

How to Make Users Adopt More Sustainable Cryptocurrencies: Evidence from Nigeria

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Abstract

Some of the most popular decentralised cryptocurrency networks have drawn widespread criticism for consuming vast amounts of electricity and have thus become targets of regulatory interest. Attempts to influence cryptocurrency network operations via policy in the pursuit of sustainability in the past, however, have been widely unsuccessful. Some were abandoned out of fear of jeopardising innovation while others failed due to the highly globalised nature of decentralised systems. Considering Bitcoin as an archetype for cryptocurrencies with high energy demand, this study takes a bottom-up approach by analysing statements made by Nigerian cryptocurrency users ($N = 158$) concerning their perception of sustainability issues. Three main findings emerged: 1) Despite self-reporting as highly knowledgeable, most participants significantly underestimate the energy demand of Bitcoin. 2) Those who accurately assess the energy demand of Bitcoin are more likely to support measures targeting its energy demand than those who misestimate it. 3) Those who support measures predominantly hold private actors responsible. In light of these findings, it is concluded that the primary task of policy makers in the context of cryptocurrency sustainability is to enforce consumer education.

1. Introduction

Bitcoin, arguably the most popular cryptocurrency (Mikhaylov, 2020), has experienced enormous success since its invention in 2008, as evidenced by its peak market capitalisation exceeding 1 trillion United States dollars (US\$) (de Best, 2021) and its growing user base (Park et al., 2019). Yet, this original 'pure digital asset' (Fang et al., 2022) has been criticised outright for reproducing societal inequality (Walsh, 2021) and for its enormous electricity demand caused by the underlying proof-of-work (PoW) consensus mechanism (Truby, 2018; De Vries, 2018; Badea and Mungiu-Pupazan, 2021; Gehlot and Dhall, 2022). While Bitcoin's exact energy footprint cannot be established with certainty, and estimates vary considerably depending on the method applied (Gallersdörfer et al., 2020; Lei et al., 2021), the cryptocurrency is commonly considered a substantial contributor to global warming. As such, it was found to produce up to 65.4 Mt CO₂ annually: the equivalent of the overall emissions of Greece (de Vries et al., 2022). Even though there are now numerous cryptocurrencies that incorporate more sustainable consensus mechanisms (Miraz et al., 2021) like proof-of-stake (PoS), the two cryptocurrencies

with the largest market capitalisation, Bitcoin and Ethereum¹, currently use PoW and remain a driving force for the overall carbon footprint of cryptocurrencies (Xue et al., 2022). In addition to concerns about criminal activity (Kethineni and Cao, 2019), these environmental concerns contribute to their negative reputation (Treiblmaier and Gorbunov, 2022).

While many experts, including the wider Bitcoin community, continue to emphasise that the security of the tried and tested PoW mechanism is unrivalled (Houy, 2014; Brown-Cohen et al., 2019; Shifferaw and Lemma, 2021), this view is not shared universally (Kiayias et al., 2017; Saleh, 2020; Rieger et al., 2022). Subsequently, the strengths and weaknesses of PoW and PoS from the perspective of economic security and decentralisation remain subject of debates (Nair and Dorai, 2021). While there are publications addressing misconceptions concerning the electricity consumption characteristics of blockchain applications in general (Lei et al., 2021), and PoW cryptocurrencies in particular (Sedlmeir et al., 2020), we are not aware of works that assess electricity consumption awareness of cryptocurrency users directly.

Furthermore, despite studies on payment system sustainability by regulatory bodies (Agur et al., 2022) and manifold attempts to regulate cryptocurrencies (Ioannou, 2020; Truby et al., 2022), legislators still lack an understanding of how policies targeting cryptocurrencies are perceived by users

¹Ethereum is scheduled to transition from PoW to PoS in September 2022 (Jha, 2022).

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and whether they have the knowledge needed to understand the motivation behind these policies. Such consumer insight is, however, essential to improve the fruitless regulatory attempts of the past that mainly focused on those that *operate* cryptocurrency networks (Gola and Sedlmeir, 2022). This paper aims to address this gap.

The social, cultural, and economic realities of Nigeria are particularly conducive to such research. As a result of recession and rising inflation, the Nigerian economy is experiencing stress (Yusuf et al., 2022). This underlying condition, coupled with the deficiencies of an outdated and costly traditional banking sector (Osugwu et al., 2018), implies that many Nigerians regularly and routinely employ cryptocurrencies as a means of payment (Lawal, 2021). This occurs despite a rejective stance of the government (Bakare, 2021b). This form of use stands in stark contrast to industrial countries, where cryptocurrencies are primarily pursued as a speculative form of investment (Baek and Elbeck, 2014; Auer and Tercero-Lucas, 2021; Steinmetz et al., 2021). Furthermore, the Nigerian public is aware that, due to the country's geographical location, they are likely to be strongly impacted by the effects of climate change (Mustapha et al., 2013; Abah, 2014; Haider, 2019). This combination of extensive use of cryptocurrencies and high awareness of the effects of climate change makes Nigeria a suitable setting for this study.

We collect and quantitatively analyse data from 158 cryptocurrency users in Nigeria. Specifically, this work centres around hypotheses in three areas: awareness, actionability, and responsibility.

Awareness The starting hypothesis of this work is that most Nigerian users of Bitcoin are unaware of its high energy demand. This hypothesis is motivated by broader research on the technological awareness of Bitcoin users in similar markets (Ku-Mahamud et al., 2019). It is furthermore motivated by earlier findings that showed that cryptocurrency users did not take sustainability into account when selecting a cryptocurrency to use or mine (Shehhi et al., 2014).

Actionability It can be further hypothesised that those users that underestimate the electricity consumption see less need for counteracting it. This is conceivable since a correct understanding of the causes of global warming was found to be a key determinant of behavioural intentions to act against it (Bord et al., 2000). Furthermore, it can be speculated that those users who are able to accurately estimate electricity consumption possess sufficient expertise to contemplate countermeasures.

Responsibility A further hypothesis is that participants who see a clear need for action counteracting the electricity consumption of Bitcoin feel that nongovernmental actors are responsible, as distrust in government has been found to be linked with cryptocurrency adoption (Bratspies, 2018).

To test these hypotheses, we apply statistical methods to the survey data collected. Initially, we compare estimates of the electricity consumption of Bitcoin that participants gave

with an approximation of its actual electricity consumption to reveal whether participants' assumptions match reality. Subsequently, we employ frequency analysis to investigate which Bitcoin user profile is most supportive of measures targeting electricity consumption. Ultimately, we analyse where participants see the responsibility of addressing Bitcoin's electricity consumption by evaluating their declared attitudes.

We observed that the survey audience indeed misjudged the electricity consumption of Bitcoin. We furthermore found that those that estimated the electricity consumption of Bitcoin correctly were indeed more supportive of measures than those who underestimated it and – remarkably – even those who overestimated it. Finally, we found that those participants that supported measures predominantly consider Bitcoin miners, Bitcoin users, and Bitcoin developers responsible. In summary, we see all three hypotheses confirmed. These results refine our knowledge of cryptocurrency user behaviour in a way that is congruent with previous studies. It is clear from our results that regulating cryptocurrencies to achieve sustainability remains a challenging undertaking considering the apparent uninformedness of their users.

We first introduce the fundamentals of blockchain technology, covering technical concepts like consensus mechanisms, focusing on their application in cryptocurrencies like Bitcoin. In this context, we also describe the drivers of electricity consumption in PoW cryptocurrencies. Subsequently, we present key insights into cryptocurrency adoption in Nigeria. Next, in section 3, we give an overview of related work with a focus on cryptocurrency user attitude research. The remainder of this paper features a description of the questionnaire-based online survey conducted (section 4), followed by a discussion of the results obtained (section 5). We conclude with policy considerations and avenues for future work (section 6).

2. Background

Blockchain technology, a kind of distributed ledger technology, goes back to the work of Nakamoto (2008) and forms the foundation of the most common cryptocurrencies (Garriga et al., 2020), including Bitcoin. A *blockchain* is commonly characterised as linear, append-only collection of data elements ('blocks'), all of which are linked to form a tamper-evident chain using hash-pointers (Zhang, 2020; Butijn et al., 2020). Different entities hold replicas of these chains and synchronise them by means of a consensus mechanism that facilitates agreement on which data elements to append next. Often, blockchains that expose a native cryptocurrency provide incentives to users that participate in consensus (see subsection 2.1). In the context of PoW, the incentives are called 'mining rewards'. Stakeholders who aim to transfer amounts of cryptocurrency offer transaction proposals to block producers, who, in turn, select transactions to maximise their reward in terms of fees (Pontiveros et al., 2018).

The reason for blockchain technology constituting the foundation for most popular cryptocurrencies is that its

technological properties (see subsection 2.1) are beneficial for maintaining the account balances that are fundamental to a digital currency in a decentralised way. This is non-trivial in an open system that allows anyone to participate yet does not require a distinguished trusted authority (Ehrenberg and King, 2019).

2.1. Cryptocurrency Mining

As noted, blockchain technology aims to provide a decentralised ledger that is synchronised across distributed replicas. To provide synchronisation that is not dependent on the availability and honesty of a distinguished entity, consensus mechanisms are used. They typically combine game-theoretic (economic) incentives and cryptographic protocols to achieve a system state in which all honest nodes come to agreement under the assumption of an honest majority of nodes (Wang et al., 2019; Sedlmeir et al., 2020). Initial research on consensus mechanisms dates to the 1980s with the work of Lamport (1998) on Paxos and Castro et al. (1999) on Practical Byzantine Fault Tolerance as key contributions. Early work focused on permissioned systems in which the number and identity of participating parties is determined in advance. For instance, in an aeroplane that requires high reliability of sensor information. In such a scenario, it may be of interest that a coherent overall picture of the system state can be formed even if some components behave unpredictably, for instance, in the presence of cosmic radiation. In such closed systems, the problem of consensus can be solved efficiently by majority voting combined with appropriate communication protocols.

In contrast, open systems, such as cryptocurrencies, which do not have predetermined groups of users. Consequently, they are not conducive to the principle of ‘one participant, one vote’ (Sedlmeir et al., 2020). In such systems, an entity that intends to control the system could skew majority votes by registering a large number of bogus accounts, a technique known as ‘Sybil attack’ (Douceur, 2002). Most commonly, preventing such attacks is done by linearly tying the weight of a vote to a scarce resource provided by the participants that is verifiable digitally, and by encouraging the provision of this resource through economic incentives (Sedlmeir et al., 2020). The earliest and, arguably, simplest approach to satisfy this requirement is to utilise computational power as a scarce resource, as first proposed by Dwork and Naor (1992) in similar contexts and later applied by Nakamoto (2008) in the context of the consensus mechanism for the first cryptocurrency. This approach, commonly termed proof-of-work (PoW), ultimately ties voting weight to hardware and energy and, thus, to capital. More precisely, miners compete by solving cryptographically hard puzzles through trial-and-error (Back, 2002). Whoever solves this puzzle can submit the solution along with the transactions collected as a new block, which will be accepted by other honest nodes. Next, all honest nodes aim to find a subsequent block, including a corresponding solution to a puzzle that is linked to the previous block.

As a consequence, the electricity demand of a PoW cryptocurrency can be determined via a simple approximation: assuming participating miners are rational, they will only provide computational power if their expected revenue (i.e. rewards for finding new blocks and the fees of the transactions included in it) will exceed the cost that they incur for buying, maintaining, and operating hardware. For Bitcoin, currently a reward of 6.25 Bitcoin (BTC) is released for creating a block; and, on average, producing a block takes 10 minutes (de Vries, 2021). Cumulative transaction fees are generally one to two orders of magnitude lower per block than mining rewards (Sedlmeir et al., 2020) and, therefore, can be ignored for rough estimates. Following this line of reasoning, a simple worst-case model for electricity consumption can be established by assuming electricity costs are the only costs for miners and a lower bound on electricity prices is 0.05 US\$ per kWh (Sedlmeir et al., 2020; de Vries, 2021). The accuracy of this model can be improved by considering that the share of electricity costs in mining is only around 40% (De Vries, 2018). On the other hand, one can derive a lower bound for electricity consumption by observing the complexity of the solved puzzles and the distribution of the deployed mining hardware’s energy efficiency. A variation of this method is also applied by the Cambridge Bitcoin Electricity Consumption Index Bitcoin network power demand model² that forms the basis of the consumption figures applied in this study. As of mid-July 2022, Bitcoin’s annual electricity consumption is within the theoretical bounds of 40 TWh to 138 TWh, with an estimate of 84 TWh.

This number appears enormous on its own, yet criticism ignites even further when looking at the energy per transaction, as cryptocurrencies only have very limited capacity (Xie et al., 2019). For instance, Bitcoin processes around four transactions per second; the theoretical maximum (given the currently accepted system parameters) is at around seven transactions per second (Georgiadis, 2019). This mathematically yields around 660 kWh per transaction, more than an average household in Germany consumes in 2.5 months, or as much as the average annual electricity consumption of four Nigerians. Nonetheless, it is important to note that, since transaction fees currently play only a marginal role in the remuneration of miners, increasing the limit of transactions in the Bitcoin protocol would not increase total energy consumption considerably. Because of this particularity, the ‘energy per transaction’ metric frequently causes misunderstandings (Dittmar and Praktiknjo, 2019; Sedlmeir et al., 2020; Lei et al., 2021). We will, therefore, consider *annual electricity consumption* exclusively in this survey.

The economic relationship between the total energy consumption of a PoW-based blockchain and the market price of its native cryptocurrency shows that increasing the energy efficiency of the mining hardware or reducing the number of transactions will not improve sustainability (Sedlmeir et al., 2020). Since both mining rewards and transaction fees are paid in the native cryptocurrency (e.g. BTC) of

²See <https://ccaf.io/cbeci/index>.

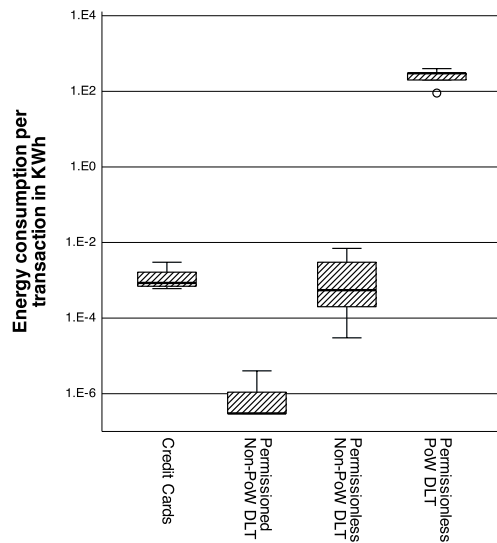


Figure 1: A comparison of data concerning the electricity consumption per transaction reported in the wider literature (logarithmic scale) compiled by Agur et al. (2022) confirms that the scientific community, despite diverging estimates, considers permissionless PoW distributed ledger technology systems to consume significantly more electricity than other payment systems.

the blockchain, the cryptocurrency market price is the most important factor influencing blockchain energy consumption systematically (Gallersdörfer et al., 2020). This price, however, cannot be directly controlled through regulatory means. Instead, a reduction in *adoption* of a given currency is likely to reduce its price (Bhambhwani et al., 2019) and can therefore be considered a sustainability policy tool. For this reason, we focus on evaluating whether consumers who are well-informed about the energy consumption of a PoW blockchain and its drivers are more willing to support countermeasures, such as abandoning an unsustainable blockchain for a sustainable one.

A popular alternative consensus mechanisms used in cryptocurrencies is proof-of-stake (PoS) that employs cryptocurrency stake as a scarce resource instead of computational work. As we illustrate in Figure 1, systems that rely on this consensus mechanism are several orders of magnitude more energy efficient than those that use PoW (Platt et al., 2021; Rieger et al., 2022). While PoS-based systems are arguably more difficult to design and to implement securely and there are doubts about their incentive compatibility in certain conditions (Houy, 2014; Brown-Cohen et al., 2019), the question whether PoW or PoS is more secure is still open. In any case, PoS-based systems enable consumer choice. For end users of cryptocurrencies, technical details around consensus are unlikely to be decisive, as the difference between PoW and PoS does not noticeably affect the usability of a cryptocurrency (Jang et al., 2021). While the cryptocurrency market offers users a wide choice, energy-intensive PoW-based currencies remain dominant (de Best, 2022) although more sustainable PoS-based alternatives exist and

are conveniently available to users via the popular centralised exchange websites (Arslanian, 2022).

2.2. Cryptocurrency in Nigeria

Nigeria, distinguished by a high position in the ‘Bitcoin Market Potential Index’ (Hileman, 2015) and touted the ‘crypto capital’ of Africa, has a cryptocurrency usership of about 32 % of the population (Adesina, 2020; Lawal, 2021). This high number may be explained by economic hardship associated with prevailing unemployment due to a recession coupled with a consistent rise in inflation (Lawal, 2021). This climate has pushed many citizens, especially the youth, into considering cryptocurrency use as a way out of their financial predicament (BBC News, 2021). In addition, the current borrowing costs, coupled with the cost of transferring funds for those who engage in international transactions, have established cryptocurrencies as an alternative to traditional banking (BBC News, 2021). The Central Bank of Nigeria (CBN) has furthermore contributed to a loss in value of the Nigerian naira (NGN) amounting to almost 15 % in 2021 (Mojeed, 2022) through devaluation, leading to fears of a further fall. Therefore, many Nigerians consider maintaining a cryptocurrency wallet a suitable hedge against looming inflation.

To this end, there were concerns among the regulatory authorities, especially the CBN, about the continuous adoption of Bitcoin, which is seen as speculative in nature and therefore considered a risk to the financial well-being of Nigerians (Bakare, 2021a,b; Nwanisobi, 2021). Therefore, in a bid to regulate the market, the CBN placed a ban on banks facilitating cryptocurrency-related transactions in 2017 (Bakare, 2021c). This, however, remained largely unenforced (Adesina, 2022). In another swift move by the CBN, after the initial order was jettisoned in 2021, an initiative to protect the public and safeguard the country from potential threats posed by ‘unknown and unregulated entities’ that are ‘well-suited for conducting many illegal activities’ was brought forward (Nwanisobi, 2021, p. 8). In this context, the CBN directed banks to stop using their platforms to transact or engage with entities that are involved in cryptocurrency activity (Bakare, 2021c; Uba, 2021). In addition, they were asked to close accounts of individuals or corporate bodies involved in cryptocurrency transactions (Nwanisobi, 2021). In April 2021, three banks were sanctioned with an 800 million NGN (approximately 2.1 million US\$³) fine for failing to prevent customers from engaging in cryptocurrency transactions (Adesina, 2021). Since then, many Nigerians have reported that their bank accounts have been frozen due to cryptocurrency-related activity. Around the same time, the CBN launched a project to improve payment systems efficiency (Olowodun, 2021) by implementing a centrally issued and regulated Central Bank Digital Currency (CBDC) which is, to date, the only fully adopted CBDC on the African continent (Ozili, 2022). The resulting system, however, notably lacks decentralisation

³According to the average inter-bank foreign exchange market rate for April 2021 published by the CBN.

and decoupling from the fluctuation of the NGN and was therefore not broadly accepted as a replacement for cryptocurrencies (Chukwuere, 2021). Despite this initiative and the heavy legislation of cryptocurrency-related activities, many citizens remain highly committed to cryptocurrencies. Growing distrust in the Nigerian government’s ability to create jobs and economic freedom have brought about an environment that has driven citizens to seek alternative technologies to realise profits and retain wealth for themselves and their dependants.

2.3. Regulating Cryptocurrency Activity

Bitcoin is the first and most significant application of blockchain technology (Gandal and Halaburda, 2016). As such, it can be considered the archetype for cryptocurrencies as it served as inspiration for most of the large number of alternative systems in the space (van der Merwe, 2021), including some who are directly derived from its core protocol (e.g., Litecoin). After over a decade, Bitcoin still accounts for around half of cryptocurrency assets’ total market capitalisation (Kulal, 2021), a condition that is referred to as ‘Bitcoin dominance’. Figure 2 shows how this measure has fluctuated in recent years with low points below 40% in 2018 or the second half of 2021 due to the rise of ‘altcoins’, alternative digital currencies, to peaks of over 70% in moments of uncertainty and market volatility. Bitcoin’s dominance may reflect its widespread and growing adoption that ultimately led it to be among the best performing assets of the last decade, often outperforming stocks, bonds, commodities and traditional currencies (Grabowski, 2019). There are now proposals at institutional level to allow banks to keep 1% of reserves in Bitcoin (Basel Committee on Banking Supervision, 2022). Thus, this study focuses on users of this archetypal cryptocurrency.

Despite being remarkably successful, cryptocurrencies have also encountered numerous setbacks. Contentious issues span from facilitating money laundering (Fletcher et al., 2021; Sicignano, 2021) to concerns regarding their impact on the environment (Jiang et al., 2021; Wanat, 2021). While this has sparked regulatory interest, decentralised, and, therefore,

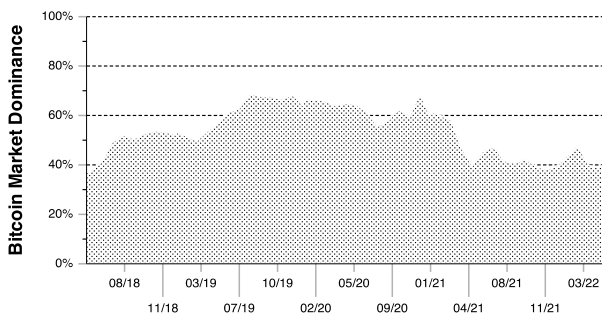


Figure 2: Bitcoin’s market capitalisation relative to that of all other cryptocurrencies combined between 2018 and 2022 (de Best, 2022).

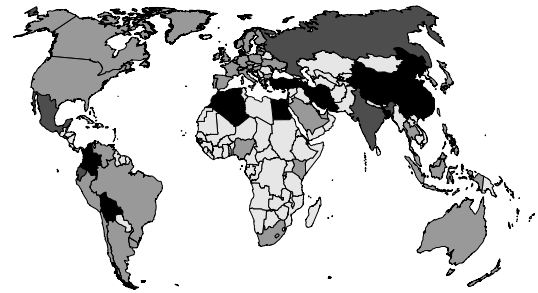


Figure 3: The visualisation of the global regulatory stance on cryptocurrencies adapted from the work of Hammond and Ehret (2022) shows that cryptocurrencies are considered ‘mostly illegal’ by the governments of Algeria, Bangladesh, Bolivia, China, Colombia, Egypt, Iran, Morocco, and Turkey.

transnational, cryptocurrency systems challenge more traditional regulatory sandboxing (Ahern, 2021). Consequently, relatively little testing of the regulatory compliance of processes and practises surrounding digital currencies has been undertaken (Filippi et al., 2022). This has contributed to regulatory gaps and, in consequence, legal uncertainty (Ferreira and Sandner, 2021).

A plethora of different approaches, mostly founded in theory, have been observed in recent years. Some regulators allowed experimentation and showed tolerance; others opted for implicit or absolute bans (see Figure 3). Numerous topical academic works followed up on regulatory aspects (Silva and da Silva, 2022). Regulatory measures in the past focused, for instance, on fiscal interventions addressing miners (Jiang et al., 2021; Oghan, 2022), on introducing sustainability criteria for institutional financial market actors (Gola and Sedlmeir, 2022), or on prohibitive regulations concerning miners (Mathews and Khan, 2019; Truby et al., 2022). Furthermore, design-side policies, such as pushing for voluntary re-designs of PoW protocols, were proposed (Truby et al., 2022). Cryptocurrency developer communities, however, apply decentralised governance and exhibit autonomous characteristics (Luther and Smith, 2020). Therefore, design-side policies are likely to suffer from a lack of enforceability. Consumer-focused policies are rarely proposed, and where they are, often make unrealistic assumptions, such as sovereign control over internet traffic (Fakunmoju et al., 2022). Despite these best efforts, regulating cryptocurrencies remains challenging (Millard, 2018), and policy makers seem to consistently underestimate the technical complexity involved in efficiently targeting this novel phenomenon.

The Chinese Example A case study that can be used to illustrate regulatory challenges globally is China. In 2017, Chinese authorities started to severely restrict the use of digital currency since the government was concerned they were facilitating capital outflows, money laundering, and other fraudulent activities. This led to banning initial coin

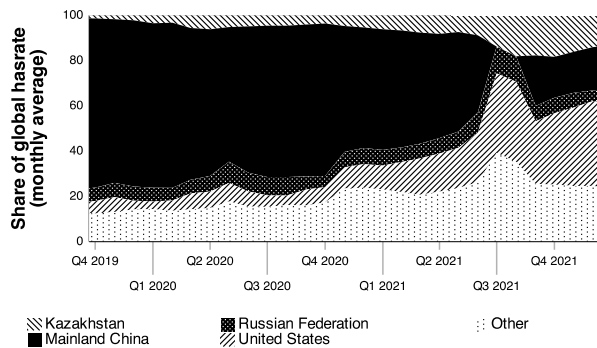


Figure 4: The evolution of mining activity between 2019 and 2022 (based on Cambridge Bitcoin Electricity Consumption Index data).

offerings – cryptocurrency-based avenues to raise funds via the issuance of digital tokens and without the involvement of a trusted and regulated authority (Okorie and Lin, 2020). Second, China passed regulations to prohibit exchanges of BTC and Renminbi (RMB), effectively cutting the link between traditional financial intermediaries and cryptocurrency markets. At the same time, the People’s Bank of China, the country’s central bank, issued several warnings concerning Bitcoin and cryptocurrencies, reminding the public that these do not enjoy the same legal status as fiat currencies. This had a major impact on BTC-RMB trading volume and spillover effects to geographically close regions were observed shortly after the introduction of more restrictive regulations, including an increase of over 25 % and 20 % in Bitcoin trading volume in Korean won and Japanese yen, respectively (Borri and Shakhnov, 2020). Chinese peer-to-peer exchanges, where buyers and sellers are matched directly, also registered ample trading increases as they could provide a way to bypass regulation.

More recently, China adopted a rejective stance on cryptocurrency-related activities, such as Bitcoin mining. In 2019, the government termed Bitcoin mining ‘undesirable’, a label used for industries that should be restricted or phased out by local governments. Finally, in 2021, Bitcoin mining was effectively forced to shut because of environmental concerns brought forward by the government. The ban was initially effective as shown in Figure 4: mining activity was halted in summer 2021, with China’s hashrate capacity, a measure of mining speed in PoW, going to zero. The two countries that benefited most from the ban in terms of share of global hashrate were the United States and Kazakhstan.

However, given the significant mining capability built in previous years, which at time accounted for over 70 % of the global share, some Chinese miners were able go return to their activities despite the bans, making China the world’s country with the second largest share of Bitcoin mining activity. Others moved hardware to less strictly regulated regions and continued activities there. Whether miners will continue to elude the ban is unclear, but the events outlined suggest that, even for countries with a strong grip on economic activities like China, enforcing outright bans is highly challenging. This

perspective is consistent with work by Chen and Liu (2022), who investigate the Chinese government’s Bitcoin trading interventions’ impact on the returns and trading volume of Chinese investors. They found that, while the Chinese remain active on the Bitcoin market, their involvement has been weakened by government interventions. Ultimately, it is not sufficient for regulators to ban and discredit cryptocurrency to effectively prevent adoption (Feinstein and Werbach, 2021).

3. Related Work

We deem the following types of studies relevant related work: first, papers that target cryptocurrency users beyond Nigeria via survey research (see subsection 3.1), thereby exposing patterns of user attitudes, behaviours, and experiences. Second, papers that investigate issues relating to Bitcoin in the Nigerian context (see subsection 3.2) to illustrate views on the increasing popularity of this cryptocurrency in Nigeria: predominantly from legal, regulatory, or macroeconomic perspectives.

3.1. Cryptocurrency User Attitudes

Most of the relevant prior literature we are aware of examine predictors of interest in using cryptocurrencies. A notable number of studies apply established psychological techniques, such as the Theory of Planned Behaviour (TOPB) (Ajzen, 1991), one of the most widely used theories of behavioural prediction. Some studies investigate which predictors influence the willingness to adopt cryptocurrencies *in general* (Schaupp and Festa, 2018; Mazambani and Mutambara, 2019; Alaklabi and Kang, 2019; Anser et al., 2020; Albayati et al., 2020). Other studies identify predictors that influence users’ decision to consider them as a *form of investment* in particular (Pham et al., 2021; Smutny et al., 2021). Still other studies specifically investigate under which circumstances users tend to support cryptocurrencies as a *means of payment* (Kim, 2021; Salcedo and Gupta, 2021). Due to the different foci of these surveys and the variety of methods used, the studies come to diverse, and, at times, contradictory conclusions.

For instance, Bashir et al. (2016) find that gender and social circle are decisive factors for Bitcoin ownership. Schaupp and Festa (2018), Mazambani and Mutambara (2019), and Pham et al. (2021) conclude that attitudes towards the behaviour of using cryptocurrencies are the determining construct in the context of TOPB. Steinmetz et al. (2021) show that German cryptocurrency users are predominantly young, male, well-educated, and affluent. Gagarina et al. (2019) confirm the common belief that a liberal worldview correlates with the intention to use cryptocurrencies (Dodd, 2017). Seemingly in conflict with this are the findings of Albayati et al. (2020), whose results suggest that users are most interested in adopting cryptocurrencies when their activities are regulated and secured by the government. Alaklabi and Kang (2019) conclude that technological awareness has a positive influence on the intention to use cryptocurrencies. This is consistent with the findings of Smutny et al. (2021), who conclude that a lack of information about the operating

environment is a disincentive to cryptocurrency investment. Anser et al. (2020) show that a high level of activity in social media correlates with the willingness to use cryptocurrencies. The findings of Kim (2021) similarly present a picture of cryptocurrency users focused on social presence: the ‘power-prestige’ dimension was established as the factor most influential on the approval of Bitcoin. Salcedo and Gupta (2021) argue that cultural values and norms have a major impact on the willingness to use cryptocurrencies: collectivists, as well as representatives of long-term oriented cultures, were found to be inclined towards blockchain technology.

In summary, the existing literature portrays users of cryptocurrencies as maintaining interpersonal relationships with other cryptocurrency users, being technically savvy, well-informed, well-networked, and as having libertarian worldviews. This user group is also strongly represented in our work. However, the attitude of this group towards sustainability has not played a significant role in the scientific discourse so far.

3.2. Cryptocurrency in Nigeria

Academic coverage of issues relating to cryptocurrencies in the Nigerian context is sparse. Many previous works position Bitcoin as a technology discovered by Nigerians in the context of the 2016 recession as a stable alternative to the rapidly depreciating Naira (Nnabuife and Jarrar, 2018). To the best of our knowledge, only two questionnaire-based quantitative academic studies with a focus on Bitcoin in the Nigerian context have been undertaken: Eigbe (2018) investigates the level of awareness and adoption of Bitcoin in Nigeria, finding that most respondents lacked proper understanding of the functionalities of Bitcoin, even if they claimed otherwise. A study by Salawu and Molo (2018) targets Nigerian professional accountants: these stated that they were considering offering services in a cryptocurrency environment, although a majority indicated that the enactment of legislation to control their use would be a prerequisite for doing so.

Most works apply other methodologies. The prevailing sentiment throughout the relevant works is that Bitcoin in the Nigerian context is not a passing fad but is of significant societal importance. This is reflected in a study by Jimoh and Benjamin (2020) that underlines the macroeconomic importance of Bitcoin by showing that the volatility of cryptocurrency returns has a measurable impact on the broader financial markets in Nigeria. Egbo and Ezeaku (2016) underscore the serious disruptive potential of cryptocurrencies by showing that these are threatening the very foundation of the business of commercial banks operating as intermediaries in Nigeria. While the previously outlined works highlight the potentially positive impact of cryptocurrencies on the Nigerian economy, other works focus on negative aspects such as the risks of using cryptocurrencies for the financing of terrorism (Emmanuel and Michael, 2020) or the inability of Nigerian legislation to effectively target cryptocurrency-related activities (Ukwueze, 2021; Gidigbi et al., 2021).

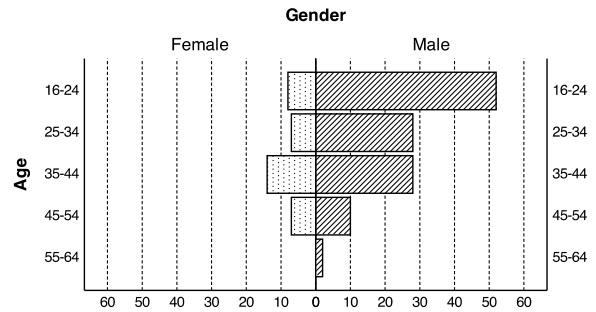


Figure 5: Absolute frequencies of distribution of valid responses for gender and age dimension.

3.3. Research Gap

The previous subsections indicate the existence of extant literature regarding cryptocurrency user attitudes, including some manuscripts that touch on sustainability issues. However, to the best of our knowledge, no existing work has addressed the perspective that cryptocurrency users have on the sustainability of the underlying blockchain in a holistic manner. Considering that the cryptocurrency market offers products with dramatically different carbon footprints, there is a clear gap in research on potential mechanisms to encourage the use of more sustainable alternatives. Due to the decentralised nature of cryptocurrencies and the corresponding challenges in banning PoW-based cryptocurrencies, measures that consider users’ perspectives and actions are likely to be the only way to bring about long-term improvements in energy use.

4. Method

We designed our study as a questionnaire-based online survey. To minimise the risk of data quality issues, a local research data collection provider was tasked with collecting data by approaching potential participants individually, ensuring they were members of the target population. Owing to the unclear regulatory situation in Nigeria and the fear of legal repercussions that may arise from it, recruiting participants proved challenging, but was ultimately successful as most participants felt reassured about their anonymity. This was helped by the fact that the study was led by a UK institution, as opposed to a local one.

4.1. Participants

158 valid responses were collected between 25th of November 2021 and 30th of March 2022 via convenience sampling. All participants were 16 years of age or older and resided in Nigeria. All participants reported to have undertaken at least one Bitcoin transaction in the last five years at the time of this study.

Ethics approval was obtained before participant recruitment started. Participant recruitment had two avenues: first, students at Covenant University, Ota, Nigeria that had a

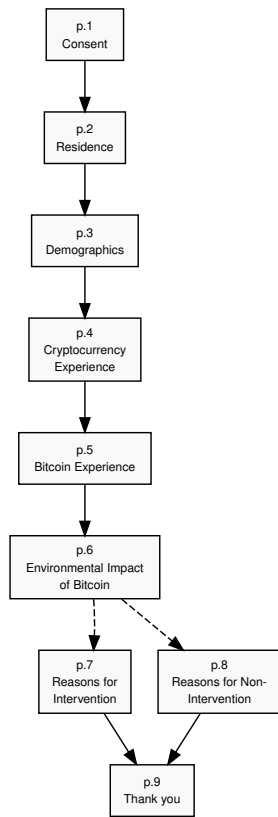


Figure 6: The sequence and routing between survey pages.

verified interest and background in cryptocurrency as evidenced by extracurricular activity were approached and offered opportunities to participate voluntarily. Second, the study was advertised in Nigerian cryptocurrency groups on the Telegram messenger, the ‘de facto messaging platform for the cryptocurrency community’ (Smuts, 2019, p. 131). For both approaches, participants were self-selected and did not receive compensation. The sample obtained is biased towards male participants with 76.9 % of respondents identifying as male (see Figure 5), an imbalance that might be explained by the convenience sampling method in conjunction with a more pronounced interest in cryptocurrencies as investment instruments amongst younger males (Senkardes and Akadur, 2021).

4.2. Materials

The questionnaire contained a total of 107 items on eight pages, some of which were conditional (see Figure 6). It employed screening questions throughout the survey to ensure that only members of the target population participated. The questionnaire was designed to measure the degree of expertise in cryptocurrency technology participants possess. It was furthermore designed to measure how accurately participants estimate Bitcoins electricity consumption. Finally, it measured the degree to which participants believe the electricity consumption poses a problem, whether measures should be taken, and which stakeholders, if any, they consider

responsible for acting against it. The full set of survey items is contained in the appendix.

In Q21, participants were presented with the following question to which six potential answers were provided (see Table 1):

What do you estimate the electricity requirements of operating the entire Bitcoin network to be?

We assume a value of 121.46 TW h to be close to the actual annual electricity consumption of Bitcoin at the time of conducting the survey. This value is the median of daily estimates for annualised consumption⁴ during the data collection period. Estimates fluctuated between 108.08 TW h and 140.11 TW h during data collection. This shows that, during the survey period, option four, ‘about four times the overall electricity consumption of Nigeria’, was the most accurate estimation on all days.

We offer a broad range of potential answers that equate to electricity consumption figures between 600 MWh and 2,845 TW h. Since participants are unlikely to have a frame of reference for physical units of measurement, the electricity values were not exposed in the questionnaire. Instead, examples that are relatable to the participants’ living situation (see Table 1) were used.

Some sections of the questionnaire reuse parts of existing surveys. This is also the case in Q19, in which we ask participants for their reasons for acquiring cryptocurrency:

Why have you acquired Bitcoin in the past?

This question, along with others in the ‘cryptocurrency experience’ section of the survey reproduced questions from the Organisation for Economic Co-operation and Development consumer insights survey on cryptoassets, a questionnaire that ‘has been designed to survey consumers/retail investors in order to collect data on their attitudes, behaviours and experiences towards digital financial assets, specifically digital (or crypto) currencies and initial coin offerings’ (OECD, 2019, p. 2).

Subsequent parts of the questionnaire assess the degree of concern participants have regarding some effects of climate change. For instance, Q20 asks about participants’ areas of concern in the context of climate change:

How concerned are you about the potential consequences of climate change to your living environment?

The options presented were taken from previous work by Haider (2019), who summarises likely impacts of climate change on Nigeria based on previous studies. Due to the localised nature, the options presented to participants were tailored to effects that were most likely to affect them.

To ensure the quality of measurements, the local research data collection provider conducted a pilot study with 12

⁴See <https://ccaf.io/cbeci/index>.

Question Wording	Annual consumption (TW h)
Similar to the overall electricity consumption of a small town in Nigeria	0.0006
Similar to the overall electricity consumption of the Lagos Metropolitan Area	5.8
Similar to the overall electricity consumption of Nigeria	29
Actual Bitcoin electricity consumption (CBECI)	121.46
About four times the overall electricity consumption of Nigeria	116
Similar to the overall electricity consumption of the entirety of the African continent	700
Similar to the overall electricity consumption of the entirety of the African and European continents combined	2,845

Table 1

Questions were asked to gauge how realistically participants estimate the annual electricity consumption of Bitcoin. The questions were worded so that participants could relate electricity consumption with the realities of their lives. The median of estimates obtained from the Cambridge Bitcoin Electricity Consumption Index is printed for the benefit of the reader only and was not given as an option to the participants.

participants, assessing the understandability of research materials with members of the target population prior to commencement of data collection. Some changes to the survey materials were implemented to action the findings of the pilot study and thereby improve comprehension of materials in the target population.

4.3. Procedure

Of 1,088 participants that started the survey, 158 completed it. Participants completed the questionnaire within 19 min 47 s on average. Deception was not used during study recruitment. Participants were told that the study was designed to understand their attitudes towards cryptocurrency usership and environmental issues. They were then informed about the fact that their participation is completely voluntary and that they should only take part if they want to. They were furthermore educated about the fact that choosing not to take part would not disadvantage them in any way. The research data collection provider then made them aware that they would be provided with an information sheet for participants prior to answering any questions. Those persons that expressed an interest in participating after this introduction by the research data collection provider were given a survey link, either in the form of a printout,

via e-mail, or via Telegram message. The research data collection provider had no knowledge of whether the potential participants indeed followed the link.

A serious concern raised by some participants was the worry that their identity might be revealed to Nigerian authorities. This concern stemmed from the fear of facing legal repercussions by the Nigerian government who have taken a rejective stance towards cryptocurrencies (see subsection 2.2). The research data collection provider was able to alleviate some of the concerns by pointing to the applicability of the UK General Data Protection Regulation, however, some potential participants were not convinced by this argument and remained disinterested in participation.

Once participants followed the link provided, informed consent was obtained using the online survey system through a series of approved questions. Participants were informed about the fact that data would be converted to an anonymised format and that data gathered might be subject to publication. After completing the survey, participants were given a written debriefing via the online survey tool, thanked for their participation, and were dismissed.

5. Results and Discussion

The results generated from the questionnaire give insight into the environmental attitudes of the Bitcoin users surveyed. Relevant results can be obtained around the key hypotheses in the areas of awareness, actionability, and responsibility, but also give insight beyond those.

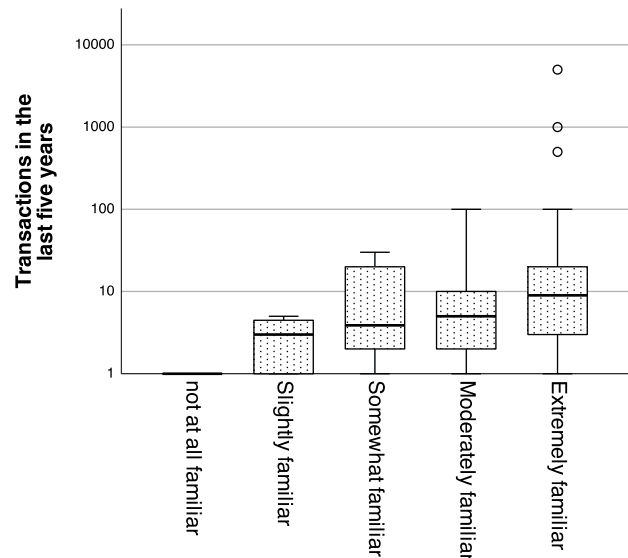


Figure 7: Respondents that report extreme familiarity with Bitcoin on average report the highest number of transactions (logarithmic scale). This group also contains outliers that report participation in very large numbers of transactions.

User Profile When analysing the user profile of participants (see Figure 7), we found no relationship between transaction volume and familiarity with Bitcoin. We, however, observed some outliers that reported large numbers of Bitcoin transactions and self-reported as being extremely familiar with this cryptocurrency. We found the median of the number of transactions undertaken in the past five years for all experience levels to be lower than 10. When analysing how participants obtained Bitcoin (see Figure 8), we found that online platforms were by far the most popular method, with 79.1 % of participants having used them to acquire Bitcoin in the past. Few participants (2.5 %) used dedicated kiosks (i.e., machines resembling cash machines) to acquire Bitcoin. The biggest motivation to obtain Bitcoin (reported by 40.5 % of participants) was as a long-term investment or retirement fund. Only 3.8 % mentioned avoiding government regulation as a reason for obtaining Bitcoin⁵.

We furthermore analysed the concern participants reported around the possible effects of climate change in their environment. Here we found great consternation amongst participants with the mode of responses being ‘extremely concerned’ for all effects provided. We found some nuances in concern, such as that participants feared freshwater resources being affected, an increase in temperature, and extreme weather events most. 56.3 % of participants believed that the electricity consumption of Bitcoin contributes significantly to CO₂ production, with almost all of those (93.3 %) also believing that the CO₂ produced by Bitcoin contributes to climate change. 65.2 % of overall participants felt that measures to

⁵This is likely under-reported as a result of a ‘chilling effect’: a condition in which prospective participants refrain from behaviour that deviates from the perceived rules, norms and guidelines of a powerful supervisor for fear of negative consequences (Schüll, 2018): in this case, Nigerian authorities.

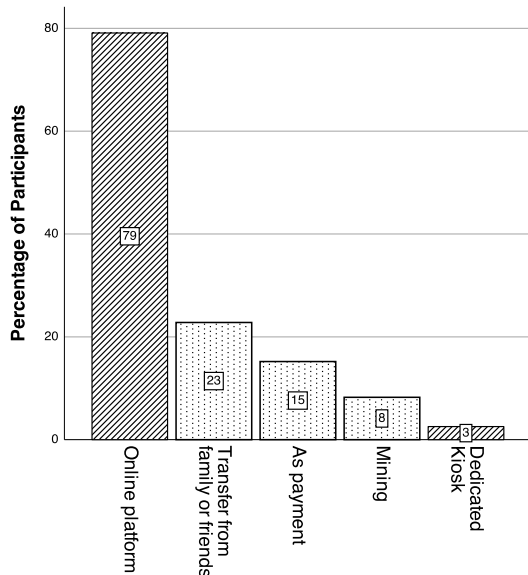


Figure 8: Participants have acquired Bitcoin through different channels. Online platforms and dedicated kiosks lend themselves well to digital energy labelling (see subsection 6.1) while others do not.

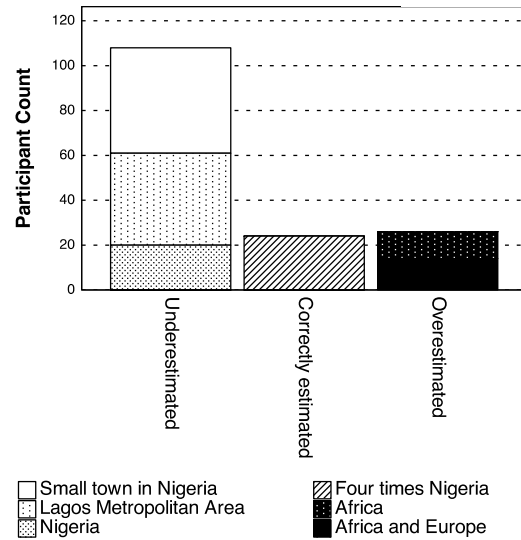


Figure 9: Most participants underestimate the overall energy demand of Bitcoin.

reduce the CO₂ footprint of Bitcoin should be taken now. A minority of 42.7 % of participants that answered the relevant question supported the view that Bitcoin users should move away from Bitcoin to other cryptocurrencies in the interest of reducing CO₂ production. Some of these participants provided the names of alternative cryptocurrencies, some of which notably were also PoW-based (e.g. Dogecoin or Ethereum). Others suggested payment infrastructure tokens like Ripple’s XRP or stablecoins like Tether’s USDT.

Awareness One of the key purposes of this questionnaire was to assess how realistic the estimates of the overall Bitcoin electricity consumption made by participants were. Here it was found that the majority (68.4 %) significantly underestimated the energy demand of Bitcoin, while a minority (16.5 %) overestimated it (see Figure 9). This goes beyond what is to be expected under random conditions: 50 % of participants selecting randomly would underestimate electricity consumption, 16.7 % would accurately assess it, and 33.3 % would overestimate it.

Actionability A variety of reference points were provided to participants (see subsection 4.2) to assess actionability. Here, a correlation between supporting measures (i.e. answering ‘yes’ to the question ‘Do you think measures should be taken now to reduce the CO₂ footprint of Bitcoin?’) and estimating the electricity consumption of Bitcoin correctly (i.e. choosing the option ‘About four times the overall electricity consumption of Nigeria’ when asked for the overall electricity consumption) was found (sample correlation coefficient $r = 0.161$; see Table 2). This correlation is due to the fact that only 60 % - 65 % of participants that misestimated Bitcoin’s electricity consumption supported measures to reduce its CO₂ footprint, whereas 83 % of users that estimated the electricity consumption correctly supported measures. Remarkably, the

		Low	Correct	High
S	Pearson	-0.126	0.161*	0.002
	Correlation			
	Sig. (2-tailed)	0.115	0.043	0.982

*. Correlation is significant at the 0.05 level (2-tailed).

Table 2

A significant correlation between estimating the electricity consumption correctly (*Correct*) and being supportive of measures (*S*) was found. No significant correlation between overestimating (*High*) or underestimating (*Low*) consumption and supportiveness was found.

willingness to support measures only correlates with the correct estimation, but not with an overestimation of energy consumption.

Responsibility Where participants did see the need for action, they felt that Bitcoin miners, Bitcoin users, and Bitcoin developers should be taking action ahead of intergovernmental organisations, the legislature, and federal agencies or regulators (see Figure 10).

Some participants named alternative actors they felt were responsible. These included Bitcoin exchanges, wealthy individuals, and activists. Where participants did not feel that action to reduce the CO₂ footprint of Bitcoin should be taken now, they predominantly supported two reasons for it (both with 30.1%): they brought forward the view that future technological improvements would reduce Bitcoin’s electricity demand and/or that the environmental impact

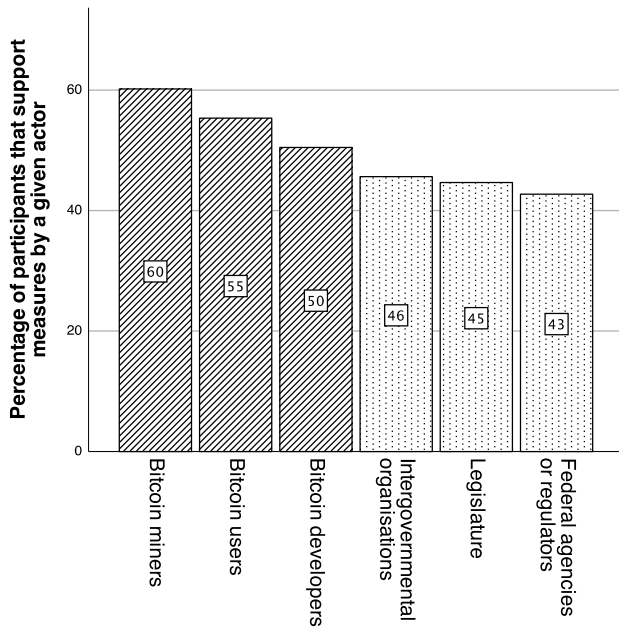


Figure 10: 60 % of those participants that support measures in principle find that Bitcoin miners should act, while only 43 % find that federal agencies or regulators should. A divide between non-governmental actors (top 3) and governmental actors (bottom 3) is noticeable.

of Bitcoin is acceptable for the benefit it provides. No meaningful alternative reasons were provided in free-text fields.

In line with the hypothesis, the data show that on average, Bitcoin users underestimate its electricity consumption. Our study also demonstrates a correlation between participants’ ability to estimate the electricity consumption of Bitcoin correctly, and their support of measures to counteract Bitcoin’s CO₂ footprint. The data furthermore suggest that even those users that consider themselves experts often lack a basic understanding of the mechanisms behind Bitcoin. These results largely corroborate previous research, specifically, they support the results of Eigbe (2018) who previously pointed out gaps in the technical expertise of Nigerian Bitcoin users and findings by Steinmetz et al. (2021) that yield a similar conclusion, albeit outside of Nigeria. The results furthermore broadly align with consumer knowledge assessments in the wider financial products space that showed that consumers often had little knowledge of the key properties of the products they were using (Ramchander, 2016; Sukumaran et al., 2022).

While previous research has focused on technical or financial parameters of user attitudes alone (see section 3), the results of this study demonstrate that, throughout the user base, concern over the effects of climate change is significant. These results should be considered when designing policy to respond to the high electricity consumption of cryptocurrencies. Our data furthermore contribute a clearer understanding of the opinions of end users towards interventions, indicating that respondents feel that private sector stakeholders should act. This aligns with earlier findings (Bratspies, 2018).

The generalisability of our results is, however, limited by the convenience sampling method. The reliability of this data is furthermore impacted by the challenging legal situation in Nigeria that may prevent cryptocurrency users from openly acknowledging their activities. A theoretical implication of this study is that improving customer knowledge around cryptocurrency sustainability might lead to more sustainable consumer behaviour (see subsection 6.1).

6. Conclusion and Policy Implications

Considering the current trajectory of CO₂ emissions, regulators face unprecedented pressure to introduce policies to avoid a climate catastrophe. Cryptocurrencies built on PoW consume large amounts of electricity while, arguably, providing very similar benefits to those built on alternative consensus mechanisms that consume orders of magnitude less electricity. Counteracting the enormous electricity consumption of PoW-based cryptocurrencies must therefore be attended with utmost urgency by energy policy makers, not least since cryptocurrencies are now ubiquitous and no longer limited to users with certain demographic or regional characteristics. To prevent further delays in action and excessive costs arising from ineffective regulatory measures, in this work, we recommend a specific course of action to promote sustainable cryptocurrency consumer behaviour.

This entails confronting users with the consequences of their cryptocurrency choices through energy labelling (see subsection 6.1). While this proposal is as yet untested, the key results of this work (systematic underestimation of cryptocurrency electricity consumption by users who fear climate change) suggest that it is likely to improve sustainability. The impact of this work lies within the quantification of attitudes of cryptocurrency users towards their sustainability and the policy considerations associated with it.

We believe that policy initiatives targeting cryptocurrency sustainability don't necessarily require a global-scale rollout to be successful. To put it in the words of Bushnell, Peterman and Wolfram (2008, p. 192): 'If local policies lead to what are effectively demonstration projects of various technologies, their successes or failures could be important first steps in adopting effective low-carbon technologies on a more global scale.' This work is therefore a call to action for the wider community to implement lighthouse projects.

6.1. Policy Implications

To develop effective strategies to reduce the popularity of PoW cryptocurrencies, and thereby, ultimately, their electricity demand, decision-makers must first realise that such strategies cannot be targeted at miners alone. While miners are indeed almost solely responsible for the energy footprint of cryptocurrencies, as shown in section 2, they can easily relocate their activities to other regions where fewer legal constraints are in place (Riley, 2021). Relocating allows them to evade regulatory access without affecting the end users of the respective cryptocurrency since those are oblivious to where mining hardware is operated. A more effective strategy instead focuses on the end users of cryptocurrencies and empowers them to make more sustainable choices. This increase in transparency is a potential enabler for a consumer movement away from unsustainable cryptocurrencies. Such a consumer movement may result in a systematic reduction of the carbon footprint of unsustainable cryptocurrencies, beyond the individual user, should the expected price effects described earlier (see subsection 2.1) materialise.

The fact that users who correctly assess the sustainability parameters of the cryptocurrencies they use tend to show more support for measures indicates that consumer education is a promising tool for policy makers. Particular care must, however, be taken that cryptocurrencies are not portrayed in an all-encompassing and overly negative way: after all, our results do not show a correlation between *overestimating* electricity consumption and supporting measures. Rather, policy makers should initiate measures that achieve basic consumer education and provide users of cryptocurrencies with a realistic view of their electricity consumption and the economic parameters they depends on.

Energy labelling, i.e. providing key sustainability metrics to cryptocurrency users at the point of exchange, is one potentially suitable measure to achieve customer education. Such labels would allow users to compare and contrast the electricity consumption characteristics in this vast market,

thereby allowing them to take sustainability into consideration when making a cryptocurrency purchasing decision. While little is known about the effectiveness of this intervention in the context of cryptocurrencies, results from the field of household appliances give cause for optimism: here it was found that customers are aware of the information on labels (Waechter et al., 2015), comprehend it (Jeong and Kim, 2014), and, ultimately, make better decisions based on it (Davis and Metcalf, 2016). Consumers were, furthermore, found to attach a value to energy efficiency beyond the prospect of reducing costs (Andor et al., 2020). Even though sustainability awareness may differ between countries (Schallehn and Valogianni, 2022), it seems conceivable that energy labelling initiatives present an effective long-term energy efficiency policy.

6.2. Future Work

To reflect the sentiment of the population of Nigerian cryptocurrency users more accurately, future studies might reproduce the survey with a representative sample instead of a convenience sample. Reproducing the study would also allow for adapting the questionnaire to assess the reasons why more knowledge on energy consumption characteristics increases support for countermeasures in greater detail. Furthermore, future studies should test the policy suggestion by running an experiment that evaluates which cryptocurrencies users select for purchase when presented with an energy label at the point of exchange, compared to which ones they choose when not presented with energy consumption information.

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Ethical Clearance

Ethical clearance for this project was granted by the King's College London ethics committee under ethical clearance reference number *MRSP-21/22-27025*.

Data Availability

The result data and the original questionnaire are available online (Platt and Ojeka, 2022).

CRedit authorship contribution statement

Moritz Platt: Conceptualisation, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualisation, Writing (original draft), Writing (review and editing). **Stephen Ojeka:** Data curation, Formal analysis, Investigation, Validation,

Writing (original draft), Writing (review and editing). **Andreea-Elena Drăgnoiu**: Writing (original draft), Writing (review and editing). **Oserere Ejemen Ibelegbu**: Writing (review and editing). **Francesco Pierangeli**: Writing (original draft), Writing (review and editing). **Johannes Sedlmeir**: Writing (original draft), Writing (review and editing).

Abbreviations

BTC Bitcoin

CBDC Central Bank Digital Currency

CBN Central Bank of Nigeria

NGN Nigerian naira

PoS proof-of-stake

PoW proof-of-work

RMB Renminbi

TOPB Theory of Planned Behaviour

US\$ United States dollar

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