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**Title: DIGITAL DESTRUCTION: EXAMINING THE SOCIOLOGICAL TENSIONS HINDERING THE REGULATION OF BITCOIN**

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**Abstract**
Bitcoin is an ecological disaster. In 2017, the Bitcoin network used the same amount of energy per year as Uruguay, when its total number of users worldwide was estimated to stand at 3.4million (Hileman and Rauchs, 2017: 99). By 2021 this number had risen to 101million, and estimates indicated the energy required to power the Bitcoin network equated to that required by all other data centres around the world combined (Blandin et al, 2020; de Vries, 2021). Moreover, Bitcoin's growing carbon footprint shows little signs of abating in spite of significant measures to limit its usage (de Vries et al, 2022). Within the context of a global energy crisis and the broader climate emergency, regulators from Beijing to New York are increasingly considering actions that will restrict the use of the energy-intensive equipment required to power cryptocurrency networks. This article seeks to contribute to Green Criminology scholarship and inform regulatory efforts by (1) outlining the trade-off made in the design process for cryptocurrencies that lies at the root of the problem; (2) emphasising the urgency of this issue via an extensive review of existing studies; and (3) drawing on the constructivist approach in studies of science and technology to highlight and examine the sociological tensions that may hinder regulatory efforts. In short, sustainable pathways of cryptocurrency development demonstrably do exist yet they present significant challenges to what many in the cryptocurrency industry hold to be the *raison d'etre* of, in particular, Bitcoin.

**Key words:** Bitcoin; Science and Technology Studies; Actor-Network Theory; Technological Frames

## Introduction

The rapid development and spread of digital technologies is having an increasingly harmful impact on the environment. Due to the mining of rare minerals required for their initial construction, the enormous amounts of energy required to power global data centres, and the escalating amounts of electronic waste resulting from devices that become obsolete within years of their production, digital environmental sustainability has become a key focus for governments around the world (Koroleva, 2022). The field of Green Criminology has long sought to throw light on such environmental harms with the aim of informing policymakers and broader publics (Frank & Lynch, 1992; South & Bierne, 1998). In recent years, scholars in the field have called for more analysis of the intersection between studies of science and technology (STS), and green criminology (White, 2017; Bedford et al, 2022). The aim of this paper is to respond to this call, examining the environmental impact of the cryptocurrency Bitcoin in order to highlight in particular the utility of two concepts from STS. It is argued that these two concepts, *technological frames* and *technical problematisation*, can help bring theoretical clarity to scholars of Green Criminology by revealing the social elements condensed in technological design and development that often influence and hinder efforts to regulate technical practices.

The escalating amount of energy required to power the Bitcoin network has received widespread criticism and policymakers around the world have attempted to restrict the destructive 'mining' practices that underpin the network's functionality.[i] In spite of these efforts however, Bitcoin's energy consumption continues to grow, with latest estimates indicating the network now has an annual carbon footprint comparable to that of Chile.[ii] At the heart of this issue is an algorithm known as *proof-of-work* which incentivises operators of specialist hardware around the world to compete with one another to process data on the Bitcoin network. The result is an incredibly wasteful form of data processing. The first section of this paper examines this algorithm as a sociotechnical combination, presenting an analysis of its design which highlights the social elements that justified this design choice. The concept of *technological frame* (Bijker, 1995) is drawn on to interpret how these ideas prominent among early developers established the purpose and meaning of Bitcoin which then shaped its use by those subsequently encountering the technology. In this way, we can see how particular values were embedded in the design process which continue to frame the way people understand Bitcoin and may lead to hostility towards regulatory efforts to restrict or redirect its development. In sum, we see a trade-off in Bitcoin's design that prioritised the ideals of a 'free market' over those of sustainability and this has entailed that the network is particularly difficult to regulate. The second section of this paper then examines the controversy that has emerged around Bitcoin's energy consumption. Public controversies have long been interpreted in STS as moments of 'democratic intervention' whereby social groups are able to impress their political, environmental, or criminal concerns regarding the use of a particular technology or diffusion of particular technical practices. In the case of Bitcoin, we see not only an attempt at such democratic intervention by environmental campaign groups and policymakers, we also see an attempt by the Bitcoin industry to stymie these efforts by redefining the problem of Bitcoin's energy use so that it is understood not as a technical problem but a *social* one, whereby Bitcoin need not be changed. Public perceptions must instead be changed. Borrowing concepts from Barthe et al (2022) these two competing attempts to shape the narrative around Bitcoin's energy consumption are interpreted as two types of *problematisation*. These concepts, it is argued, help bring clarity to those seeking to understand the debates around Bitcoin's energy use and how it could be regulated. In concluding the article, we consider how the two concepts of *technological frame* and *problematisation* may be used in tandem to examine future case studies at the intersection of STS and Green Criminology.

## Bitcoin's Technological Frame: Social Elements in Design and Development

In February 2024 email exchanges between the mysterious inventor of Bitcoin, Satoshi Nakamoto, and other early developers were released as part of a court case regarding Nakamoto's true identity. One email exchange revealed how Bitcoin's developers were aware of how wasteful the network could become. This was however, weighed against the 'economic liberty' that Bitcoin would provide via it's 'decentralized' architecture.[iii] From the very beginning there was a trade-off in Bitcoin's development whereby sustainability was sacrificed for 'decentralisation'. In this this section, we examine how this trade-off was made, and the values guiding Bitcoin's development which, when combined with its technical components, gave rise to its *technological frame*: a meaning and purpose for the technology that continues to guide its use and development by many and, we argue, stymie efforts at regulation.

As indicated in the Nakamoto emails, the source of Bitcoin's energy problem can be traced back to decisions made in its initial design and the imperatives guiding these decision-making processes. Bitcoin was first developed in 2009. Its technical configuration has been discussed elsewhere and at length (Antonopoulos, 2014; Song, 2019), as have questions regarding the ideologies motivating its early users and developers (Du Pont, 2014; Scott, 2014; Golumbia, 2016; Dodd, 2018; Brekke, 2021). It is necessary to revisit these debates however in light of the current controversy surrounding Bitcoin's energy usage and environmental impact. In particular, it is important we understand the reasoning behind Bitcoin's wastefulness, which has been observed – notably by Gerard (2017), MacKenzie (2019), and Du Pont (2019) – as stemming from a commitment to 'decentralisation' among developers. Decentralisation, defined as liberation from centralised social power, has long been observed as a guiding ideal among the key operatives of the digital revolution (Winner, 1997; Turner, 2010). Among developers of Bitcoin, this was fused with a particular strain of anarcho-capitalist ideology which identified as the cause of social and economic problems the authoritarian and prohibitive restrictions imposed on economic actors by nation states and central banks (Golumbia, 2016; Swartz, 2018; Brunton, 2019). This distinctly anarcho-capitalist conceptualisation of decentralisation lies at the heart of Bitcoin's *technological frame*: a combination of goals, key problems, ideas, practices and knowledge that emerged around Bitcoin in its early development and continue to serve as a cohesive schema through which Bitcoin is understood by many users. Within this framework of meaning decentralisation is not a straightforward expression for Bitcoin's technical architecture; it is imbued with a vision for designing computer networks that are impervious to state regulation and organised around principles of individualistic competition and capital accumulation. Ultimately, it is this socially constructed meaning and purpose of Bitcoin that underlies its problematic energy consumption.

Bitcoin was designed to be a "new electronic cash system that uses a peer-to-peer network… [and] is completely decentralised with no server or central authority" (Nakamoto, 2008: 1). Such systems for exchanging digital cash directly, without the need for mediating organisations, had long been a principal goal for a network of programmers that frequented the *Cryptography* mailing list, where the designs for Bitcoin were initially published.[iv] These self-described 'Cypherpunks' are Bitcoin's first *relevant social group*; a group of actors whose shared interests constitute a technical artefact by defining its meaning and purpose (Bijker, 1995: 77). The archives of *Cryptography* reveal this group to be one committed to developing technical solutions to political problems, most commonly by addressing issues of privacy via techniques of encryption. Of key concern was the observation that the increased electronic mediation of society would inevitably lead to increases in surveillance. Cypherpunks thus attempted to develop computer networks in which information was encrypted and data storage was decentralised. This latter goal found its expression in the utilisation of peer-to-peer networks where each user constitutes both a *client*: someone who accesses a network; and a *server*: someone who stores and provides data for other users. Such networks were popular as they removed the necessity for large data centres that pose a threat to the privacy of users. Alongside this principled stance against surveillance however, were also views that conflated politics with tyranny and advocated an anarcho-capitalist future known as 'crypto-anarchy' in which all functions of governance are reduced to encrypted computer networks and individuals are subsequently freed from political power to engage in entirely unregulated capitalist markets.[v] As one of *Cryptography*'s contributors put it when outlining his designs for 'B-Money', a direct forerunner to Bitcoin, 'in a crypto-anarchy the government is not temporarily destroyed but permanently forbidden and permanently unnecessary.'[vi] The functions nation states perform in capitalist economies would instead be performed by encrypted and decentralised computer networks.

Throughout Nakamoto's (2008) white paper that sets out the designs for Bitcoin, and the archives of forums *Cryptography* and later *BitcoinTalk* where its development is discussed, design choices for developing and implementing Bitcoin reflect the groups' aims for enhancing personal privacy via encryption and employing peer-to-peer techniques to remove the need for central servers and central authorities. Discussion threads also demonstrate the key technical problems dealt with when attempting to overcome the necessity for any organisations to record, validate and secure transactions. The principal breakthrough of Bitcoin was to offer an innovation – the blockchain – that allowed for encrypted information to be recorded on an immutable ledger that was validated by hardware operators that competed with one another across a peer-to-peer network that functions as a free market. The blockchain thus addressed the practical problems encountered by this social group within the parameters of acceptability set by the group's shared goals and values.

Where other previous attempts proposed to the group, such as B-Money, had failed to adequately address certain technical concerns; and other innovations in electronic payments systems were not considered due to ideological concerns regarding 'central authorities', the designs for Bitcoin managed to satisfy these various interests around one technical artefact. In Pinch and Bijker's (1984) SCOT model, this process is known as *stabilisation* and serves as an important stage in the social construction of technology. Where previously contributors to *Cryptography* debated many alternatives, now efforts became gradually more focused on developing Bitcoin. The various goals, values and techniques brought together in Bitcoin's design were now *stabilised* in one project that increasingly encapsulated the meaning and purpose of digital currency for this group of actors. As collaboration on Bitcoin's development increased and moved to more specialised forums such as *BitcoinTalk*, this meaning became fixed and reified, constituting what Bijker terms a *technological frame*:

> A technological frame structures the interactions among the actors of a relevant social group. Thus it is not an individual's characteristic, nor a characteristic of systems or institutions; technological frames are located between actors, not in actors or above actors. A technological frame is built up when interaction "around" an artefact begins. Existing practice does guide future practice, though without logical determination. If existing interactions move members of an emerging relevant social group in the same direction, a technological frame will build up; if not, there will be no frame, no relevant social group, no future interaction. (1995: 123)

As interactions increased around the implementation and expansion of the Bitcoin network, the various goals and interests that influenced its initial design crystallised into a discourse that gave purpose and direction to the actions of those involved. It is this discourse that has since become the focus of sociological critiques of Bitcoin that assert the technology is 'politics masquerading as technology, or technology soliciting and promoting a very specific politics' that centres on a 'right-wing, libertarian anti-government politics' (Golumbia, 2015: 119). While the presence of such libertarian politics is well documented among networks of users (Karlstrom, 2014; Redshaw, 2017; Parkin, 2020), its presence as part of Bitcoin's technological frame is more pertinent to the issue of sustainability. This is because Bitcoin's design brings together ideas from anarcho-capitalist ideology with particular algorithmic techniques and it is this specific synthesis that underlies its escalating energy demands.

No single authority in the Bitcoin network is specifically tasked with authenticating the transfers of tokens that take place, or ensuring that units of money are not duplicated, or verifying that transactions result in the correct adjustments to the account balances of users. These are precisely the services offered by 'central authorities' that Bitcoin aims to dispense with. Instead, these actions are organised by Bitcoin's core algorithm. In brief, when a transaction takes place it is broadcast to the network, where it becomes possible for one hardware operator to group together this data with that of other transactions into a 'block' that is then time-stamped, encrypted as a *hash*,[vii] and embedded into the immutable 'chain' of all events to have transpired on the network.[viii] This process circumvents the need for central authorities, thus satisfying Cypherpunk interests, yet it requires constant maintenance. An algorithm, after all, is only a set of instructions for hardware devices. Machines must carry it out, and people must operate these machines.

A key problem for those designing Bitcoin therefore lay in motivating people to operate these machines, to participate and contribute their computational power to the network. In theory, there are any number of ways in which this may be done, and subsequent developments by various groups have highlighted the contingency of this issue. Perhaps the most prominent example is *proof-of-stake*, an algorithm first designed in 2012 as part of an effort to construct a more sustainable cryptocurrency known as *Peercoin*.[ix] In this network, one specific hardware operator is selected based on qualifying criteria to validate transactions for one block. This responsibility is then passed on to another hardware operator for the next block, and so on. This algorithm has since been adopted by various other blockchain technology projects, most notably Ethereum in 2022. The immediate point however is that in the context in which Bitcoin was developed and implemented – as documented on the *Cryptography* and *BitcoinTalk* forums – solutions to this technical problem were formulated within a framework of anarcho-capitalist values. Individual hardware operators, across an ever-expanding network, are tasked with intensely competing with one another to validate blocks of transactions in return for units of Bitcoin. This is the activity demanded by Bitcoin's *proof-of-work* algorithm.

Originally, *proof-of-work* had been designed as a means to deter abuses of free-to-access computer networks – such as email spamming – by intentionally making data processing a more difficult and energy intensive process. The algorithm required a computer to pass a cryptographic test by generating a value (a *hash*) that met certain criteria before data could be sent across a network. If the criteria are met, the algorithm produces a token to signify proof that this work had been carried out. This technique was introduced to the *Cryptography* mailing list by Adam Back, who proposed that the algorithm could serve 'as a minting mechanism for Wei Dai's B-Money electronic cash proposal' (2002: 7).[x] The tokens produced that signified a successful hash could also function as new units of currency. This was to be taken up in the design proposal for Bitcoin, where it was employed as an incentive structure for ensuring maintenance of the network:

> The steady addition of a constant amount of new coins is analogous to gold miners expending resources to add gold to circulation. In our case, it is CPU time and electricity that is expended (Nakamoto, 2008: 4)

People programming their computers to hash together transaction information in pursuit of rewards in the Bitcoin network have subsequently become known as *miners*, and it is this activity that now constitutes a serious ecological concern. The reason for this is that the competition between miners is a process of brute computational force, in which computers are programmed to continually generate numbers at random until one finally matches with the arbitrary criteria generated by the core algorithm.

In the early stages of Bitcoin's development when it was tested by enthusiasts from the *Cryptography* and *BitcoinTalk* message boards, the average computational power required before a successful hash was generated was minimal, and undertaken on personal computers.[xi] Before long however, specialised hardware devices, such as 'application-specific integrated circuits', (ASIC chips) were required that could process data more efficiently and at much higher speeds. Currently, there exist vast warehouses of specialised hardware perpetually generating hashes to sustain the Bitcoin network, and the principal reason for this increase in energy demand lies with the design choice to secure the network by incentivising intentionally wasteful competition among miners.

As generating a successful hash is a matter of brute computational force, a miner's chances of obtaining a reward in Bitcoins are diminished unless they continuously increase their hashing power. This competition is further intensified by the fact that the *proof-of-work* algorithm is programmed to increase the hashing difficulty at regular intervals. One reason for this design choice is to maintain balance in the network by ensuring that competitive hardware operators do not reach levels of computational power that allow them to process blocks of data too easily and consequently exert undue influence over the network by manipulating the transaction validation process. In practice, this has led to exponential increases in energy consumption as hardware operators engage in a computational arms race. As previously stated, this is not a necessity driven solely by technological concerns. At the heart of this design choice is a conviction in the self-regulating capacities of free markets, a conviction that reflects the libertarian economic principles contained within ideas of crypto-anarchy. Not only is Bitcoin designed to circumvent central authorities, it is also built on specific forms of economic activity. As stated in the Nakamoto whitepaper, incentivising hardware operators to compete with one another is intended to secure the network by appealing to their rational self-interest:

> The incentive may help encourage nodes to stay honest. If a greedy attacker is able to assemble more CPU power than all the honest nodes, he would have to choose between using it to defraud people by stealing back his payments, or using it to generate new coins. He ought to find it more profitable to play by the rules, such rules that favour him with more new coins than everyone else combined, than to undermine the system and the validity of his own wealth. (2008: 4)

The future security of the incentive structure is thus founded on the rational self-interest of profit-seeking users that will see more value in competing to mine a new block of Bitcoin than they will in augmenting their influence over the network itself. Proof-of-work therefore prescribes particular practices based on a particular logic. Namely, assembling hardware devices to continuously run the Bitcoin algorithm in order to make a profit. This prescribed usage is intentionally competitive and wasteful, as the more hashing power a miner possesses the more chance they have of obtaining the reward. This entails that miners are ever seeking new ways of introducing more computational power into the network, a process that ensures continuous expansion, and is further incentivised by the predetermined increase in hashing difficulty.

Bitcoin's energy consumption is thus predicated on the anarcho-capitalist principles contained within its technological frame. The notion of 'decentralisation' identified as the principal justification for its wastefulness epitomises this, representing Bitcoin's peer-to-peer technical architecture; a particular set of values relating to institutions that must be circumvented and ultimately rendered powerless; and economic individualism which prescribes intense competition as the means for organising hardware operators in the network. For many of those engaging with Bitcoin and other blockchain technologies these are inseparable components of its technological frame that serve to justify one another and give purpose to the technology.[xii]

In *Cryptocurrencies and Blockchains,* Quin DuPont (2019) notes the 'morally reprehensible' wastefulness of *proof-of-work* as well as its other drawbacks relating to inefficiency and performance but states that for users these are necessary trade-offs for an 'open blockchain' that provides a

> highly secure but decentralised network with no supervising organisation and no restrictions on who can participate. Before Bitcoin there were no known solutions to this hard problem (111)

This problem however only makes sense within the value-laden technological frame of Bitcoin. In many ways, Bitcoin is far from 'open' or 'decentralised' even when compared to other 'permissioned' blockchains that restrict the number of hardware operators, permitting only a select number of validators. While in theory anyone can become a hardware operator in Bitcoin, there are levels of cultural, technical, and economic capital that have always been necessary to participate, along with regional infrastructure issues such as fast broadband connectivity and cheap electricity. More pertinently however, this relative openness faded quickly as the hardware necessary to participate became highly industrialised. Considerable concentrations of power have since emerged as hardware operators pool their resources together under the supervision of commercial enterprises. By 2017, three of these mining enterprises oversaw 56% of the network's hashing rate (Hileman and Rauchs, 2017: 92). Recent reports indicate that just two mining pools now control 53.4% of the network's global hashing power, raising concerns among some Bitcoin users that these firms hold too much control over the network (Reynolds, 2023). Accessing the Bitcoin network as a user is also far from decentralised, with an estimated 99% of all transactions mediated by centralised exchange platforms, private companies who offer services for the trading and management of cryptocurrencies (Roubini, 2018). Moreover, in the absence of regulatory bodies capable of recovering lost bitcoins or redistributing them, concentrations of wealth in the Bitcoin network surpass those of practically any other monetary network, with 97% of all Bitcoins held by just 4% of user addresses.[xiii] Bitcoin is thus 'decentralised' only in a very specific sense that is highly imbued with an anarcho-capitalist antipathy toward actors or institutions that are not operating as private competitive enterprises. It is clear that what the Bitcoin industry is truly committed to is unbridled capitalism, which presents a significant obstacle to regulators seeking to work with the industry to introduce constraints on some of its more destructive social and environmental consequences.

This paper has so far sought to identify and explain the root cause of Bitcoin's energy problem, which we argue lies with the particular concatenation of technical and social elements in its design, namely the proof-of-work algorithm and anarcho-capitalist values. These elements came together in Bitcoin's technological frame, establishing its meaning and purpose for future users and guiding its development in particular directions. This technological frame remains a significant obstacle to Bitcoin's regulation as it defines such external state-led efforts as the antithesis of Bitcoin's core purpose. As with all technologies however, Bitcoin has been subject to interpretation, critique, and adaptation as it has diffused through different social contexts. In many cases this has led to new versions of Bitcoin, alternative cryptocurrencies of which there are now thousands, or projects that seek to use Bitcoin's blockchain component for other purposes, such as Ethereum. This could be highlighted as a weakness of the technological frame concept as at first glance it appears the meaning and purpose of Bitcoin is far fixed and reified. Yet while other cryptocurrencies and blockchain technologies have come and gone, Bitcoin retains its original form and remains by far the most widely used cryptocurrency, representing over 50% of the global cryptocurrency market (de Best, 2024a). Moreover, the anarcho-capitalist ideals underpinning Bitcoin's design now permeate a global subculture of Bitcoin users (Brunton, 2019; Parkin 2020; Bruun et al, 2020; Venkataramakrishnan & Wigglesworth, 2021; Lichti & Tumasjan, 2023). Interpreting the social elements of Bitcoin's design and development via the conceptualisation of its technological frame thus retains utility as it helps clarify the backdrop against which attempts to regulate Bitcoin must operate. This is true in cases whereby controversy, and subsequently efforts at regulation, have arisen around tax evasion (Ylönen et al, 2024) or various other forms of criminality (Foley et al, 2019; ElBahrawy et al, 2020; Trozze et al, 2022). In each case, regulatory efforts are thwarted by a technology which is specifically designed to evade regulatory oversight and is understood in this way by many of its users. Attempts to curb the environmentally destructive aspects of Bitcoin must therefore engage in ways of problematising the technology which acknowledge and challenge these values embedded in its design. Such approaches to problematising Bitcoin are the subject of the next section.

## Problematising Bitcoin: Democratic Intervention and Industry Response

Bitcoin is now a global industry with a reputed market capitalization of one trillion dollars (John et al, 2024). Approximately half a million Bitcoin transactions take place every day (de Best, 2024b). And each year, the Bitcoin network consumes more energy than entire countries (Stoll et al, 2019). Bitcoin's rise from an obscure experiment in electronic cash to a worldwide industry for the trading of 'digital assets' has entailed the growth of various sectors: (1) mining: the infrastructure that processes transactions and produces new Bitcoins; (2) exchanges: platforms that facilitate the trading of cryptocurrencies; (3) wallet applications that allow for the storage of Bitcoins; (4) payment services platforms; (5) media ecosystem: news sites, research centres, and lobbying groups generating information about cryptocurrencies and seeking to inform and influence public opinion and policymaking. Detailed analyses of these sectors can be found elsewhere (Rauchs & Hileman, 2017; Rauchs et al, 2018; Blandin et al, 2020). The focus of this section lies with the mining infrastructure that is having an increasingly damaging impact on the environment; and elements of the cryptocurrency media ecosystem that are seeking to influence policymakers and broader publics regarding this problem. In response to the former, we have seen the emergence of a critique of Bitcoin mining that may be best understood – borrowing concepts developed by Barthe et al (2022) – as *technical problematisation*: an attempt to generate controversy and public scrutiny around the social impact of a technology with the aim of redirecting its development. In turn however, we have seen a counter-critique emerge from Bitcoin's media eco-system, as think tanks, advocacy groups, and news sites converge around a *social problematisation* of the issue: an attempt to redefine Bitcoin's energy problem as a social or cultural issue, a controversy primarily borne out of misinformation and misunderstanding. By throwing light on these two processes, this section aims to identify and theorise important sociological tensions that policymakers must understand when seeking to regulate technologies such as Bitcoin.

While there had been some early attempts to calculate the environmental impact of Bitcoin (cf. Becker et al, 2013), efforts to raise public awareness of the issue can be traced back to 2016, when Alex de Vries introduced his *Bitcoin Energy Consumption Index* that tracked Bitcoin's environmental footprint over time. De Vries subsequently published several peer-review studies on the subject (de Vries, 2018; 2019; 2020; 2024)**.**[xiv] In 2017, Marc Bevand presented an alternative analysis based on a critique of de Vries' method (Bevand, 2017). Bevand's calculations were cited in several articles and became the basis for the *Cambridge Bitcoin Electricity Consumption Index* (Kraus & Tolaymat, 2018; Masanet et al, 2019).[xv] Calculations from these two indices reached public audiences immediately, appearing in global news outlets such as *The Guardian, CNN,* and *BBC* in 2017.[xvi] Shocking comparisons between Bitcoin's annual energy use and that of entire countries made headlines around the world. Bitcoin was increasingly scrutinised in the public sphere.

Further research revealed different dimensions of the problem. Intense competition among the operators of specialised Bitcoin mining hardware was leading to 'arms race' that not only consumed escalating amounts of energy but threatened global supply chains of semiconductors and produced incredible amounts of e-waste, again comparable to that of entire countries (Vranken, 2017; de Vries & Stoll 2021). Studies also highlighted how the growth of the Bitcoin network disproportionately impacted on poor and vulnerable communities where hardware operators take advantage of weak regulations, cheap access to resources, and economic instabilities (Howson & de Vries, 2022). Such 'Bitcoin mining hotspots' were found to impact considerably on local air pollution and the health of residents (Goodkind et al 2020). By 2021 the energy required to power the Bitcoin network equated to that consumed by all other data centres around the world combined (de Vries, 2021). In the same year, mounting public pressure led various organisations to take action. In May, Elon Musk announced Tesla was suspending vehicle purchases using Bitcoin due to concerns over rapid increase in use of fossil fuels for Bitcoin mining. In June, US Senator Elizabeth Warren called on policymakers to tackle the growth in the use of cryptocurrencies which 'worsen the climate crisis'.[xvii] In September, China banned the trading and mining of cryptocurrencies, again citing the latter process as harmful to global environmental goals.[xviii] In November, the European Union began the process of establishing a regulatory framework for 'crypto assets' which was to include considerations of their environmental impact.[xix] By 2022 however, elements of the bill which called for the banning of cryptocurrencies that use proof-of-work algorithms like Bitcoin were rejected.[xx] And, despite a dip in carbon emissions reported by both the *Bitcoin Energy Consumption Index* and the *Cambridge Bitcoin Electricity Consumption Index* in mid 2021, by the end of the year both reported a return to the broader pattern of escalating energy consumption once more. By 2024 the Bitcoin network had an annual carbon footprint comparable to that of Chile, produced as much electronic waste per year as the Netherlands, consumed as much water as Switzerland, and required the same electricity as Malaysia.[xxi] Bitcoin mining had continued to grow, and showed no signs of turning to more sustainable energy sources. In part this is due to a different diagnosis of the problem amplified by the Bitcoin industry.

The sources discussed so far define Bitcoin's energy use as a technical problem, calling on policymakers and firms to take action that will restrict the use of 'proof-of-work' algorithms that incentivise energy intensive cryptocurrency mining.[xxii] This is encapsulated in Greenpeace's 'change the code, not the climate' campaign that advocates for Bitcoin's core algorithm to be changed to reduce its escalating energy demands.[xxiii] Such public campaigns for redirecting technological development due to perceived social and environmental concerns have been interpreted by STS scholars as democratic interventions. As social movements emerge among broader publics and seek to influence changes in the use of technology, such as those campaigning for the banning of plastic production or hazardous pesticides, they must struggle against a dominant normative framework that defines technology and its development as something pertaining only to the knowledge, practices, and rules that comprise the fields of science and industry. Public campaigns are in this way defined as external and problematic interferences. This has been theorized in various ways, via the Marxist concept of *hegemony* by Feenberg (1995; 1999; 2017), the Bourdieusian theory of *fields* by Hess (2007), and as *delegative democracy* by Callon et al (2009). In each case, boundaries are drawn which determine who can *legitimately* influence and participate in technological development, and these boundaries are maintained through a variety of processes and strategies. In their case study of nuclear waste management in Europe, Barthes et al. (2022) outline how campaigners for safer disposal encountered pushback from those responsible for national waste programmes. Their critique was dismissed by technical experts, who instead interpreted these grievances as mental health issues that could be corrected with more information. The nuclear industry thus sought to rebuild 'trust' and 'support' for nuclear power. As Barthes et al. state, "the standard response given by the 'technical community' to such concerns is that people are ignorant and should be better informed" (2022: 12). Yet as Barthes et al highlight, the definition of 'safety' that was used in the design for nuclear waste programmes was in part normative, not technical, and was influenced by a range of social factors. The aim of the campaigners was to contest this definition of safety, so that a better, safer technical implementation may be found. This is what they call *technical problematisation,* whereby "the problematic situation will lead to a change to the initial technical project. Here the problematic situation creates a new constraint that will be integrated into the technical project" (2022: 15). On the other hand, the industry response is defined as *social problematisation*, whereby:

> opposition to a project is seen as a problem in itself (as autonomous and completely independent of the characteristics of the project). As such, it should – and therefore a priori could – be treated with a solution other than a technical one, that is, a solution that does not require a modification of the project itself (16)

As already noted, a similar process is unfolding around Bitcoin's energy consumption. On the one hand, those critiquing Bitcoin's carbon footprint are advocating for a change to its core algorithm. On the other hand, we see the emergence of an industry response which denies that such technical modification is necessary. Instead, publics and policymakers must be educated regarding the benefits of Bitcoin. This latter process is evidenced by the emergence and actions of thinktanks and lobby groups whose specific remit is to reframe the issue of Bitcoin's environmental impact.

One such group is Satoshi Action, a non-profit that launched in 2022 to 'shine a light on the benefits of Bitcoin and Proof-of-Work technology for our economy, our environment, and our energy systems', specifically targeting policymakers with the aim of shaping legislation across the United States.[xxiv] The CEO of Satoshi Action, Dennis Porter, has written for multiple cryptocurrency news outlets, appeared on several podcasts, and spoken at various conferences, proclaiming that Bitcoin mining is actually good for the environment.[xxv] Similarly, Sam Lyman, public policy director at Riot Platforms, a leading bitcoin mining company, wrote an article for Forbes magazine explaining 'Why Bitcoin Mining Might Actually Be Great For Sustainability'.[xxvi] Stephen Stonberg, the CEO of another Bitcoin mining company Bittrex Global, argued on the World Economic Forum website that 'rather than harm the planet, crypto and blockchain can actually be a force for environmental good'.[xxvii] Didar Bekbauov is the CEO of yet another Bitcoin mining company Xive, and outlined for CoinTelegraph how Bitcoin mining is becoming more environmentally friendly.[xxviii] Such rebuttals of the Bitcoin energy problem are common across the media eco-system of cryptocurrency news sites, often written by those working for mining companies and aiming to reach public audiences. Alongside such public campaigns are also the emergence of various lobbying organisations. The Texas Blockchain Council and the Chamber of Digital Commerce are two such organisations in the US, aiming to ‘champion Bitcoin’ in America and shape legislation.[xxix] In 2023 the Digital Energy Council was founded, recognised as the first lobby group in the US to advocate for the interests of cryptocurrency mining firms specifically in relation to environmental legislation.[xxx] Between 2019 and 2023, the cryptocurrency industry spent $56.44million on lobbying in the US, with the total amount rising each year.[xxxi] The common thread running through the output of such lobby groups and thinktanks is that Bitcoin itself, in its current form, is not problematic. Instead, it is a combination of misunderstandings and misinformation that have led to this narrative. As one cryptocurrency advocate summarised:

> governments, traditional fund managers and journalists do not yet understand this new technology. The FUD (fear, uncertainty and doubt) in the media is often misinformed or downright dangerous. (Ward, 2023)

It is this framing of the issue which underpins the millions of dollars being invested in campaigns to ‘educate the public’ on the benefits of Bitcoin and proof-of-work and shape policy. In response to the technical problematisation of Bitcoin pushed by scholars and environmental groups, the Bitcoin industry is amplifying a social problematisation whereby regulation and development must seek solutions that leave the current technical configuration of the Bitcoin network intact.

By identifying and theorising important sociological tensions that have emerged around the regulation of Bitcoin, namely two competing attempts to define problems with the network and how they ought to be addressed, this section has sought to highlight issues that policymakers must understand when seeking to regulate technologies such as Bitcoin, as well as suggesting that Green Criminology may benefit from incorporating concepts of problematisation when examining the environmental impact of new technologies. However, as outlined in the previous section, Bitcoin is and has always been a sociotechnical combination, whereby particular values have guided design and development and continue to give purpose to Bitcoin as a project. Separating the social from the technical when examining its functionality and materiality is in reality a messy process. Following Latour (1999; 2005**)** many scholars in STS now reject the notion that ‘social’ elements can be drawn on for explanatory value at all. On the contrary, “the social has never explained anything; the social has to be explained instead. It’s the very notion of a social explanation that has to be dealt with” (Latour, 2005: 97). This approach has become very influential in STS, with scholars now focusing on sociotechnical networks or ‘assemblages’ of human and ‘nonhuman’ actors. In making the argument for the utility of technological frames and technical/social problematisation for Green Criminology then, it would be remiss not to address these critiques. In concluding this article therefore, we reflect on these debates to ascertain how useful *technological frames* and *technical problematisation* may be for scholars of Green Criminology.

## Conclusion

While the major contribution of STS as a tradition has historically been to highlight the social elements active in technological development, Latour argues that STS has forcefully demonstrated that conventional conceptions of the ‘social’ are fundamentally flawed. Latour argues that STS has shown that there are no fixed and stable social ‘forces’ or ‘factors’ which lie *behind* technical development which can be revealed and drawn on for explanation. Technical development is instead produced and sustained via the continuous activity of interacting agents. These agents, which Latour asserts can be objects as well as humans, are constantly at work, forming and maintaining particular types of *association* with one another through which meaning and force are transported. Should this interaction cease, and the associations break down, meanings and forces dissolve with them. There is therefore no repository of social forces or factors that may be investigated outside of *associations*, no distinct realm of 'the social' to be revealed and analysed. For Latour, the task of the sociologist is thus one of tracing and explaining new *associations* as they arise, and attempting to *reassemble* through documentation the networks of interacting agents these associations have given rise to. This argument reconceptualises 'the social' as 'a fluid visible *only* when new associations are being made' (2005: 79). Latour's arguments have become highly influential in STS, where his actor-network theory (ANT) is now a leading approach. Indeed, the most thoroughgoing analyses of Bitcoin have pursued this approach, tracing and describing the networks of 'blockchain assemblages' that emerge differently in different contexts, always retaining flexibility and lacking any overarching framework of meaning (DuPont, 2019; Parkin, 2020). Methodologically, Parkin's work in particular is the most empirically robust study of Bitcoin to date for these reasons. Yet as he concedes, his study is somewhat restricted theoretically by the limits of ANT, with its 'flat ontology' that prescribes endless description and leaves little basis for critique or normative interrogation. Green Criminology, as with many disciplines in the social sciences, has from its beginnings been rooted in normative and critical conceptions of justice (Lynch et al, 2017). Such moral imperatives are diluted by ANT, which prescribes value neutral descriptive sociology. This is clearly problematic for any politically-engaged social science. Moreover, it presents theoretical problems. If objects and people possess no properties independent of the assemblages of which they form part, generating theory which helps clarify distinct phenomena becomes impossible. Such abstractions are crucial in formulating explanations that go beyond direct observation. Various competing firms and workers across different sectors could not be theorised as pertaining to capitalist social relations, just as various prejudices and inequalities could not be theorised as pertaining to systems of oppression. As Mills states in his critique of ANT:

> The radically descriptive approach which ANT shares with ethnomethodology leaves no room for judgments as to the accuracy or otherwise of the explanatory frameworks into which 'actants' are 'enrolled'. Neither is there any space from which to make normative judgements as to the desirability of any particular outcome or assemblage. (2017: 298)

In the context of the climate crisis, such normative judgements are imperative when rapidly growing industries are having a measurable and harmful impact on the natural environment. This is the case with Bitcoin. While it is certainly possible to parse the various networks of activity that comprise the cryptocurrency industry and identify ideological variances and sociotechnical offshoots that are developing into distinct associations and assemblages, such analyses shift focus away from the overall impact and social value of an industry that uses the same amount of resources as entire countries to generate digital tokens. It is for this reason we argue for the importance of problematising technologies, which is vital in a critical tradition such as Green Criminology. Moreover, it is possible to retain some of the conceptual tools of ANT that come out of Latour's critique without succumbing to its flat ontology. In what remains of this paper, we identify two concepts from Latour's work which we argue sharpen the concept of technological frames so that they too may be useful for Green Criminology scholars.

As we have seen in section one of this paper, the concept of technological frames helps make sense of the social and technical elements that are condensed in design processes and how they can continue to guide the use and development of a technology. This can appear to be a problematic abstraction when considering the supposed influence that ideas may have on technical objects and vice versa. This line of critique is persuasive for example, when applied to Golumbia's (2016) arguments that Bitcoin constitutes 'software as right-wing extremism'. Collating the political expressions among some early users of a technology does not explain how social groups encountering the technology later in different contexts may be influenced by these same ideas. The incorporation of Latour's concepts of *delegation* and *prescription* into an analysis of Bitcoin's technological frame can assist in this explanation however. In his (1992) essay *Where are the Missing Masses?* Latour describes how humans and nonhumans within a sociotechnical network follow and enforce 'programs of action'. Latour uses the example of an alarm in a car that reminds passengers to wear seatbelts. The car, the seatbelt, the alarm, and the passengers all play equal roles in enforcing this program. To explain this, Latour introduces two concepts: *delegation* and *prescription*. Nonhumans perform activities that have been 'delegated' to them, which then disappear from view and no longer constitute social action. Yet they retain a crucial role in sustaining a program of action. The inverse of delegation is prescription, whereby 'behaviour is imposed back onto the human by the nonhuman' (1992: 57). In the design for Bitcoin, we see a similar process whereby the role of recording and validating transactions is delegated to the proof-of-work algorithm, which in turn prescribes humans to run increasingly energy-intensive machinery. In this way, we can interpret how the social elements in Bitcoin's design are not mysterious 'forces' or 'factors' lying behind the technology that sociologists have invented to explain its 'politics'. On the contrary, they are observable elements of Bitcoin's functionality which influence how humans interact with the technology. Moreover, as this process of prescription involves rewards in units of Bitcoin, the humans involved are incentivised to further expand the network in order to increase the value of these tokens. In this way, the meaning of the technology encoded in its design is carried to further groups of users. This is not deterministic, people can and have interpreted Bitcoin and blockchain technology in various ways, but it helps explain how one particular set of practices and their ideological justifications can spread across different contexts, in particular the imperative to expand an energy-intensive industry for the valorisation and accumulation of a decentralised digital currency.

To conclude, this paper aimed to respond to the call for more analysis of technologies in the field of Green Criminology by presenting the case study of Bitcoin, which has proven to be incredibly wasteful and harmful to the environment. Through this case study, we aimed to clarify the case of Bitcoin for policymakers whilst also highlighting the utility of two concepts from STS for Green Criminology scholars: *technological frames* and *technical problematisation*. Digital environmental sustainability is of increasing importance and Bitcoin in particular demonstrates this.

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[i] Cryptocurrency 'mining' refers to the data processing on a cryptocurrency network that records and validates transactions. This is a considerably more wasteful form of data processing than occurs in other data centres.
[ii] See the *Bitcoin Energy Consumption Index.* Available here: https://digiconomist.net/bitcoin-energy-consumption (accessed 20/03/24)
[iii] See the Craig Wright court case, reported here: https://www.coindesk.com/consensus-magazine/2024/02/26/5-things-satoshi-nakamoto-correctly-predicted-about-bitcoin/ (accessed 20/03/2024)
[iv] These mailing lists are publicly archived. Cryptography is available at http://www.metzdowd.com/pipermail/cryptography/ (accessed 19/05/2016); Cypherpunk at
[v] 'Crypto-Anarchy' was theorised in a number of texts produced by Cypherpunks, most notably Tim May (1994) who argued that new innovations in cryptography were establishing the basis for a new society founded on anonymous markets, 'a form of anarcho-capitalist market system I call 'crypto-anarchy'.
[vi] This is an extract from Wei Dai's B-Money proposal, taken from his personal website. It is undated. Available here http://www.weidai.com/bmoney.txt (accessed 15/06/16) Dai was a regular contributor to the *Cryptography* mailing list, and B-Money is referenced in the designs for Bitcoin, which replicates its function of broadcasting encrypted transaction information for confirmation by the network (Nakamoto, 2008: 2).
It is undated. Available here http://www.weidai.com/bmoney.txt (accessed 15/06/16)
[vii] A 'hash' in this context refers to a string of data that is reduced to a specific size to facilitate its processing.
[viii] For further elaboration of blockchain's technical architecture, see Redshaw (2017), or chapter four in Du Pont (2019).
[ix] See Peercoin's webpage for their design history: https://peercoin.net/ (accessed 11/07/19)
[x] Back provides the link on his personal website - http://www.cypherspace.org/adam/ - to the original posting of the *HashCash* paper in which he first presents the *proof-of-work* algorithm.
[xi] These were most often committed libertarians, such as the group 'New Liberty Standard.' See https://bitcointalk.org/index.php?topic=16.msg73#msg73 (accessed 27/08/17)
[xii] See Sadowski & Beegle (2023) for a discussion of how conceptions of 'decentralisation' have continued to guide development of various other blockchain projects, collectively referred to as 'Web 3'.
[xiii] Analysis conducted by Credit Suisse, 2018, report available here: https://markets.businessinsider.com/currencies/news/bitcoin-97-are-held-by-4-of-addresses-2018-1-1012932501 (accessed 15/07/19)
[xiv] De Vries' *Bitcoin Energy Consumption Index* can be found here: https://digiconomist.net/bitcoin-energy-consumption (accessed 20/03/24)
[xv] The *Cambridge Bitcoin Electricity Index* can be found here: https://ccaf.io/cbnsi/cbeci (accessed 20/03/24)
[xvi] 'Bitcoin: Does it really use more electricity than Ireland' *BBC,* 2017. Available here: https://www.bbc.co.uk/news/technology-42265728 (accessed 20/03/24);
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'The trouble with bitcoin and big data is the huge energy bill' *The Guardian*, 2017. Available here: https://www.theguardian.com/commentisfree/2017/nov/26/trouble-with-bitcoin-big-data-huge-energy-bill (accessed 20/03/24)
[xvii] See Reuters: https://www.reuters.com/technology/warren-us-government-needs-confront-crypto-threats-head-on-2021-06-09/ (accessed 20/03/24)
[xviii] See Reuters: https://www.reuters.com/world/china/china-central-bank-vows-crackdown-cryptocurrency-trading-2021-09-24/ (accessed 20/03/24)
[xix] See https://www.europarl.europa.eu/legislative-train/theme-a-europe-fit-for-the-digital-age/file-crypto-assets-1 (accessed 20/03/24)
[xx] See https://www.euronews.com/next/2022/03/14/europe-to-vote-on-limiting-pow-crypto-mining-used-by-bitcoin-and-ethereum (accessed 20/03/24)
[xxi] See the *Bitcoin Energy Consumption Index.*
[xxii] These efforts did have an impact on the broader use of blockchain technology. In 2022 Ethereum, a blockchain technology firm with the second most popular cryptocurrency, Ether, altered its core algorithm from proof-of-work to a more energy-efficient alternative known as 'proof-of-stake'. Ethereum reduced its direct energy consumption by 99%. See Castor (2023).

[xxiii] See Greenpeace's campaign to change cryptocurrencies that use the 'proof-of-work' algorithm here: https://www.ewg.org/areas-focus/key-issues/change-code-not-climate (accessed 20/03/24)
[xxiv] See https://www.satoshiaction.org/ (accessed 28/03/24)
[xxv] See https://www.coindesk.com/consensus-magazine/2023/03/06/bitcoin-mining-is-good-for-the-energy-grid-and-good-for-the-environment/ (accessed 28/03/24)
[xxvi] See https://www.forbes.com/sites/digital-assets/2023/09/21/why-bitcoin-mining-might-actually-be-great-for-sustainability/?sh=eab6e143f316 (accessed 28/03/24)
[xxvii] See https://www.weforum.org/agenda/2021/06/how-blockchain-and-cryptocurrencies-can-help-build-a-greener-future/ (accessed 28/03/24)
[xxviii] See https://cointelegraph.com/news/bitcoin-mining-becoming-more-environmentally-friendly (accessed 28/03/24)
[xxix] Texas Blockchain Council org: https://texasblockchaincouncil.org/ (accessed 28/03/24)
Chamber of Digital Commerce: https://digitalchamber.org/ (accessed 28/03/24)
[xxx] See https://www.coindesk.com/policy/2023/08/15/crypto-mining-gets-its-own-lobbying-voice-in-washington/ (accessed 28/03/24)
[xxxi] See https://www.nasdaq.com/articles/crypto-lobbysists-spent-over-$56m-on-lobbying-in-2023:-did-it-make-a-difference (accessed 28/03/24)