such devices would perhaps require a higher administrative burden than device-based taxes at the point of sale, import, or registration. There is also a mooted possibility of including mining operations with existing industrial emissions trading [44][44] schemes [45].[45]

The limitation of these measures is that they do not affect mining operations overseas, and they may simply push miners to friendlier foreign jurisdictions, thereby causing both carbon and tax leakages for existing operators [46].[46] However, this may not be a concern for policymakers seeking to reduce the burden on their energy networks and minimise national emissions. To avoid such distortion, policy intervention may focus instead on the point of transaction, such as the digital currency exchange, the smart contract provider, or the NFT exchange. Placing the onus on those regulated exchanges, who are required to operate within a jurisdiction to interact with national banks and financial institutions, would allow a tax or charge to be collected at the point of transaction. This could be dependent on the estimated levels of emissions for each type of blockchain used in the transaction. An NFT transaction would therefore be subject to a charge based on the emissions of the existing Ethereum network; however, this can be reduced once Ethereum has upgraded to a less energy-intensive blockchain platform. Transactions with less polluting blockchains would become less expensive, thereby affecting the decisions of blockchain users whose demand impacts blockchain developers' decisions. Internalising the polluting costs by introducing such emission-based charges would only impact the decisions of users within an intervening jurisdiction, but the demand-side implications would indirectly impact the behavioural decisions of all miners both domestically and abroad.

### 3.4.2. Obtaining data for the taxation-based differentiation of carbon impact

To introduce and differentiate rates of taxation or charges based on the carbon impact of the blockchain being used, it is necessary to have access to sufficient user data. Recent years have witnessed regulatory steps to decrease the anonymity of digital currency users. It is also possible to introduce charges or taxes on other applications, such as smart contracts and NFTs, depending on the environmental impact of the blockchain platform being used.

Truby previously argued that the digital asset ownership information utilised by the Financial Action Task Force (FATF) recommendations and the EU's Fourth Anti-Money-Laundering Directive[90] could provide taxation authorities with adequate information vis-à-vis energy consumption-related taxes. This has not happened so far in terms of distinguishing between digital assets as a result of environmental impact.

In 2021, the FATF issued a public consultation on new recommendations, changing the previous terminology of 'assets that are fungible' to 'assets that are convertible and interchangeable'.[91] This is expected, therefore, to incorporate NFTs in the updated recommendations applied to money laundering, terrorist financing, and proliferation financing. Thus, this would enable national legislators to require national tax authorities to utilise this information to distinguish between the carbon impacts of different digital assets. The United States Senate Infrastructure bill[92] would also be partially funded by a taxation of digital assets, but the details were unclear at the time of writing.[93] In neither case was there any indication that digital asset taxes or financial measures would be distinguished based on carbon impact.

Without sufficient data, policymakers may simply find it simpler to differentiate based on consensus protocols, such as introducing high rates or limitations on proof-of-work blockchains. This more simplistic method may not be as accurate as differentiating based on the actual energy use of blockchain miners, such as by checking the forms of energy consumption, the types of energy being used, or the mining device efficiencies. Nevertheless, the administrative simplicity of grouping all types of consensus protocols into categories for differentiated treatment may make it the preferred option for regulatory intervention.

## 4. Conclusion

Policy intervention options once mooted in theory have now been experimented with across jurisdictions, enabling a novel and timely

[86] See for example Belgium's Ecotax Law, which did not contravene World Trade Organisation rules. Articles 369 to 401 of the Law of 16/7/1993 completing the Federal Structure of the State (Moniteur Belge), 20/7/1993, p. 17013.

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[93] Split over crypto tax threatens to bog down US infrastructure bill, Financial Times 6 August 2021 https://www.ft.com/content/6a398ea8-e5d8-4489-bf7c-06932618e45b, accessed 24 August 2021.

analysis of available policy tools herein to reduce the wholly unsustainable levels of emissions from the blockchain industry.

The level of the environmental impact of NFTs is inextricably linked to the type of blockchain the NFT platform operates within. Smart contracts used for NFT transactions depend on platforms already employed to verify digital currency and other blockchain transactions, whose energy consumption levels differ depending on their consensus protocols, the mining devices being used, and the polluting level of the energy being used. Since the acknowledgement of the causes and carbon impacts of NFTs and other blockchain technologies on the planet, limited regulatory action or fiscal tools have been introduced globally to counteract the growing problem. Environmental awareness resulting from the use of NFTs in the art market has impacted users' blockchain choices and, ultimately, the consensus protocol choices of blockchains supporting NFT platforms.

A range of tools are available and have either been mooted or used in some locations, but with poor international coordination, the problem has grown. Industry has sought in parts to become more energy efficient, namely, to save costs and avoid reputational damage that may result in regulatory intervention, but this has not happened universally. Indeed, energy-saving regulations applicable to other types of products or business activities specifically do not always apply to the blockchain industry, thus creating a perverse incentive[94] to continue polluting.

The author recognises the commercial, security, and social benefits of NFTs and alternative applications of blockchain, and ensuring that costs are internalised is a crucial means of fostering the sustainable development of the industry. This can, and in some places has, included measures to change the design of the blockchain transaction verification processes away from the resource-inefficient proof-of-work to alternative methods.

In particular, this study shows that proof-of-work models need to be phased out in the same way that inefficient appliances are eliminated from the market. Required measures also include eliminating electricity subsidies and charging a premium for miners' electricity consumption to factor in the added social cost of this private enterprise. They include encouraging more efficient hardware through additional costs for inefficient models or energy efficiency standards. They include requiring dependence on clean energy and mandating carbon offsets and/or a carbon trading scheme [47][47] for mining operators and transacting parties.

Developers, miners, and traders should be more willing to work with local communities to minimise their environmental impact because where such measures fail, there is a more severe regulatory option available that they should be apprehensive of [49]. Chinese-style prohibition has shown what one nation can do, and others can follow if regulators decide that they can no longer benefit from working with the blockchain industry. Moreover, NFTs and the blockchain industry have the potential to bring considerable benefits to society and business, thus switching to more sustainable alternatives ahead of time would prevent the need for taxes, standards, and regulations [48].

Blockchain [49] is at a crossroads and awaits the evaluation of Ethereum's performance. The success or failure of Ethereum in switching to proof-of-stake while proving its security advantages will be crucial towards determining what the future of the blockchain industry will look like. Success would be persuasive for other blockchains to switch to such less polluting designs, while failure would reinforce the path dependence towards the polluting proof-of-work model. Similarly, industry responses to policy intervention measures, which have largely been localised outside of China, will impact whether further harsher interventions are required.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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