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Preying on the poor? Opportunities and challenges for tackling the social and environmental threats of cryptocurrencies for vulnerable and low-income communities

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Preying on the poor? Opportunities and challenges for tackling the social and environmental threats of cryptocurrencies for vulnerable and low-income communities

Abstract

The rate of adoption of some cryptocurrencies is triggering alarm from energy researchers and social scientists concerned about the industry's growing environmental and social impacts. In this paper we argue that the unsustainable trajectory of some cryptocurrencies disproportionately impacts poor and vulnerable communities where cryptocurrency producers and other actors take advantage of economic instabilities, weak regulations, and access to cheap energy and other resources. [redacted] Globally, over 100 million people hold cryptocurrency, mostly as a speculative asset. The digital infrastructure behind the most popular cryptocurrency, bitcoin, currently requires as much energy as the whole of Thailand, with a carbon footprint exceeding the gold mining industry. Should bitcoin's mass adoption continue, an escalating climate crisis is inevitable, disproportionately exacerbating social and environmental challenges for communities already experiencing multiple dimensions of deprivation. In mitigating these impacts, the paper considers 4 potential regulatory pathways, including: 1) promoting voluntary private-sector commitments to using only renewable energy, 2) encouraging a system of voluntary carbon offsetting, 3) using existing financial regulations and tax frameworks, and 4) imposing national and/or international bans on cryptocurrency 'mining'. The paper argues that effective environmental regulation of cryptocurrencies is urgently required, both to reduce the threat of catastrophic climate change, and to help the world's poorest towards sustainable development. However, regulating cryptocurrency mining in any context is likely to require a combination of efforts and is unlikely to result in win-win outcomes for all.

Keywords

Cryptocurrency; Proof-of-Work; Bitcoin; Sustainability; Poverty; Climate change

Introduction

Since the advent of bitcoin in 2009, the use of cryptocurrencies has increased significantly. Estimates suggest that 106 million people (roughly 1.3% of the global population) have used bitcoin at least once [1]. Others suggest there are around 25 million 'active' cryptocurrency users [2]. Maintenance of the bitcoin network requires significant material resources. As of November 2021, bitcoin is using more energy than the whole of Thailand (around 185 TWh), the majority of which is generated from fossil fuels [3], emitting approximately 88 Mt CO_2e per year [4]. This is up from around 22 Mt CO_2e annually just two years ago [5]. This now significantly exceeds the carbon emissions produced by the gold mining industry [6]. Today, a single Bitcoin transaction has an electrical energy footprint roughly equal to the total energy consumed by a US household for two months [7][a]. The cryptocurrency is unsustainable by design. In producing new bitcoins, using large amounts of electrical energy is incentivised through a process known as Proof-of-Work (PoW) mining. The PoW consensus protocol is an intentionally energy-inefficient mechanism designed to promote behaviour in the interest of the network, whilst securing a blockchain from bad-actor interference [8]. With such a significant and growing footprint, PoW cryptocurrencies, like bitcoin, are threatening global commitments for mitigating carbon emissions [9]. Predictions suggest the network could be responsible for emitting 90 to 131 Mt CO_2e per year in the mid-term [10,11]. Bitcoin's growing energy footprint correlates strongly with its dollar value, but even without the forecasted growth, PoW mining already has consequences for human health and climate. Research indicates that for every $1 of value created by Bitcoin's energy use, $0.49 needs to be spent on mitigating the network's associated environmental issues and remedying other associated public health problems [12].

There is near-unanimous consensus in the academic literature asserting that PoW cryptocurrencies cause significant challenges for meeting global sustainable development goals. However, some argue the technology offers opportunities for helping towards poverty reduction globally, enabling strong political institutions [13], providing clear property rights, and tackling corruption [14], whilst promoting entrepreneurialism and equal opportunities [15]. In this paper we show how PoW cryptocurrencies disproportionately impact vulnerable and developing communities globally, where PoW miners and other actors take advantage of economic instabilities, weak regulations, and access to cheap energy and other resources. Around 1 third of PoW miners are currently in countries with a Human Development Index (HDI) score below 0.85[redacted] [16]. Some of the world's poorest and most vulnerable people are likely to be those disproportionately impacted by PoW mining's local social and environmental issues (see Figure 1)[c].

[a] The transaction throughput of the bitcoin network is independent of the hash rate or consumed energy. Even without any transactions occurring, bitcoin would still use energy. This data also assumes that miners always use the most efficient equipment available. However, the more profitable PoW mining becomes, the more inefficient the network. During periods of high cryptocurrency prices, miners use older specialist equipment with better availability and lower acquisition costs, meaning bitcoin's current and forecasted energy consumption is probably underestimated [7].

[redacted]

[c] Following a Chinese government crackdown from April 2021, the global distribution of mining activities is shifting significantly, with much of the displaced operations migrating to as yet unknown locations, including neighbouring developing countries as well as developed countries, e.g. Canada and the US. Under such conditions of uncertainty, we argue that it is sensible to adopt the 'precautionary principle of environmental science' towards the regulation of PoW cryptocurrencies, which has 4 central components: 1) taking preventive action in the face of uncertainty; 2) shifting the burden of proof to the proponents of an activity; 3) exploring a wide range of alternatives to possibly harmful actions; and 4) increasing public participation in decision making [17].

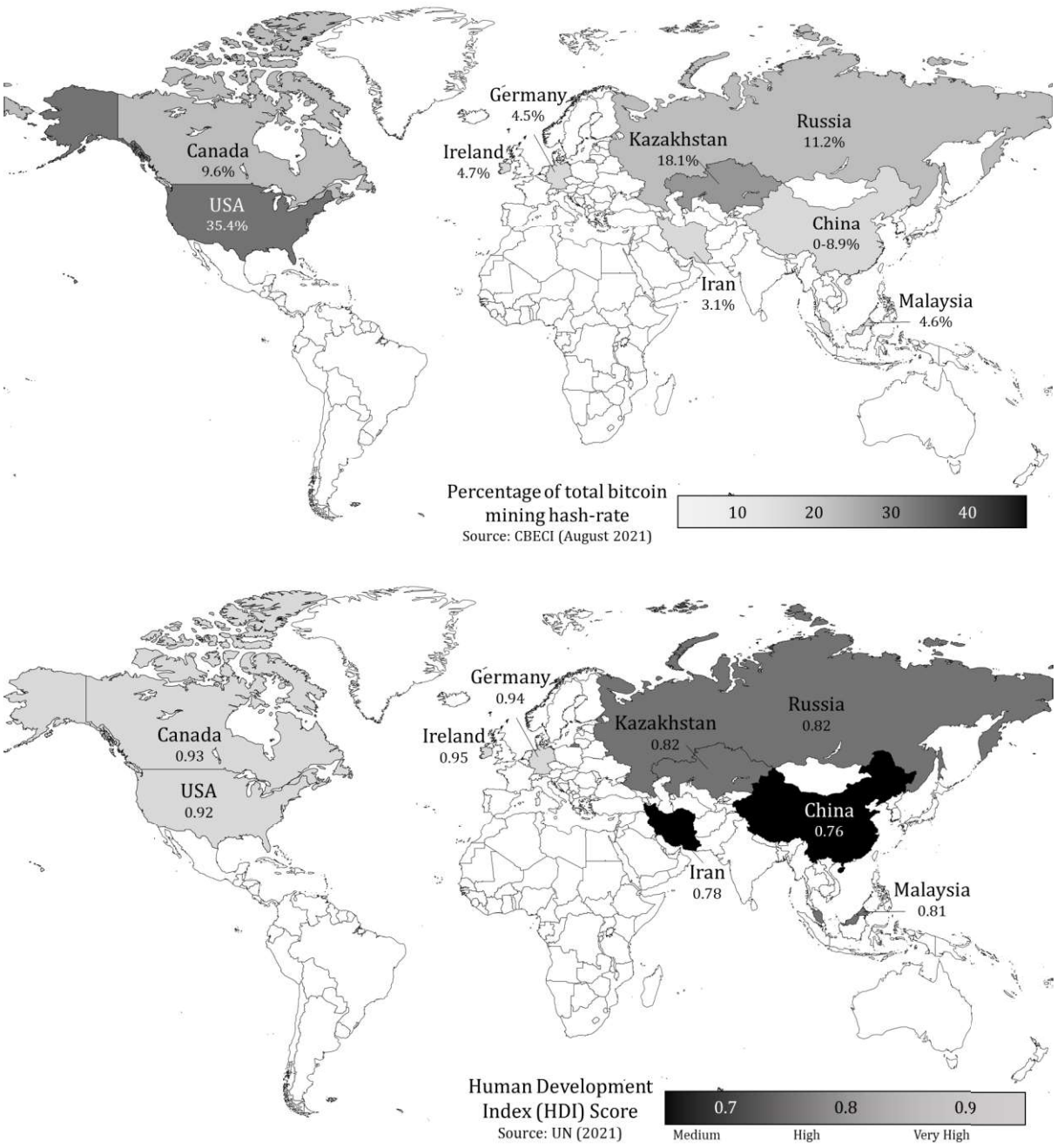

Figure 1: Global distribution of bitcoin mining hash-rate (top) and Human Development Index (HDI) scores[d] of bitcoin-producing countries (bottom)

Combined with the most optimistic climate scenarios for the end of the century, bitcoin's growth and inefficiency will likely play a significant part in placing the poorest parts of the world at the threshold of catastrophe [18]. Several provincial bitcoin mining bans across China in 2021, including Inner Mongolia, Xinjiang, Yunnan and Sichuan provinces, have forced much of the country's mining infrastructure to relocate. The bans followed a nationwide crackdown imposed due to safety and climate change concerns from associated coal mining activities [19]. Where Chinese mining operations relocate to developing countries, for example towards less politically stable ex-soviet borderlands,

[d] HDI Technical Notes: http://hdr.undp.org/sites/default/files/hdr2020_technical_notes.pdf

electricity supplies are often accessed illicitly, fuelling conflict over resources [20]. The exodus is also impacting opportunities for sustainable livelihoods, for example in Democratic Republic of Congo (DRC) where local people are outcompeted by bitcoin miners for access to cheap renewable energy [21]. As mining operations use vast amounts of highly specialised and short-lived hardware, obsolete equipment is likely to cause additional damage to the environment and human health, especially in developing areas where much of this hazardous electronic waste (e-waste) is disposed [22].

Without robust regulation, bitcoin's increasing price and associated level of adoption will continue to cause harm globally. To mitigate these impacts, this paper considers the challenges in developing potential regulatory pathways for effective social-environmental management of bitcoin and other PoW cryptocurrencies. Histories of colonialism, including imposition of neoliberal structural reforms, have placed many vulnerable communities at the frontier of cryptocurrency production [23,24,25]. Economic instability, inadequate tax policy frameworks, and weak regulatory institutions are also encouraging increased levels of adoption within communities with the least resilience towards both economic and climatic shocks [24].

The following section offers a short introduction to PoW mining, before discussing the challenges and trade-offs in relation to 4 potential pathways for regulating it. These pathways include: 1) promoting voluntary private-sector commitments to mining with only renewable energy, 2) encouraging a system of voluntary carbon offsetting for miners and users of PoW cryptocurrencies, 3) using existing financial regulations and tax frameworks, and 4) imposing national and/or international bans on PoW mining. The paper concludes by summarising the key social and environmental benefits of effective action.

Proof-of-Work / Proof-of-Waste

PoW cryptocurrencies, like bitcoin, rely on a global network of several million competing specialist computers [26]. These bitcoin miners, like safe-crackers, repeatedly guess the combination to a digital lock (a long string of digits) with the computer guessing the correct combination winning an ever-decreasing number of new bitcoins. The combination changes as miners successfully create new blocks, every ten minutes on average. The number of bitcoins released with each new block halves every 4 years, from 50 in 2009, to 6.25 in 2020. The contest continues up till the year 2140[e]. From then on, miners compete only for user transaction fees. The planned cut-off gives bitcoins their theoretical scarcity. While only 10-years ago, competing miners could successfully win blocks with an average laptop, today, viable operations require significant investment in specialised hardware known as Application Specific Integrated Circuit (ASIC) units[f] to avoid spending more money on electricity than can be gained through mining (see Figure 2).

[e] The total amount of bitcoins is limited to 21 million. Such caps are not an integral feature of PoW cryptocurrencies generally.

[f] ASIC chips are tailor-made to fulfil a single specific function with power, performance and cost benefits that normally cannot be achieved using a general-purpose chip.

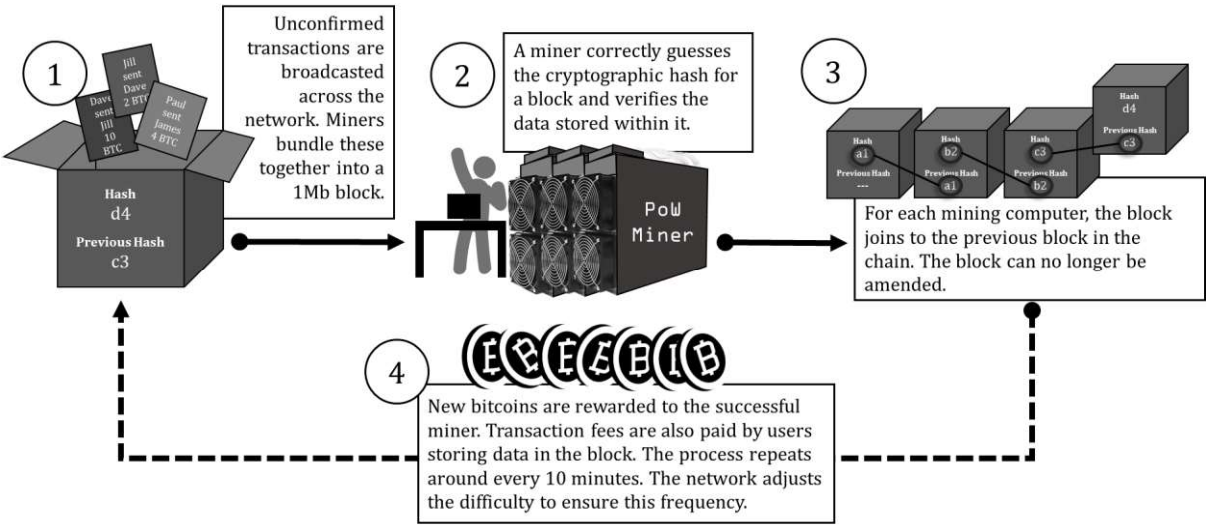

Figure 2: Bitcoin's 'Proof of Work' consensus protocol (Source: Author)

In stable market conditions, where miners use the world's cheapest electricity, the global PoW arms race still requires ASIC units to be replaced for newer and more efficient models approximately every 12 to 24 months [7]. Bitcoin's global network of tailored ASIC units, more powerful than all the world's super-computers put together many times over, cannot be repurposed to do anything else, besides running the SHA-256[g] hash function used to mine a cryptocurrency that few will ever use, beyond short term speculation. Redundant units created around 30.7 kilotons of e-waste in 2021 [22], much of which was disposed of in developing countries [27,28,22]. Identifying redundant ASIC units as waste is difficult, which causes enforcement challenges with regards to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1992). E-waste is often falsely labelled as electronic goods or as charitable donations [28]. Awasthi and Li [29] argue that China and India are the two countries that mostly suffer from illegal e-waste imports from developed countries. This e-waste is one of the fastest growing and most hazardous waste streams [28]. Bitcoin is likely to increase total global e-waste by up to 64.4 kilotons if bitcoin's 2021 price levels continue [22].

According to Gallersdörfer et al. [30], bitcoin accounts for around 66% of the total energy consumption of PoW cryptocurrencies. Other PoW projects, including Ethereum, Monero, Zcash and others, add nearly 50% on top of bitcoin's energy demand. However, not all blockchain consensus protocols are as resource intensive as bitcoin's. For example, 'Proof of Stake' (PoS) protocols require less than 1% of the energy consumption needed for bitcoin. 'Delegated proof of stake' (DPoS) and the 'delegated Byzantine fault tolerance' (DBFT) models use negligible amounts of energy to secure blockchain networks[h] [31]. Shifting bitcoin and other PoW cryptocurrencies to PoS is possible. Such a shift has been part of Ethereum's development road map since inception. However, some proponents of PoW argue that for bitcoin, a shift will cause barriers to entry, reduce network security and risk bitcoin's decentralised architecture [32]. For others, bitcoin's high energy demand is an integral feature of the

[g] SHA (or Secure Hash Algorithm) -256 is a cryptographic hash function that generates a unique 256-bit (32-byte) signature for a text or data file.

[h] PoW consensus protocols necessitate miners to inefficiently compete for new coins. Miners with the most hash power are statistically most likely to win the most coins. For PoS protocols, competing miners are replaced by a system of random assignment, where validators are automatically assigned to 'mint' (or forge) new blocks. Validators must 'stake' tokens as a security deposit. If they validate fraudulent transactions, the stake is lost. For DPoS protocols, token holders vote for the most qualified block producers, to ensure a faster network that is more energy efficient. DPoS networks usually maintain a very short list of qualified block producers, taking turns to receive production rights. For example, the EOS blockchain maintains a list of 21 block producers. Similarly, DBFT blockchains allow nodes to assign delegates (who can approve blocks), and a speaker (who proposes the next block).

network, rather than a bug [33]. Despite the unsustainability of PoW consensus protocols, blockchain developers suggest the technology can be useful for tackling social-environmental issues, for example, in incentivising tropical forest conservation [34], climate change mitigation [31], and marine protection [35]. However, all these contributions come with challenges and benefit trade-offs, with limited efficacy when reliant on voluntary commitments without centralised coordination.

Voluntary private-sector commitments to PoW mining with renewable energy

In April 2021, with the endorsement of the UN High-Level Climate Champions, a Crypto Climate Accord was voluntarily established by 3 companies advocating profitable innovations for financial regulation, energy and resource efficiency [36]. The founders had all adopted a critical stance towards government regulation that could bring about significant costs for financial technology companies [37]. Any prospective partners working in the crypto industry were invited to sign, support or participate in the initiative [37]. The Accord represented an industry pledge purportedly committing the entire crypto community to a 'net zero' emissions target, using renewable energy generation, 'Proof of Green' carbon accounting, and climate offsets by 2040 [38]. The Accord included central representatives from major cryptocurrencies, Ethereum and Ripple. However, both had already committed to non-PoW consensus protocols in their development road maps. Some North American bitcoin investment and mining centres also signed the Accord, some of which already used renewables for PoW mining [38]. This was problematic because the PoW mining signatories represented less than 0.1% of the crypto industry's overall energy usage, and therefore did not represent the interests of bitcoin miners globally, many of whom continue to value and rely on a climate of secrecy between industry players [39]. The Accord also did not account for bitcoin's adaptive system effects, which act against the need, as far as possible, for dialogue, negotiation, and social interaction to ensure rational gaming [8].

PoW systems are based on principles that were held by bitcoin's ideologically-committed designers – anonymity, immutability, and the bypassing of human trust. Game theory is integral to bitcoin's automated decentralised design maintained through economic incentives [8]. All participants within the network are understood as rational economic agents, making decisions based purely on individual self-interest towards the accrual of new bitcoins [40]. Central oversight by third-party intermediaries is understood as an imposition, which could interfere with the network achieving the Hayekian ideal of 'spontaneous order' [41]. Bitcoin's game theory framework means that if miners in one location use renewables because that is the cheapest (and most profitable) option, the entrance of new miners automatically adjusts the network's difficulty level and the necessary hash power for winning new bitcoins. This reaction continues until a bitcoin-energy price equilibrium is reached, which is dependent on bitcoin's dollar price at any given moment, and associated energy costs for each miner. Availability of energy from renewables is usually more intermittent than for miners using fossil fuels only. All miners, running equipment to the same specifications, have the same constant energy demand and usually run their machines 24/7. Therefore, miners cannot exclusively rely on intermittent renewable energy sources to meet their energy requirements [42].

Following concerns over potential centralisation of bitcoin regulation in the hands of the Crypto Climate Accord, a Bitcoin Mining Council was convened in May 2021 by prominent Bitcoin advocates, including Michael Saylor, CEO of Microstrategy – a software company holding over $7 billion dollars-worth of bitcoin at the time of writing – and Tesla CEO, Elon Musk [43]. While the Accord was made up mainly of companies ostensibly committed to alternative consensus protocols, including Ethereum, the Council focused specifically on the energy footprint of bitcoin. However, while the Accord aimed to provide a centralised strategy for delivering cleaner cryptocurrencies, the Council explicitly acts

purely as a public relations device. According to Saylor, the group aims to shape the narrative and "defend bitcoin against uninformed and hostile energy critics" [44 p1].

There are no established requirements that qualify someone before joining the Council. Similarly, the Accord explicitly frames itself as a 'big tent', inviting anyone working in the crypto industry to participate [37]. However, like the Council, this 'big tent' voluntary approach has attracted prospective participants using the Accord to promote disingenuous green credentials. Luxxfolio Holdings, for example, a Canadian digital asset company, is a signatory of the Accord, highlighting their "commitment to green cryptocurrency mining and exchange" [45 p1]. However, Luxxfolio continue to operate a 15 MW cryptocurrency mining operation in the Navajo Nation territory, New Mexico, produced using the Navajo's coal reserves [45]. The company claims the operations bring prosperity and jobs to the Navajo. Yet, like traditional data centres, even the world's largest bitcoin operations employ very few people [46]. The Navajo Nation experiences the highest rates of poverty, crime, alcoholism, incarceration, and suicide, of any racial group in the US [47]. Nearly 15% of the Navajo population suffer extreme poverty [48]). Despite over 14,000 of the 55,000 Indigenous households located on Navajo lands not having access to electricity [49], the Navajo agreement ensures Luxxfolio can access land, energy infrastructure, and subsidised electricity at less than a tenth of the price paid by the average citizen [45].

Advocates of the Accord and the Council have argued that bitcoin will eventually function like a battery. That is, wherever there is unused residual electrical energy from renewables, bitcoin miners can act as buyer of last resort, converting and storing it as 'financial energy' [50]. This synopsis is problematic because it is not just renewable energy that has a residual fraction available to miners. In developing countries like Ukraine and Kazakhstan, Bitcoin is delaying grid transitions to renewables, by making oil and gas operations more profitable, allowing bitcoin miners to make use of residual methane that could otherwise be used in pursuit of constructing more sustainable communities [51]. Residual fractions of gas and renewables have been used previously for aluminium recycling and hydrogen fuel projects [52]. With competition from bitcoin miners, industrial transitions to sustainability become less economically feasible [53]. Furthermore, increasing Bitcoin prices and the relatively low cost of fossil fuels, has enabled redundant coal, oil, and gas plants to reopen specifically for bitcoin mining [54]. Burning inexpensive, yet highly polluting coal tailings is also an increasingly popular energy production method for bitcoin mining [55]. It is not clear how a voluntary Accord could disincentivise such activities. All bitcoins are fully fungible. It is not possible to make bitcoins mined using low-carbon renewables more valuable than those mined using fossil fuels. The Accord also relies on the false logic that renewables are environmentally benign. Wang, et al. [56] argues that hydroelectric facilities across Asia are responsible for intensifying biodiversity loss, including extinction of key species of fish and river dolphin. The Accord also assumes that producers of renewable energy would always prioritise non-mining activities before selling to bitcoin miners. Research shows the opposite [42]. For example, in Virunga National Park in the Democratic Republic of Congo, an EU funded hydroelectric plant has been constructed to help ex-combatants build sustainable livelihoods beyond poaching. The plant was also intended to prevent local people needing to cut down trees for wood fuel [57]. However, contrary to these objectives, the plant has been re-purposed for French bitcoin miners able to negotiate special access [21]. Lastly, the Accord doesn't cover other externalities of PoW mining such as the impact of the devices used on the global semiconductor supply chain and the generation of e-waste [19,22].

PoW mining with voluntary carbon offsetting

Voluntary options have also been established for cryptocurrency exchanges and third-party intermediaries. Personal carbon footprint calculators and offsetting websites have been around for some time, though several specialist brokering sites have recently offered offsetting services specifically for PoW cryptocurrency investors. Examples include Impact Scope[i], which allows investors the opportunity to donate funds using Bitcoin or Litecoin to finance forest conservation projects in developing countries, like Brazil, Indonesia, and Kenya. The Carbon.fyi[j] calculator is targeted at Ethereum investors, specifically those using the network to buy Non-Fungible Tokens (NFTs).

To effectively tackle emissions from fossil fuel power stations requires switching to non-fossil fuel production methods. Carbon off-set markets, as a false solution to climate change, act as an impediment to fossil fuel divestment [58]. The gas-fired power plant operator and bitcoin mining company, Greenridge Generation Holdings, for example, has pledged to tackle its carbon footprint by simply offsetting 100% of the company's emissions from its 40MW gas plant [59]. Similarly, the cryptocurrency exchange platform, Gemini, has established its own methodology for calculating the company's share of overall emissions from the bitcoin network. Gemini Green has donated around $4 million (US) to climate change mitigation projects. Gemini is collaborating with Climate Vault to purchase carbon permits for 342,000 metric tons of carbon offsets, representing half of the company's overall share (around 1.34%) of bitcoin's emissions [60]. Similarly, the Wrapped platform aims to allow crypto investors the ability to offset the associated emissions from their bitcoin investments automatically. Wrapped claims their Eco-BTC (eBTC) token is the world's first carbon-neutral bitcoin-backed asset. eBTC combines Bitcoin and MOSS.Earth Carbon Credits (MCO2) in a single digital asset [61]. However, the lack of an official international standard for carbon accounting means that voluntary offset mechanisms, like that used by Gemini Green, have limited credibility [62]. It is not possible to accurately quantify the capacity of a defined area of tropical forest in sequestering carbon over a defined timescale [34].

Like the Crypto Climate Accord, voluntary offsets are not intended to disincentivise the use of cryptocurrencies. Therefore, they do not tackle the root causes of associated increases in CO_2 emissions. Howson et al. [34] suggest that although cryptocurrency investors are providing a funding lifeline to existing offset schemes, including the Clean Development Mechanism of the Kyoto Protocol, and the UN Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism for developing countries, there remains significant mechanical faults to carbon offsetting that cannot be fixed simply with more funding or digital wrapping. Offsetting projects rely on a false equivalence between fossilised carbon that takes many thousands of years to become locked in geologically secure conditions, and biospheric carbon that exists only fleetingly in protected or restored woody biomass. To commodify carbon for exchange on international markets requires verification of a plausible baseline narrative, substantiating forest protection interventions that are likely to have resulted in a measurable additionality. Howson et al. [34] argue that accurately predicting what might have happened in the absence of an offset being purchased is impossible. Furthermore, while deforestation might have been avoided in one place, the root causes of deforestation and climate change are not being tackled [24]. The drivers of the problem are simply moved to another area of forest or a different country. Carbon offsetting projects have also frequently been implicated in forced evictions of indigenous communities, and there are usually inequitable outcomes with regards to benefit sharing between stakeholders [63,58]. These problems have beset climate offset projects for nearly 25 years,

[i] https://impactscope.com/
[j] https://carbon.fyi

making carbon offsetting for PoW mining a fantasy solution. Offsets are dependent on a mobilisation of supportive discourses and overly economistic knowledge-claims to retain any sense of credibility [64].

Using existing financial regulation and tax frameworks

Truby [9] argues that more mandatory fiscal tools can effectively provide the incentives required to promote behavioural modifications among blockchain developers and PoW miners to reduce energy consumption. These environmental tools could occur while governments impose 'Anti-Money Laundering' (AML) / 'Know Your Client' (KYC) requirements for crypto exchanges that could ultimately negate the privacy use case for many PoW cryptocurrencies, lowering their market value and disincentivising their production [65]. However, this assertion is problematic. In Nigeria, financial regulation has increased cryptocurrency prices, rather than decreased them. After the Central Bank of Nigeria reminded banks of legislation prohibiting provision of financial services to crypto exchanges, the local price of Bitcoin rose to $86,000 US, 46% higher than elsewhere. However, the premium would be paid only by buyers without access to US dollars, and would be paid to intermediaries, rather than as an additional incentive to miners. The actual number of Bitcoin transactions has fallen significantly within Nigeria [66]. Yet, the regulatory move and associated price shock is likely to have disproportionately impacted poorer investors without access to US dollar markets. To counter this effect, the Government of India has proposed an 'exit window' enabling citizens to sell their crypto-assets over a 3 to 6 month period before regulations on trading cryptocurrencies would be enforced [67].

In China, existing carbon tax mechanisms have been used to disincentivise highly polluting activities, including PoW mining. However, exploring the China context, Jiang et al. [10] suggests that moving away from a punitive carbon tax policy to a site regulation policy, induces changes in the energy consumption structure of local mining activities. In their site regulation scenario, bitcoin miners in a coal-based area are incentivised to relocate to areas with 'residual' hydroelectricity. However, these movements were seasonal and may have acted to reduce localised coal prices. This reduction may ultimately increase the network hash-rate as new miners replace those relocating, without reducing the networks overall carbon footprint.

Truby [9] argues that mandatory energy efficiency standards could be effectively extended to PoW mining equipment, for example through the China Energy Label (CEL), which provides information on associated energy costs for consumers. However, it is very unlikely, given the high cost of entry (approximately $1.8 million US for 1 bitcoin per day aggregated over a year), that prospective consumers would not already be investigating the energy efficiency of ASIC units [26]. Bitcoin miners have strong economic incentives to develop and use more energy efficient devices. The energy efficiency of available bitcoin mining machines is continually improving [22]. This reduces energy expenses and improves miners' capacity to acquire more machines. More machines will continue to be added to the network until the market reaches an economic equilibrium [11]. This increasing number of machines negates the effect of machines becoming more energy efficient.

Furthermore, bitcoin tokens are fully fungible, meaning that it is not possible to apply price premiums (creating additional incentives) to bitcoins mined with renewable energy. However, Truby [9] argues that it would be administratively straightforward to introduce taxes, charges, or fees on currency transactions based upon their related energy consumption, payable at the exchanges who are ultimately liable for paying local revenue authorities. Such an approach may be useful for encouraging investors to purchase only non-PoW cryptocurrencies. This could impact the value of PoW-based cryptocurrencies and, in turn, their environmental impact. However, this would need to be applied

across-the-board for all bitcoin purchases as it is unfeasible for fossil-fuel derived bitcoins to be taxed differently to those mined using renewables. Moreover, a previous attempt to implement a Financial Transaction Tax (FTT) in Europe, in 2011, failed to get unanimous backing from all EU member states, indicating that such a solution may be politically unfeasible.

Rather than disincentivising PoW cryptocurrencies, many bitcoin mining operations benefit from government tax incentive frameworks which were designed to attract data centres, rather than bitcoin miners. For example, state-commissioned renewable energy infrastructure feeding data centres along the Angara River in Siberia have become dominated by more profitable bitcoin interests [68]. In El Salvador, a state-owned geothermal electric company plans to dedicate a 95 MW facility for bitcoin mining [69]. However, El Salvador does not produce enough energy to meet its existing needs, importing 25 per cent of its electricity from elsewhere in the region [70]. The high cost of electricity in El Salvador is a significant driver of poverty [71]. In order to attract bitcoin miners and encourage foreign direct investment, investors are not required to pay property tax or capital gains taxes on profits from bitcoin investments in El Salvador, as they are in most other jurisdictions [70]. Offering such tax breaks means El Salvador will continue to struggle to raise funds for basic services such as healthcare and education. As the UK Tax Dialogue reports state, "If we are to achieve the ambitious Sustainable Development Goals (SDGs), then considerable new sources of finance need to be found, and this includes domestic tax revenue" [72 p3]. Rather than enabling equitable human development pathways, cryptocurrencies are proving an impediment to those goals.

There are also frequent disingenuous claims that Bitcoin will help El Salvador's poorest by 'banking the unbanked' [73]. Yet, bitcoin cannot resolve structural problems preventing Salvadorans from accessing financial services. Up to 49% of adults without bank accounts do not have the necessary documentation to open them. Others may not have a stable income to warrant it [74]. Bitcoin cannot solve either of these problems.

Banning PoW cryptocurrencies

Unlike voluntary mechanisms, national and international bans tackle the drivers of anthropogenic CO_2 emissions associated with PoW mining. At the time of writing, a number of countries have banned the holding of any cryptocurrencies, including Egypt, Morocco, and Bolivia. China has banned Bitcoin mining on explicitly environmental grounds. However, this has had adverse impacts in other countries, including coal rich areas of Kazakhstan where purpose-built coal-fired power plants have been developed catering for Chinese bitcoin mining companies. For example, the 180MW Enegix coal-powered data centre near the eastern city of Pavlodor is due to be expanded to 500MW in order to host miners exiting China's Xinjiang province [75]. Following China's crackdown, bitcoin mining in the Black Sea territory of Abkhazia has been blamed for overloaded electricity lines and power station fires, leaving some areas without power for days [76]. Miners have been attracted to the disputed territory due to the state's subsidised energy [19]. These subsidies were designed to reduce fuel poverty, rather than increase profitability for Bitcoin miners.

The Central Bank of Iran has prohibited the trading of bitcoin and other cryptocurrencies that are mined outside the country. Iran has also confiscated mining equipment from foreign owners judged to be complicit in power shortages and regional blackouts [77]. According to Baydakova [78], the Government of Iran continues to promote the use of PoW mining to make up for lost revenues from oil exports caused by international sanctions. In Abkhazia, authorities have imposed a temporary ban on Bitcoin mining until at least May 2022, following reports of theft of electricity from the national grid causing fires and regional blackouts [79]. Like China, following the reopening of redundant fossil fuel power plants for bitcoin mining, the New York State Senate is considering a 3-year moratorium

on mining centre operations [80]. If approved, miners using fossil fuels will be required to complete a generic environmental impact statement before being allowed to operate. However, such an assessment would only consider the local environmental impacts, as well as greenhouse gas emissions of the cryptocurrency mining centre itself, not the impacts of the wider Bitcoin network. Any new mining operations in New York would increase the network hash rate, inadvertently exacerbating environmental issues elsewhere, as well as the network's overall carbon footprint [11].

A permanent national ban on PoW mining, that gives law enforcement agencies the power to seize mining equipment, would reduce the carbon footprint of the network, even if other countries continue to allow PoW mining. However, banning ASIC units specifically might drive miners towards general purpose equipment instead, such as Graphics Processing Units (GPUs)[k]. National bans on the sale or ownership of specialist PoW mining equipment would be significantly more effective in Asia, where the vast majority of the world's ASIC units are produced and exported [81]. Due to continued global shortages of computer chips, it is unlikely that such a ban will affect industrial productivity [82]. For countries like the UK, where institutional exposure to cryptocurrency investments is small and only a relatively tiny amount of PoW mining is carried out, implementing a ban on such activities would be politically unproblematic. Only 0.1% of the network's total hash rate comes from UK miners [16]. Most UK banks currently refuse to serve business customers who accept cryptocurrencies [83], and the UK's Financial Conduct Authority has banned the sale of crypto-derivatives to retail consumers [84]. In developing countries where adoption is much higher, for example in Russia, Moldova, Ukraine and Venezuela, such bans could prove more politically challenging. However, China's enforced regulatory framework shows that national mining bans can be highly effective, albeit for more autocratic states.

To ensure localised bans do not simply move the problem elsewhere, an international approach could be required. To mediate international consensus around a ban, the OECD, and UN bodies, namely the UN Environment Programme and UN Framework Convention on Climate Change (UNFCCC), could prove best placed to broker agreement. Such an international ban would not conflict with the UN's wider innovation agenda, which so far involves a warm embrace of blockchain technology [85]. Enterprise solutions are unlikely to ever run on a PoW blockchain [86]. However, a ban may conflict with the UN's market-based commitment to environmental regulation. These commitments include the UN-REDD programme, the UN International Civil Aviation Organization's (UN-ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), and more specifically, its endorsement of the Crypto Climate Accord. These market-based approaches have all so far failed to reduce CO_2 emissions [87]. Some accuse the approach of increasing emissions and preventing more decisive climate action [88]. However, precedence exists where UN bodies have successfully orchestrated non-market-based mechanisms for environmental protection. These include a global ban on ozone-depleting CFCs at Montreal in 1987, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, 1992, and the MARPOL convention for preventing pollution from ships, 1998. These have all required on-going political commitments from signatories as well as enforcement through non-compliance procedures[l]. Unlike market-based approaches, they have all resulted in some success in mitigating social-environmental issues.

[k] Like ASIC units, Graphics Processing Units (or GPUs), are specialised processors originally designed to accelerate graphics rendering. GPUs can process many pieces of data simultaneously. While GPUs are fast, ASICs are much faster. But while GPUs are relatively flexible, ASICs are limited to a much narrower set of functions.

[l] Non-compliance measures listed under the Montreal Protocol include provision of appropriate assistance, issuing cautions, and suspensions of benefits [89].

Conclusions: Social and environmental benefits for regulating PoW mining

PoW is a blockchain consensus protocol that allows the decentralised networks behind some cryptocurrency projects to agree account balances and the order of transactions. PoW also ensures that blockchains are difficult to attack or overwrite. However, the amount of energy required to run PoW cryptocurrencies as well as the energy mix of PoW mining operations, make them highly polluting. They are also difficult to scale without third party applications, sacrificing aspects of their decentralised architecture and negating their overall purpose. Bitcoin's advocates insist the network's environmentally catastrophic trajectory is worthwhile, as bitcoin could replace all other stores of value (including gold) and means of exchange, with an efficient digital alternative [90]. However, bitcoin's architecture currently permits only a maximum of 7 transactions per second. The Visa network alone handles 1,700 transactions per second and can handle a maximum of 65,000 transactions per second if needed [91]. An average Bitcoin transaction fee can vary from anywhere between $2 US to $59 US, with a transaction taking several minutes to several days to complete[m] [92]. As well as being unfeasible towards achieving its prescribed use case, there is broad consensus among scientific experts that a climate-friendly bitcoin enabling broad environmental, social, and governance benefits, is highly unlikely in its current form [93,94]. Individual investors may benefit from the speculative gamble of cryptocurrency production and trading. But those who are socially, economically, culturally, politically, institutionally, or otherwise marginalised are especially vulnerable to bitcoin's climate costs [95]. Regulating the inefficient and polluting technology slows the climate crisis, reduces hazardous e-waste, and improves local air quality.

To tackle the multiple social and environmental impacts of PoW cryptocurrencies, we argue for a regulatory approach beyond existing voluntary, free market mechanisms. There are (at least) 3 fundamental challenges in adopting such a centralised approach: 1) Centralised regulation of cryptocurrencies by 3rd parties, including governments, stands at odds with cryptoeconomic principles of individual sovereignty and bitcoin's decentralised architecture [8]; 2) Such regulation is especially challenging in developing countries where communities suffer economic instability, inadequate tax policy frameworks, and weak regulatory institutions. 3) The bitcoin narrative fits neatly into prevailing neoliberal government approaches to managing global challenges and is generally considered ideal to most liberal democracies. This narrative maintains a mistrust towards the State with calls for markets (idealised as decentralised social systems) and business logics to be introduced in public management and services wherever possible [96]. However, the drivers of climate crises are structural in nature [97]. They cannot be solved through small individual acts alone, such as switching off light bulbs.

Every hour of every day in 2020, bitcoin used an amount of energy equivalent to leaving on several hundred billion lightbulbs [11]. Bitcoin is cancelling out breakthroughs for global climate governance in other areas. For example, global take-up of electric vehicles has prevented 50 Mt CO_2e so far [98]. This is significantly less than Bitcoin's carbon footprint for a single year. Effective environmental regulation is urgently required that will not only reduce the threat of catastrophic climate change but will help the world's poorest people towards sustainable development. Implementing restrictions on PoW mining would prove an easy win in progressing global sustainable development and climate change goals negotiated by the UNFCCC. Such measures should be pursued during the organisation's 2021 Conference of the Parties (COP26) in Glasgow, and beyond. Voluntary mechanisms for incentivising renewable energy use and sustainable e-waste management could prove useful in

[m] A short-term hash-rate drop coinciding with high demand in April 2021 was responsible for record-high transaction fees of $59 US. Average fees of $50 US were incurred by users in December 2017.

regulating non-PoW cryptocurrencies, as well as tax frameworks to discourage investment in the most polluting projects. However, in tackling the many social and environmental impacts of PoW mining explored in this paper, a global coordinated ban is likely to prove the most effective policy option.

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Disclosure statement

No potential competing interests to report.