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Energy Demand Unawareness and the Popularity of Bitcoin: Evidence from Nigeria

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Abstract

Decentralised cryptocurrency networks, notably those with high energy demand, have faced significant criticism and subsequent regulatory scrutiny. Despite these concerns, policy interventions targeting cryptocurrency operations in the pursuit of sustainability have largely been ineffective. Some were abandoned for fear of jeopardising innovation, while others failed due to the highly globalised nature of blockchain systems. In search of a more effective angle for energy policy measures, this study adopts a consumer-centric perspective, examining the sentiments of Nigerian cryptocurrency users ($N = 158$) towards Bitcoin's sustainability, a representative cryptocurrency known for its high electricity demand. Three main findings emerged: 1) Even among those self-identifying as highly knowledgeable, the majority considerably underestimated Bitcoin's electricity consumption. 2) Participants with a more accurate understanding of Bitcoin's energy demand were more inclined to support sustainability measures. 3) The majority of this supportive cohort viewed private entities as the primary stakeholders for implementing such measures. Given these findings, we suggest that consumer education should be at the forefront of policy initiatives aimed at cryptocurrency sustainability.

Key words: Survey, Energy demand, Proof of work, Cryptocurrency mining, Electricity demand, Energy-efficiency label

Lay Summary

Cryptocurrencies like Bitcoin consume a lot of electricity, raising environmental concerns. This study surveyed 158 Nigerian cryptocurrency users to understand their awareness of the energy use of Bitcoin. The findings revealed that, although many participants considered themselves Bitcoin experts, most underestimated its energy demand. Those who were aware of the actual energy demand were more supportive of measures to reduce it. The study suggests that better educating consumers about the environmental impacts of their cryptocurrency choices, potentially through energy labelling (a practice that provides information on cryptocurrency energy efficiency to users), could lead to more sustainable practices.

1. Introduction

Bitcoin is arguably the most popular cryptocurrency [Mikhaylov, 2020] and has a major impact on the wider crypto-asset ecosystem [Ante, 2022]. It 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 of measurement 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 CO_2 annually: the equivalent of the total emissions of Greece [de Vries et al., 2022]. There are now numerous cryptocurrencies that incorporate more sustainable consensus mechanisms [Miraz et al., 2021], including the second-largest cryptocurrency by market capitalisation, Ethereum, that has recently transitioned to proof-of-stake (PoS) [de Vries, 2022].

Still, many cryptocurrencies, first and foremost Bitcoin, continue to apply PoW. Consequently, a critical examination of this technology remains pressing beyond the ongoing debate on cryptocurrencies as instruments of payment in the context of criminal activity [Kethineni and Cao, 2019, Treiblmaier and Gorbunov, 2022].

Although many experts, including many in 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]. The strengths and weaknesses of PoW and PoS from the perspective of economic security and decentralisation remain the subject of debates [Nair and Dorai, 2021]. Some publications address misconceptions concerning the electricity consumption characteristics of blockchain applications in general [Lei et al., 2021] and PoW cryptocurrencies in particular [Sedlmeir et al., 2020a]. However, we have no knowledge of academic works that directly assess the awareness of electricity consumption of cryptocurrency users.

1.1. Research Objectives

This research seeks to bridge the gap between cryptocurrency understanding and environmental consciousness within the Nigerian context. As the global conversation around Bitcoin's environmental impact intensifies and with the rising prominence of cryptocurrency transactions in Nigeria, the insights from this study can potentially shape policies, steer educational initiatives, and guide stakeholder decisions.

1.2. Research Gap and Study Context

Despite studies on the sustainability of payment systems by regulatory bodies [Agur et al., 2022, 2023] and various attempts to regulate cryptocurrencies [Ioannou, 2020, Truby et al., 2022], legislators still lack an understanding of how users perceive policies targeting cryptocurrencies and whether they have the knowledge needed to understand the motivation behind these policies. 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. Considering that the cryptocurrency market offers products with dramatically different carbon footprints, there is a clear gap in research on potential mechanisms to encourage users to explore more sustainable alternatives.

This paper aims to address this gap through field research in Nigeria. Nigeria's social, cultural, and economic realities are particularly conducive to such research: as a result of a recession and rising inflation, the Nigerian economy is experiencing stress [Yusuf et al., 2022]. Coupled with the deficiencies of an outdated and costly traditional banking sector [Osuagwu et al., 2018], this implies that many Nigerians regularly and routinely use cryptocurrencies as a means of payment [Lawal, 2021] despite the rejective position of the government [Bakare, 2021a]. This application stands in stark contrast to industrial countries where cryptocurrencies are pursued primarily as a speculative form of investment [Baek and Elbeck, 2014, Glaser et al., 2014, Auer and Tercero-Lucas, 2021, Steinmetz et al., 2021]. Furthermore, the Nigerian public is aware that, due to their location, they could be severely affected by the effects of climate change [Mustapha et al., 2013, Abah, 2014, Haider, 2019]. The combination of the extensive use of cryptocurrencies and the high awareness of the effects of climate change makes Nigeria a suitable setting for our study.

1.3. Hypotheses

We collect and quantitatively analyse data from 158 cryptocurrency users in Nigeria, focusing on hypotheses in three areas: awareness, actionability, and responsibility.

1.3.1. Awareness

The starting hypothesis of this work is that most Nigerian Bitcoin users 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 influenced 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].

1.3.2. Actionability

It can be further hypothesised that users who misestimate electricity consumption see less need to counteract 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 can accurately estimate electricity consumption possess sufficient expertise to contemplate countermeasures.

1.3.3. 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].

1.4. Outline

In section 2 of this paper, we introduce the fundamentals of blockchain technology, covering technical concepts like consensus mechanisms and their application to cryptocurrencies like Bitcoin. In this context, we also describe the drivers of electricity consumption in PoW cryptocurrencies. Subsequently, we present critical insights into cryptocurrency adoption in Nigeria and explain the situation in China as a case study. Next, in section 3, we give an overview of related work with a focus on research on cryptocurrency user attitudes. 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 7).

2. Background

Blockchain technology, a kind of distributed ledger technology (DLT), 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 a linear, append-only collection of data elements ('blocks'), all of which are linked to form a tamper-evident chain using hash-pointers [Butijn et al., 2020, Zhang, 2020]. The data in blocks can be arbitrary [Gregoriadis et al., 2022] but, in the case of blockchains with native cryptocurrencies, consist mainly of transfer instructions between accounts [Wu et al., 2021]. Although, in theory, transfers can occur between arbitrary addresses, real-world systems typically constitute small-world networks [Serena et al., 2021]. Different entities hold replicas of chains and synchronise them by means of a consensus mechanism that facilitates decentralised agreement on which data elements to append next [Tai et al., 2017]. Often, blockchains that expose a native cryptocurrency provide incentives to those users who participate in consensus [Mukhopadhyay et al., 2016]. 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].

Blockchain technology constitutes the foundation for most existing cryptocurrencies. This is because blockchain technology is well suited to record account balances in decentral systems that allow anyone to participate, yet do 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, a wide variety of consensus mechanisms can be applied [Platt and McBurney, 2023]. These typically combine 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., 2020a]. Initial research on consensus mechanisms dates back to the 1980s with the work of Lamport [1998] on 'Paxos' and Castro and Liskov [1999] on Practical Byzantine Fault Tolerance as key contributions.

Early work focused on *closed* systems in which the number and identity of participating parties are determined in advance. For example, in an aeroplane that requires a particularly high reliability of sensor information, 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 many cryptocurrencies, do not have predetermined groups of users. Consequently, they do not conform to the principle of 'one participant, one vote' [Sedlmeir et al., 2020a]. 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., 2020a]. 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] and later applied by Nakamoto [2008] in the context of the consensus mechanism for the first cryptocurrency Bitcoin. This approach, commonly termed proof-of-work (PoW), ultimately ties a 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 a puzzle can submit its 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.

2.2. Electricity Demand

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) exceeds the cost that they incur for buying, maintaining, and operating hardware. At the time of writing, Bitcoin releases a reward of 6.25 Bitcoin (BTC) for creating a block; and, on average, producing a block takes 10 minutes [de Vries, 2021]. Cumulative transaction fees have consistently been one to two orders of magnitude lower per block than mining rewards in many cryptocurrencies, including Bitcoin [Sedlmeir et al., 2020a] 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 kW h [Sedlmeir et al., 2020a, 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]. In general, the decline in hash rate following price shocks on the revenue side (e.g., a sharp decrease of the Bitcoin price and halving events) and on the cost side (e.g., a sharp increase in electricity prices at the end of the rainy season in China) suggest that the upper bound is relatively accurate [Sedlmeir et al., 2020b, Stinner, 2022]. On the other hand, a lower bound for electricity consumption can be derived by observing the complexity of the solved puzzles and the distribution of the energy efficiency of the mining hardware deployed. A variation of this method is also applied by the Cambridge Bitcoin Electricity Consumption Index (CBECI) Bitcoin network power demand model[1], a widely recognised consumption model [Kohli et al., 2023, Zhang et al., 2023, Maiti et al., 2023], that forms the basis of the consumption figures applied in the survey (see subsection 4.2). As of mid-July 2022, Bitcoin's annual electricity consumption is within the theoretical limits of 40 TW h to 138 TW h, with an estimate of 84 TW h according to the CBECI model.

This number appears enormous on its own, yet criticism ignites even further when considering the energy requirements *per transaction*, as cryptocurrencies only have very limited transaction processing capacity [Xie et al., 2019]. For instance, Bitcoin processes around four transactions per second; the theoretical maximum (given the currently accepted system parameters) is around seven transactions per second [Georgiadis, 2019]. Mathematically this yields around 660 kW h 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 electricity consumption considerably. Due to this particularity, the *energy per transaction* metric frequently causes misunderstandings [Dittmar and Praktiknjo, 2019, Sedlmeir et al., 2020a, Lei et al., 2021, Carter, 2021]. In this survey, we will, therefore, consider *annual electricity consumption*, as described in subsubsection 4.2.1.

[1] See `https://ccaf.io/cbeci/index`.

The economic relationship between the total electricity consumption of a PoW-based blockchain and the market price of its native cryptocurrency suggests that increasing the energy efficiency of the mining hardware or reducing the number of transactions will not help much to improve sustainability [Sedlmeir et al., 2020a]. Since both mining rewards and transaction fees are paid in the native cryptocurrency (e.g. BTC) of the blockchain, the cryptocurrency market price is the most important factor influencing blockchain electricity 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 electricity consumption of a PoW blockchain and its drivers are more willing to support countermeasures, such as abandoning an unsustainable blockchain and moving to a sustainable one.

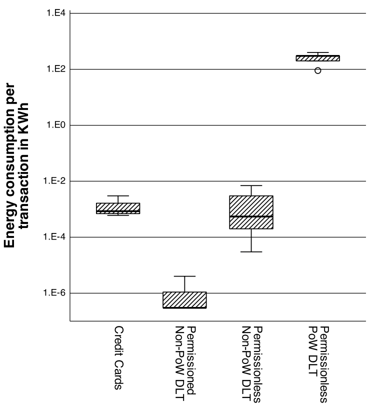

Figure 1. A comparison of data concerning the electricity consumption per transaction reported in the wider literature (logarithmic scale) compiled by Agur et al. [2022] confirms that the scientific community, despite divergent estimates, considers permissionless PoW DLT systems to consume several orders of magnitude more electricity than other payment systems.

2.3. Alternatives to PoW

A popular alternative consensus mechanism used in cryptocurrencies is proof-of-stake (PoS), which 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 challenging to design and implement securely and there are doubts about their incentive compatibility under certain conditions [Houy, 2014, Brown-Cohen et al., 2019], the question of whether PoW or PoS is more secure remains unresolved [Keenan, 2017, Ouyang et al., 2021]. In any case, PoS-based systems enable consumer choice: while end users are challenged by the usability of blockchains in general [Shin and Bianco, 2020], whether systems are operated using PoW or PoS, does not noticeably affect their usability [Jang et al., 2021]. Energy-intensive PoW-based currencies, foremost Bitcoin, remain dominant [de Best, 2022] although more sustainable PoS-based alternatives exist and are conveniently available to users through popular centralised exchange websites [Arslanian, 2022] that offer comparatively good usability and low transaction fees [Zhou and Shen, 2022].

2.4. Cryptocurrency in Nigeria

Nigeria, distinguished by a high position in the 'Bitcoin Market Potential Index' [Hileman, 2015] and considered an attractive environment for commercialisation of cryptocurrency activities [Jutel, 2023], has a cryptocurrency usership of approximately 32 % of the population [Adesina, 2020, Lawal, 2021]. This high number may be explained by economic hardship associated with the prevailing unemployment, which is believed to be structural [Olubusoye et al., 2022], coupled with a worsening inflation [Lawal, 2021]. This climate, linked with the proliferation of mobile and wireless devices [Burns, 2022], allowed many citizens, especially the youth, to interact with and adopt cryptocurrencies as a safe haven from looming inflation [Zhao, 2022]. Furthermore, high fees for international transfers of funds have established cryptocurrencies as an alternative to traditional banking [BBC News, 2021]. Consequently, Nigerians consider international acceptance as one of the key advantages of cryptocurrencies [Onyekwere et al., 2023]. In addition to legitimate applications, cryptocurrencies have been found to be used for illicit purposes in Nigeria, including money laundering [Ediagbonya and Tioluwani, 2022] and financing acts of terrorism [Emmanuel and Michael, 2020]. Furthermore, they can be used in the context of scams around fabricated cryptocurrencies or cryptocurrency theft [Kothari, 2023], activities that entrenched youth unemployment contribute to [Ewuzie et al., 2023]. Nigeria has become infamous for such scams [Ibrahim, 2016, Lazarus and Okolorie, 2019, Okosun and Ilo, 2022] and cryptocurrency transactions, due to their non-reversible nature, hold a special allure for scammers [Butler, 2021]. Despite these concerns, cryptocurrency activity in Nigeria is believed to predominantly help people address their daily financial needs [Stringham, 2023], contrary to the portrayals in popular media. This sentiment was echoed by many Nigerians we interacted with in the course of our fieldwork.

Due to the rising popularity of cryptocurrencies concerns arose among the regulatory authorities, especially the Central Bank of Nigeria (CBN): cryptocurrencies were seen as excessively speculative in nature and therefore considered a risk to the financial well-being of Nigerians [Bakare, 2021b,a, Nwanisobi, 2021]. Therefore, in an effort to regulate the market, the CBN placed a ban on banks that facilitate 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 dropped in 2021, an initiative was taken 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' [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 and institutions involved in cryptocurrency transactions [Nwanisobi, 2021]. In April 2021, three banks were sanctioned with an 800 million Nigerian naira (NGN) (approximately 2.1 million US$) 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. Approximately the same time, the CBN launched a project to improve the efficiency of payment systems [Olowodun, 2021] by implementing a centrally issued and regulated Central Bank Digital Currency (CBDC) which is, at the time of writing, the only fully adopted CBDC on the African continent [Ozili, 2022]. The resulting system, however, notably lacks decentralisation and decoupling from the fluctuation of the NGN and was therefore not widely recognised as a replacement for cryptocurrencies [Chukwuere, 2021]. Therefore, and because it lacked other desirable characteristics such as interest-bearing capacity or feelessness [Ozili, 2023], ultimately, this CBDC achieved only 'disappointingly low' public adoption [Ree, 2023, p. 12]. Despite this initiative and the legislative focus on cryptocurrencies, many citizens remain highly committed to them.

2.5. Regulating Cryptocurrency Activity

Bitcoin is the first and arguably one of the most relevant applications of blockchain technology. As such, it can be considered the archetype for cryptocurrencies [Ram, 2019], since it served as inspiration for most of the large number of alternative systems in the space [van der Merwe, 2021], including some that are directly derived from its core protocol (e.g., 'Litecoin'). After more than a decade, Bitcoin still accounts for around half of the cryptocurrency market capitalisation [Kulal, 2021], a condition that is known 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 exceeding 70 % in times of uncertainty and market volatility.

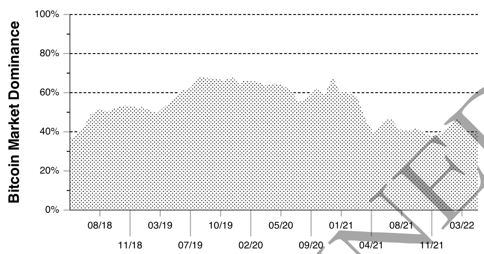

Figure 2. Bitcoin's market capitalisation relative to that of all other cryptocurrencies combined between 2018 and 2022 [de Best, 2022].

Bitcoin's dominance may reflect the widespread and growing adoption that ultimately led it to be among the best-performing assets of the last decade, outperforming many stocks, bonds, commodities, and traditional currencies [Grabowski, 2019]. There are now proposals at the 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 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 transnational cryptocurrency systems challenge more traditional regulatory sandboxing [Ahern, 2021]. Consequently, relatively little validation of the regulatory compliance of the processes and practices surrounding cryptocurrencies has been undertaken [Filippi et al., 2022]. This has contributed to regulatory gaps and, thus, to legal uncertainty [Ferreira and Sandner, 2021]. This affects not only environments with conservative attitudes towards digitalisation but also jurisdictions that are generally perceived and seen as leaders in such matters, for instance, South Korea [Shin and Ibahrine, 2020] or the United Arab Emirates [Shin and Rice, 2022, Shin et al., 2022].

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 considered regulatory aspects [Silva and da Silva, 2022]: regulatory measures in the past focused, for instance, on fiscal interventions addressing miners [Jiang et al., 2021, Oğhan, 2022, United States Department of the Treasury, 2023], an approach with relevance beyond cryptocurrencies as evidenced by the increasing attention environmental taxation receives [Patel and Jhalani, 2023]. Some proposed measures revolved around 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 redesigns 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]. Regulating cryptocurrencies remains challenging [Millard, 2018], and policymakers seem to consistently underestimate the technical complexity involved in efficiently targeting this novel phenomenon [Mezquita et al., 2023].

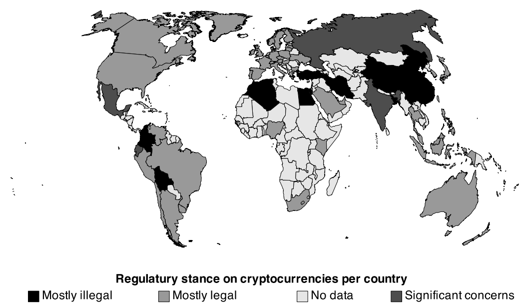

Figure 3. The visualisation of the global regulatory stance on cryptocurrencies adapted from the work of Hammond and Ehret [2022] shows that cryptocurrencies are considered 'mostly illegal' by the governments of Algeria, Bangladesh, Bolivia, China, Colombia, Egypt, Iran, Morocco, and Turkey.

2.5.1. The Chinese Example

A case study that illustrates these regulatory challenges 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 as well as money laundering and other fraudulent activities. This led to banning initial coin offerings – cryptocurrency-based avenues to raise funds via the issuance of digital tokens and without the participation 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 other 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 caused spillover effects to geographically close regions shortly after the introduction of more restrictive regulations, including an increase of over 25 % and 20 % in the trading volume of Bitcoin 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 provided a way to bypass regulation.

More recently, China has adopted an even more rejective stance on cryptocurrency-related activities, particularly 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 down due to environmental concerns brought forward by the government. As illustrated in Figure 4, the ban was initially effective: mining activity halted in the summer of 2021, with China's hash rate, a measure of mining speed in PoW, going to zero. The two countries that benefited most from the ban in terms of share of the global hash rate were the United States and Kazakhstan.

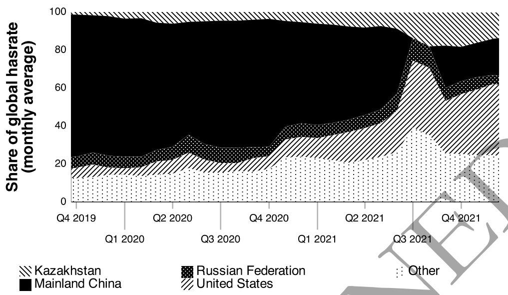

Figure 4. The evolution of mining activity between 2019 and 2022 (reproduced from CBECI data).

However, given the significant mining capability built in previous years, which at the time accounted for more than 70 % of the global share, some Chinese miners were able to return to their activities despite bans, making China the country with the second-largest share of Bitcoin mining activity globally. Others moved hardware to less strictly regulated regions and continued activities there. Whether or not miners will continue to elude the ban in the future is unclear, but the events outlined suggest that even for countries with a strong grip on economic activities, such as China, enforcing outright bans is highly challenging. This perspective is consistent with work by Chen and Liu [2022] who investigated the impact of government Bitcoin trading interventions on the activities of Chinese investors. They found that, while Chinese participation in the Bitcoin market has decreased, local actors remain deeply involved. Ultimately, the Chinese example shows that it is not sufficient for regulators to ban and discredit cryptocurrencies to effectively prevent adoption [Feinstein and Werbach, 2021].

3. Related Work

We consider the following types of studies as relevant related work: first, articles that target cryptocurrency users beyond Nigeria through survey research (see subsection 3.2), thus exposing patterns of user attitudes, behaviours, and experiences. Second, articles that investigate issues related to Bitcoin in the Nigerian context (see subsection 3.3) from legal, regulatory, or macroeconomic perspectives.

3.1. Search Strategy

We used the database *Web of Science*, which is widely acknowledged in the librarian and research communities for listing highly relevant peer-reviewed content [Mikki, 2009]. Initially, we ran the search query `(cryptocurrency OR cryptocurrencies OR bitcoin)AND attitude` to retrieve works on cryptocurrency user attitudes (see subsection 3.2). Subsequently, we ran the query `(cryptocurrency OR cryptocurrencies OR bitcoin)AND (nigeria)` to obtain relevant literature on cryptocurrencies in the Nigerian context (see subsection 3.3). Finally, we manually screened the abstracts of the identified manuscripts for relevance to our work and included those we deemed relevant in the corresponding subsections. We also added references to some works as a consequence of addressing reviewer comments.

3.2. Cryptocurrency User Attitudes

Most of the relevant prior literature of which we are aware examines 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]. Research has been conducted on the circumstances under which users tend to support cryptocurrency as a *means of payment* by Kim [2021] and 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] conclude 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 more 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 finding of Smutny et al. [2021] that shows that a lack of information on 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 dimension 'power-prestige' was established as the most influential factor in 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 their peers, being technically savvy, well-informed, well-networked, and 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.

3.3. Cryptocurrency in Nigeria

Academic coverage of issues related 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 our knowledge, only two quantitative academic studies based on questionnaires have been conducted with a focus on Bitcoin in the Nigerian context: Eigbe [2018] investigates the level of awareness and adoption of Bitcoin in Nigeria, finding that most of the respondents lacked a proper understanding of the functionalities of Bitcoin, even if they claimed otherwise. A study by Salawu and Moloi [2018] targets Nigerian professional accountants: they were considering offering services in a cryptocurrency environment, although a majority indicated that the enactment of specific legislation would be a prerequisite for doing so.

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], negative effects of cryptocurrencies on the exchange rate [Aberu et al., 2023], or the inability of Nigerian legislation to effectively target cryptocurrency-related activities [Ukwueze, 2021, Gidigbi et al., 2021].

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 individually approaching potential participants and ensuring that 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 the 25th of November 2021 and the 30th of March 2022 by convenience sampling. All participants were 16 years of age or older and resided in Nigeria. All participants reported having undertaken at least one Bitcoin transaction in the last five years at the time of this study.

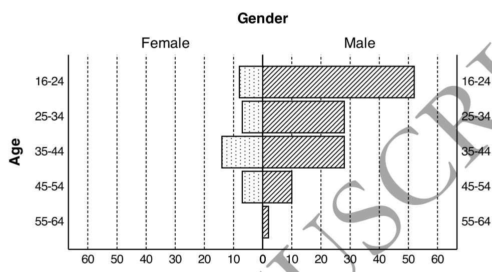

Figure 5. Absolute frequencies of distribution of valid responses for gender and age dimension.

Ethics approval was obtained before participant recruitment began. Participant recruitment had two avenues. First, Covenant University students from Ota, Nigeria who had a verified interest and background in cryptocurrency, as evidenced by extracurricular activities, 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, the participants were self-selected and did not receive compensation. The sample obtained is biased towards male participants, with 76.9 % of the respondents identifying as male (see Figure 5). This imbalance may be traced back to the convenience sampling method in conjunction with a more pronounced interest in cryptocurrencies as investment instruments among younger men [Senkardes and Akadur, 2021, Steinmetz, 2023].

4.2. Materials

The questionnaire contained a total of 107 items on eight pages, some of which were conditional[2]. 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 Bitcoin's electricity consumption. Finally, it measured the degree to which participants believe that Bitcoin's electricity consumption poses a problem, whether measures should be taken, and which stakeholders, if any, they consider responsible for acting against it.

4.2.1. Network-Wide Electricity Consumption as Anchor Point

As described in subsection 2.2 and visualised in Figure 6, typically PoW electricity consumption is quantified either on a system-wide basis (taking into account transaction fees, block

[2] See supplementary material for the original questionnaire.

rewards available to miners, and the price of the cryptocurrency) or per transaction by additionally considering network throughput.

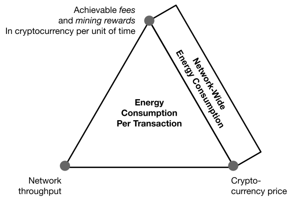

Figure 6. Comparison of network-wide electricity consumption models and transaction-based consumption models.

Consequently, when preparing the materials for this survey, the choice arose as to whether users should be questioned about their assessment of electricity consumption per transaction or about network-wide electricity consumption. We decided on the latter, considering that an increase in the transaction throughput of Bitcoin does not cause a substantial increase in its total electricity consumption. As such, a user who decides to engage in a Bitcoin transaction will not directly contribute to increasing the electricity consumption of the system but only via secondary effects, such as increases in the transaction fee levels and cryptocurrency prices, owing to increased popularity. Yet, in our experience, most users (and even researchers [Mora et al., 2018]) are not aware of this nuance and assume that additional transactions will proportionately increase Bitcoin's total electricity consumption. Therefore, it seems more appropriate to survey users about network-wide electricity consumption. In *Q21*, participants were, therefore, 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 of annualised consumption[3] 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 estimate on all days.

We offer a wide range of potential answers that correspond to electricity consumption figures between 600 MW h and 2,845 TW h. The values chosen as potential answers were deliberately extreme to avoid ambiguity. Since participants are unlikely to have a reference point 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.

4.2.2. Experience Assessment and Opinions

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?

[3] See `https://ccaf.io/cbeci/index`.

Table 1. We asked questions to gauge how realistically participants estimate the annual electricity consumption of Bitcoin. We wrote the questions so that the participants could relate electricity consumption to the realities of their lives. The median of estimates obtained from the CBECI is printed as *actual* value for the benefit of the reader only and was not shown to the participants.

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: *Total 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

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 crypto assets, 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 example, *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 the likely impacts of climate change in Nigeria based on previous studies. By using this previous work, the options presented to participants were tailored to the 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 participants, assessing the understandability of research materials with members of the target population prior to the commencement of data collection. Some changes to the survey materials were implemented according to the findings of the pilot study and thereby improved comprehension of the 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 use 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. Furthermore, they were educated about the fact that choosing not to participate 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.

Some participants raised a serious concern that their identity could be revealed to Nigerian authorities. This concern stemmed from the fear of facing legal repercussions by the Nigerian government which has taken a rejective stance towards cryptocurrencies (see subsection 2.4). The research data collection provider was able to alleviate some of the concerns by pointing to the applicability of the United Kingdom 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 that the data would be converted to an anonymised format and that the data collected might be subject to publication. After completing the survey, participants received a written debrief through the online survey tool, were thanked for their participation, and were dismissed.

4.4. Data Analysis

To test the hypotheses (see subsection 1.3), we applied statistical methods to the collected survey data. To begin, descriptive statistics were employed to illustrate both the user profile of participants and their attitudes toward Bitcoin.

Next, we examined three crucial variables: awareness, actionability, and responsibility. To assess the correlation between actionability and awareness, considering their nominal nature, we conducted a Chi-Square test.

Responsibility for addressing Bitcoin's electricity consumption was assessed using a 5-point Likert scale that measured participants' attitudes towards the responsibility of six different actors: Bitcoin miners, Bitcoin users, Bitcoin developers, intergovernmental organisations, the legislature, and federal agencies/regulators. We divided the six different actors into two distinct groups: non-government actors and government actors. Based on this assessment, we computed the average Likert scores by analysing participants' responses on the 5-point Likert scale.

5. Results

The results generated from the questionnaire provide insights into the environmental attitudes of the surveyed Bitcoin users and provide information on the key hypotheses (see subsection 1.3) in the areas of awareness (see subsection 5.2), actionability (see subsection 5.3), and responsibility (see subsection 5.4).

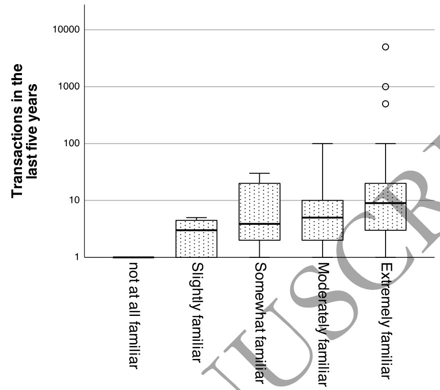

Figure 7. Respondents that report extreme familiarity with Bitcoin on average report the highest number of transactions (logarithmic scale). This group also includes outliers that report participation in very large numbers of transactions.

5.1. User Profiles

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 being extremely familiar with this cryptocurrency. We found that the median number of transactions conducted in the last five years for all levels of experience was 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 main motivation to acquire Bitcoin (reported by 40.5 % of the participants) was as a long-term investment or retirement fund. Only 3.8 % mentioned avoiding government regulation as a reason for obtaining Bitcoin[4].

In addition, we analyse the concerns that participants reported about the possible effects of climate change on their environment. Here, we found great consternation among participants with the mode of responses being 'extremely concerned' for all the effects provided. Participants expressed significant concerns about freshwater resources, rising temperatures, and extreme weather events, while they were less troubled by variable rainfall. 56.3 % of participants believed that Bitcoin's electricity consumption contributes significantly to global CO_2 emissions, with almost all of these (93.3 %) also believing that the CO_2 emissions caused by Bitcoin contribute to climate change. 65.2 % of overall participants felt that measures to reduce the CO_2 footprint of Bitcoin should be taken now. A minority of 42.7 %

[4] This is likely under-reported because 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.

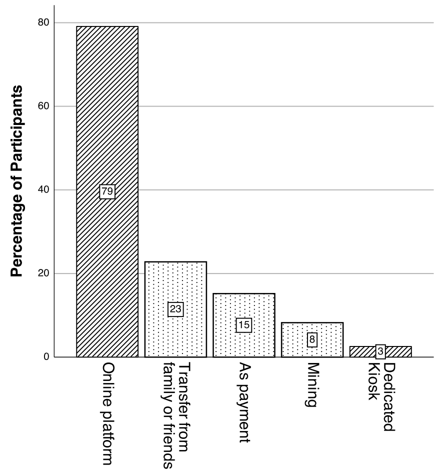

Figure 8. Participants have acquired Bitcoin through different channels. Online platforms and dedicated kiosks lend themselves well to digital energy labelling (see section 6) while others do not.

of the participants who answered the relevant question supported the view that Bitcoin users should move away from Bitcoin to other cryptocurrencies in the interest of reducing CO_2 emissions. Some of these participants provided the names of alternative blockchain-based cryptocurrencies (e.g. Dogecoin and Ethereum). Others suggested alternative payment infrastructure tokens such as Ripple's XRP.

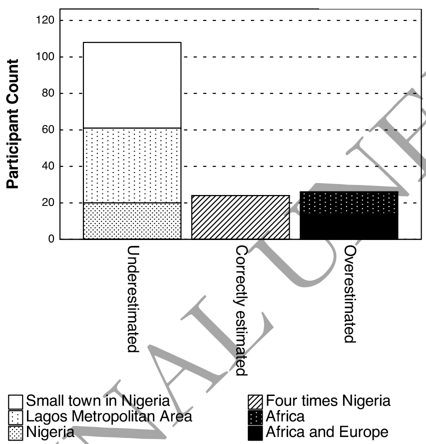

Figure 9. Most participants underestimate the overall energy demand of Bitcoin.

5.2. Awareness

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

5.3. Actionability

We provided a variety of reference points to participants (see subsection 4.2) to assess actionability. Based on the participants' estimates of the overall Bitcoin electricity consumption, we separated the participants into two groups: those who estimated energy demand correctly and those who did not. Thus, being supportive of measures and estimating the electricity consumption of Bitcoin correctly both constitute dichotomous variables.

Subsequently, we conducted a Chi-Square test to analyse the relationship between supporting measures and estimating the electricity consumption of Bitcoin correctly: we found a medium correlation between these two variables ($\chi^2(1, N = 158) = 4.105$, $p = 0.043 < 0.05$, $\phi_c = 0.16$, see Table 2). Specifically, a *post-hoc* comparison test with correction showed that under $\alpha = 0.05$, the proportion of participants supporting measures in the correct estimates group (83.3 %) is higher than in the incorrect estimates group (61.9 %). Consequently, the proportion of the non-supporting measures group in the correct estimates group (16.7 %) is lower than that of the incorrect estimates group (38.1 %).

Table 2. We found a medium correlation between estimating the electricity consumption correctly and being supportive of measures.

Supportive	Estimates		Total	χ^2
	Correct	Incorrect		
Yes	83	20	103	4.105*
	61.90 %	83.30 %	65.20 %	
No	51	4	55	
	38.10 %	16.70 %	34.80 %	
Total	134	23	158	

* Correlation is significant at the 0.05 level.

5.4. Responsibility

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

To further examine participants' notion of the responsible actors, we rendered paired sample t-tests to compare the mean Likert scores in support of non-government actors (averaged by Bitcoin miners, Bitcoin users, and Bitcoin developers) and government actors (averaged by intergovernmental organisations, the legislature, and federal agencies or regulators). We observe a significant difference in mean Likert scores in support of non-government actors and government actors ($t = 2.943$, $p = 0.004$, see Table 3). On average, participants expressed a stronger expectation of responsibility towards non-government actors ($M = 3.490$) compared to government actors ($M = 3.260$).

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 CO_2 footprint of Bitcoin should be taken now, they predominantly articulated two reasons for this perspective (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 of Bitcoin is

Table 3. On average, participants hold private sector actors more accountable.

Group	μ	σ	t
Non-government actors	3.49	1.02	2.943**
Government actors	3.26	1.15	

μ: Mean, σ: Standard deviation; ** Significant at the 0.01 level.

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

6. Discussion

Our results are largely corroborated by previous research. Specifically, they support the results of Eigbe [2018] who previously pointed out gaps in the technical expertise of Nigerian Bitcoin users, as well as the findings of Steinmetz et al. [2021] and Duggan [2022] which yield similar conclusions, although outside of Nigeria. The results furthermore broadly align with consumer knowledge assessments in the broader 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]. Although previous research has focused on technical or financial dimensions of user attitudes alone (see section 3), the results of this study demonstrate that, throughout the user base, the concern over the effects of climate change is significant. These results should be taken into account when designing policies to respond to the high electricity consumption of cryptocurrencies.

To develop effective strategies to reduce the popularity of PoW cryptocurrencies, and therefore, ultimately, their electricity demand, decision-makers must first realise that such strategies cannot be targeted at miners alone. While miners are, in fact, almost solely responsible for the energy footprint of cryptocurrencies (see subsection 2.1), they can quickly relocate their activities to other regions where there are fewer legal restrictions (see subsubsection 2.5.1). Relocating allows them to evade regulatory access without affecting the end users

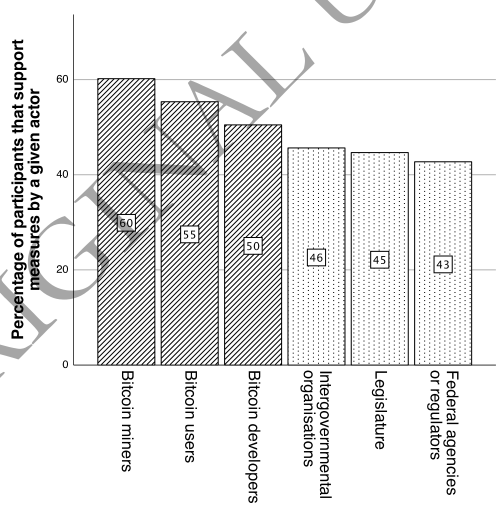

Figure 10. 60 % of those participants that support measures in principle find that Bitcoin miners should act, while only 43 % find that federal agencies or regulators should. A divide between non-governmental actors (top 3) and governmental actors (bottom 3) is noticeable.

of 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 by empowering 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 finding that users who correctly assess the sustainability parameters of cryptocurrencies tend to show more support for measures indicates that consumer education is a promising tool for policymakers. Care must, however, be taken that cryptocurrencies are not portrayed in an all-encompassing and overly negative way: after all, our results do neither support nor rule out a correlation between *overestimating* electricity consumption and supporting measures. Rather, policymakers should initiate measures that achieve basic consumer education and provide users of cryptocurrencies with a realistic view of their electricity consumption and economic parameters.

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 the electricity consumption characteristics in this vast market, thereby allowing them to take sustainability into consideration when making cryptocurrency purchasing decisions. The concept of energy labelling aligns with the broader discussion of the importance of transparency and adequate disclosure in the blockchain and cryptocurrency industry [Liebau and Krapels, 2021]. While little is known about the effectiveness of this intervention in the context of cryptocurrencies, the assessment of a protocol's consensus algorithm has previously been contemplated as a key environmental metric [Liebau, 2021] and early research into measures to reduce the carbon impact of digital behaviours has produced promising results [Seger et al., 2023]. Furthermore, results from the field of household appliances, where energy labels are common, give cause for optimism: here it was found that customers are aware of the information on labels [Waechter et al., 2015] and comprehend it [Jeong and Kim, 2014], albeit being confused by changes in labelling schemes [Stasiuk and Maison, 2022]. Ultimately, consumers were found to make better decisions when guided by labels [Davis and Metcalf, 2016]. Furthermore, consumers were 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 for cryptocurrencies that may promote green innovation [Li et al., 2022].

7. Conclusions

The data obtained suggest that most 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 CO_2 footprint. Furthermore, we find that users predominantly hold private actors (e.g. Bitcoin miners, users, and developers) responsible for addressing Bitcoin's energy demand. Subsequently, the empirical results lend support to all three hypotheses posited.

Taking into account the current trajectory of CO_2 emissions, regulators face unprecedented pressure to introduce policies to avoid a climate catastrophe. Cryptocurrencies based on PoW consume large amounts of electricity, while, arguably, providing very similar benefits to those built on alternative consensus mechanisms that are orders of magnitude less energy-demanding. The counteracting of the enormous electricity consumption of PoW-based cryptocurrencies must therefore be urgently attended to by policymakers, not least since cryptocurrencies are now ubiquitous and no longer exclusive to users with specific demographic or regional characteristics. Improving customer knowledge about cryptocurrency sustainability could lead to more sustainable consumer behaviour.

Therefore, in this work, we recommend a specific course of action to promote customer knowledge: confronting users with the consequences of their cryptocurrency choices through energy labelling. Although this proposal has not yet been tested, the key results of this work suggest that it may improve sustainability.

8. Limitations and Future Work

It is important to note that our study is based on a small sample with a narrow scope, since it focused solely on one asset and country and was obtained by convenience sampling. This sampling method may introduce biases from self-selection, inadvertent selection of specific groups, and recruitment channel preferences. Furthermore, the reliability of the data we collected is impacted by the challenging legal situation in Nigeria that may prevent cryptocurrency users from publicly acknowledging their activities. These factors warrant caution when generalising our findings to larger populations.

In the future, experiments should evaluate the impact of presenting energy labels at the point of exchange[5] to test our policy suggestion. This will provide valuable insights into consumer behaviour. Additionally, future research should focus on developing metrics that mitigate the misunderstandings around the concepts of network-wide and per-transaction electricity consumption measurements in Blockchain energy demand research, thereby creating criteria that are intuitive to experts and laypeople alike.

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Ethics Approval

Ethical clearance for this project was granted by the King's College London ethics committee under ethical clearance reference number *MRSP-21/22-27025*. Freely given informed consent to participate in the study was obtained from all participants.

Availability of Data and Materials

The data underlying this article are available in Mendeley Data, at `https://dx.doi.org/10.17632/j5j3gh4ps4.1`. The questionnaire used in this study is available within the article's supplementary materials.

[5] Such research effort is undertaken by Drăgnoiu et al. [2023].

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Competing Interests

M.P. reports a relationship with Amazon Web Services EMEA SARL that includes: employment. M.P. reports a relationship with R3 Ltd. that includes: employment. M.P. reports a relationship with the University College London Centre for Blockchain Technologies that includes: consulting or advisory. S.O. reports a relationship with Stojeka Consulting Nig, Ltd. that includes: consulting or advisory and equity or stocks. Stojeka Consulting Nig, Ltd. was commissioned as a research data collection provider. Competing interests were evaluated after the completion of the initial draft of this study in July 2022.

Author Contributions Statement

Conceptualisation: M.P. and S.O.; Data curation: M.P., S.O., and Z.W.; Formal analysis: Z.W.; Funding acquisition: M.P.; Investigation: M.P., S.O., A.D., O.E.I., F.P., J.S., and Z.W.; Methodology: M.P. and S.O.; Project administration: M.P. and S.O.; Supervision: M.P.; Visualisation: M.P.; Writing—original draft: M.P., S.O., A.D., O.E.I., F.P., J.S., and Z.W.; Writing—review & editing: M.P., S.O., A.D., O.E.I., F.P., J.S., and Z.W.

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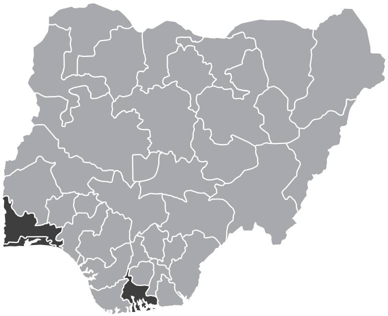
Energy Demand Unawareness and the Popularity of Bitcoin

Evidence from Nigeria



Participants predominantly resided in the *Lagos*, *Ogun*, and *Rivers* states.

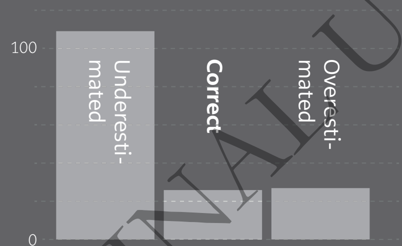
Fieldwork in Nigeria: Africa's "Crypto Capital" *n=158*

32% of Nigerians use cryptocurrencies. Many as a hedge against inflation and to circumvent the limitations of an ageing banking system. We surveyed 158 Nigerian *Bitcoin* users via an online questionnaire to test the following hypotheses:

i. Most Nigerian *Bitcoin* users are unaware of its high energy demand.
ii. Users who misestimate electricity consumption see less need to counteract it.
iii. Participants who see a clear need for action feel that nongovernmental actors are responsible.

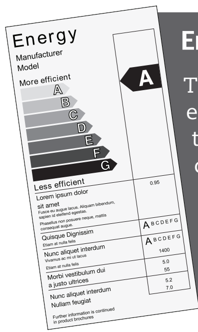
Awareness

Most participants (*68.4%*) significantly underestimated the energy demand of *Bitcoin*, while only a minority (*16.5%*) overestimated it.



Actionability and Responsibility

The proportion of participants supporting measures was higher when they correctly estimated the electricity consumption (*83.3%*) than in the incorrect estimates group (*61.9%*)



Energy Labels as a Solution?

The study proposes that strategies to reduce the energy demand of *proof-of-work* cryptocurrencies should target end users, promote transparency, and educate consumers. Energy labelling is suggested as a potential measure to inform users about sustainability metrics when making cryptocurrency investment decisions, drawing parallels with successful energy label initiatives in other industries.