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What Potential Does Bitcoin Have for Supporting the Transition to Renewable Energy Sources and Reducing Carbon Emissions?

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13/03/2023 Rubin, Eva

Acronyms

ASIC	Application-Specific Integrated Circuit
BIS	Bank for International Settlements
BTC	Bitcoin
CASPs	Crypto-Asset Service Providers
CBDC	Central Bank Digital Currency
CCAF	Cambridge Center for Alternative Finance
DAME	Digital Asset Mining Energy
dApps	Decentralized Applications
DeFi	Decentralized Finance
DLT	Distributed Ledger Technology
e-CNY	digital yuan
EACs	Energy Attribute Certificates
ECB	European Central Bank
ECON	Economic and Monetary Affairs Committee
ESMA	European Securities and Markets Authority
ETF	Exchange Traded Fund
ETH	Ethereum
EU	European Union
EW	Energy Web
FUD	Fear, Uncertainty, Doubt
GOs	Guarantees of Origin
GW	gigawatts
I-RECs	International Renewable Energy Certificates
IEA	International Energy Agency
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
LEC	Lonsdale Energy Corporation
MiCA	Markets in Crypto Assets
NFT	Non-Fungible Token
PBOC	People's Bank of China
PoA	Proof of Authority
PoS	Proof of Stake
PoW	Proof of Work
PPAs	Power Purchasing Agreements
PV	Photovoltaic
RECs	Renewable Energy Certificates
REGOs	Renewable Energy Guarantees of Origin
SDCs	Sovereign Digital Currencies
SEC	Securities and Exchange Commission
TWh	Terawatt hours

UK	United Kingdom
US	United States
USD	US Dollar
USDC	USD Coin
USDT	Tether

Abstract

This thesis explores the relationship between Bitcoin and renewable energy, and demonstrates how they can mutually benefit each other in the transition to a low-carbon economy. Bitcoin is a decentralized digital currency that provides a global, freely available, censorship resistant, and human rights preserving monetary network for the entire world. In a time where digitalization is outpacing regulations, this research offers solutions in the form of policy suggestions and case studies.

The data analysis quantifies and compares the energy consumption and potential reductions in the carbon footprint of Bitcoin mining and other forms of energy use. The case studies illustrate how Bitcoin mining can utilize renewable energy sources such as solar, wind, and hydropower in different regions and contexts, and how carbon emissions can be significantly reduced through implementation of mining heat recovery technology and blockchain enabled supply chains. The policy recommendations suggest how to facilitate renewable energy mining through incentives, platforms, and regulations.

Contents

Introduction

The world is currently undergoing what's known as the Fourth Industrial Revolution, where emergent and disruptive technologies are reshaping industries. This revolution is characterized by the integration of communication, information, and intelligence technologies into production systems, giving rise to a new paradigm of smart and autonomous manufacturing (Bai et al. 2020). However, alongside these advancements, the global community is facing the pressing difficulties of human induced climate change, that come from the rising concentration of greenhouse gases in the atmosphere. These consequences are evident in the increasing number and intensity of extreme weather events such as heatwaves, droughts, floods, and extreme wildfires (Intergovernmental Panel on Climate Change 2023). To combat these challenges and meet the climate goals outlined in the Paris Climate Accord, there is an urgent need to accelerate the transition to renewable energy sources.

Simultaneously, digitalization is rapidly transforming the financial system, with an increasing number of countries exploring the implementation of their own central bank digital currencies (CBDC) (Masterson 2022). In 2021, Bitcoin, the first and most prominent digital currency, experienced rapid and unprecedented institutional adoption driven by recent factors such as low-interest rates and rising inflation during the global pandemic. Bitcoin is not just a currency, but is also a store of value and a hedge against the rapidly increasing inflation. After Tesla's 1.5 billion dollar purchase in January of 2021 (Boudette 2021), several other institutions bought their own sizable investments, including a 170 million USD purchase from Square a month later in February 2021, and a business intelligence firm called MicroStrategy bought more than 2 billion dollars of Bitcoin throughout 2021 (Pirus 2021).

However, amidst this digital revolution, the environmental impact of certain digital assets, particularly Bitcoin, has raised concerns and prompted evaluation and criticisms of its sustainability. Just a few months after piloting the allowance of Bitcoin payments for electric vehicle purchases, Tesla temporarily halted its new payment program over concerns about the usage of fossil fuels for Bitcoin mining, saying that payments would continue again once there was evidence that more than half the energy consumed by Bitcoin was coming from renewable sources (Boudette 2021). Despite now having an estimated renewable energy mix of 58.9% (Council 2022), Tesla has yet to follow through on its promise to reactive its Bitcoin payment system.

Other actors have taken action against Bitcoin to reduce it's carbon footprint. During the major rise in value of Bitcoin in 2021, China's State Council announced a formal ban on all crypto mining citing environmental concerns over the use of coal for mining operations (Wong 2022). Although seemingly bad at the time for Bitcoin, it proved to be fortunate because mining can be done anywhere. Afterwards, many miners relocated from China to the US, where renewable energy sources are more abundant and accessible. According to a report by the Cambridge Centre for Alternative Finance, the US share of global Bitcoin mining increased from 4.1% in September 2019 to 35.4% in April 2021, while China's share decreased from 75.5% to 46% in the same period (Alternative Finance

2021a). This migration of miners has allowed the US to lead the way in sustainable green energy crypto mining, as well as to benefit from the economic and social opportunities that Bitcoin offers.

Shortly after, the central bank in China ordered banks and payment platforms to stop facilitating crypto transactions, effectively cutting off the access of Chinese crypto users to the global market (Wong 2022). While they banned all use of cryptocurrency, they implemented their own central bank digital currency, the digital yuan (Conrad 2022). The digital yuan is highly centralized and allows the People's Bank of China (PBOC) control over its users. With a centralized digital currency, the PBOC can monitor all transactions made by citizens, which reveal personal and financial information such as their spending habits, income, assets, debts, ect (Broby 2021; Conrad 2022). Not only can they monitor citizens, but they can manipulate the economy by doing things like putting expiration dates on savings, forcing people to spend or lose their money, and adjusting interest or exchange rates according to their policy goals (Conrad 2022).

This type of power is dangerous because it can allow the government to enforce compliance with the law and the party's ideology by imposing fines, sanctions, or rewards when a user behaves a certain way. For example, they could freeze or confiscate the digital yuan of dissidents, activists, or minorities if they behave in a way that doesn't align with the political views of Beijing (Broby 2021). This power could also extend beyond beyond China's borders, by promoting adoption of digital yuan among trading partners and allies, this would allow the PBOC to expand its influence and surveillance (Broby 2021). It wasn't that blockchain was so bad for the people, it's that a decentralized currency wouldn't give China control over its citizens and their finances.

The potential security threats and a destabilization of the dominance of the US dollar has accelerated the research being done in the US for the development of their own digital dollar (Wong 2022), but there already exists a global decentralized digital currency, one outside of the control of governments. Bitcoin offers freedom, privacy, and sovereignty to its users, both as a way for them to make payments and a store of value. That's one of the many reasons that Nayib Bukele, the president of El Salvador, made BTC its national currency in 2021. Bukele believes that adopting Bitcoin as legal tender would improve the economy by making banking easier for Salvadorans, especially those who do not have access to traditional financial services, or who live abroad and send remittances back home (Hart 2021). Several other countries have looked to El Salvador and have considered doing the same, and less than a year later in April of 2022, the Central African Republic followed suite and made Bitcoin its legal tender too (Volyntseva 2023).

While Nayib Bukele has faced criticism for the environmental impacts of BTC mining (Eugenio 2022), he has also taken steps to address these concerns by promoting the use of renewable energy sources, such as geothermal power from volcanoes, to power Bitcoin mining operations (Hart 2021). In the future it's quite possible that more countries will follow suit and look to El Salvador as a model and a leader for innovative and sustainable implementation of mining operations, as well as for embracing Bitcoin as a legal tender and a catalyst for social and

economic change.

However, a lot of unfounded fear, uncertainty, and doubt (FUD) still surrounds Bitcoin and its environmental impact, which often prevents people from recognizing its potential benefits and opportunities. Many of the claims and criticisms that are made against Bitcoin are based on inaccurate or outdated data, assumptions, or methods, or are motivated by ideological or political agendas (Council 2022). For example, some critics compare Bitcoin's energy consumption to that of entire countries, without considering the context, quality, source, and purpose of that energy use (Bendiksen and Gibbons 2021). Others ignore or dismiss the fact that Bitcoin mining can utilize renewable energy sources that would otherwise be wasted or curtailed, such as solar power in remote areas or wind power on floating platforms (Masterson 2022).

Nevertheless, Bitcoin is here to stay, and it is therefore important to conduct rigorous and objective research on BTC and its environmental impact, as well as to educate and inform the public and policymakers about the benefits and opportunities it provides.

This research aims to highlight the potential that Bitcoin has to reduce the levels of global carbon emissions, and how it can help accelerate the transition away from fossil fuels towards renewable energy. To answer this research question, investigation was done using a mixed-methods approach that combines literature review, data analysis, case studies, and recommendations for policies to improve the sustainability of Bitcoin.

The first chapter delves into the background behind Bitcoin, explaining blockchain technology and how it works. It details what a consensus mechanism is and shows the similarities and trade-offs between three of the most common protocols. The history, utility, and improvements to Bitcoin such as the lightning network are explained. As Bitcoin isn't the only type of blockchain based currency, the other types are explained and a comparison is done.

The second chapter is about renewable energy and the amount of Bitcoin mined using sustainable electricity, along with various types of renewable energy sources. Including a case study where using hydro energy helps citizens in Africa. It also investigates utilization of verifiable renewable energy certificates that can be issued and traded on blockchain platforms to incentivize usage of green energy sources.

In the third chapter different ways that Bitcoin and blockchain technologies can be implemented to reduce carbon dioxide and methane emissions are investigated. It covers topics such as replacing cooling systems with waste heat recovery technology and the use of this thermal energy to provide heat to cities, homes, and greenhouses. The chapter finishes with a study on the potential of blockchain to facilitate a lower carbon economy through transparent and traceable supply chains.

Finally, the last chapter looks towards the future including recent regulations such as the Markets in Crypto Assets (MiCA) and their potential impacts, and how they could be improved to increase the sustainability of crypto. Along with the future outlooks on central bank digital currencies and their relationship with

Bitcoin, with a focus on the impending digital euro.

Methodology and Literature Review

As society seeks sustainable solutions, emerging technologies like Bitcoin have earned attention for their capacity to support renewable energy initiatives and contribute to carbon footprint reduction. This section provides an overview of the materials and methods employed in this study, which investigates the potential of Bitcoin in facilitating the transition to renewable energy sources and reducing carbon emissions.

This research was done using a mixed methods approach, combining qualitative methods and quantitative calculations to gain a comprehensive understanding of the topic. The qualitative methods involved a thorough review of existing research on the topic, including studies on the energy requirements of Bitcoin mining, efforts to use renewable energy for Bitcoin mining, and initiatives to use Bitcoin, blockchain, or other cryptocurrencies to support the development of renewable energy. The sources included scientific literature, reports, white papers, articles, and veritable news sources. This literature review provides valuable insights into the current state of research, key findings, and potential gaps in knowledge.

Qualitative data was collected through an extensive search of databases such as ScienceDirect and Google Scholar using relevant keywords such as "Bitcoin," "renewable energy," "carbon emissions," "solar energy," and related terms. Only articles published in peer-reviewed journals or reputable outlets were considered for inclusion. The search was limited to articles published in English from 2017 to 2023, to ensure currency and relevance of the data.

The literature review provides an overview of the history, technology, economics, and environmental impact of Bitcoin and renewable energy. Case studies on different technologies illustrate how Bitcoin mining can utilize renewable energy sources such as solar, wind, hydro in different regions and contexts, and how heat energy can be recovered from the mining process to improve the efficiency and sustainability of the system. This technology can reduce the need for energy costly cooling systems and lower the carbon emissions of Bitcoin mining, as well as provide useful heat for other purposes, such as heating buildings, greenhouses, or water in homes.

In addition to the qualitative analysis, quantitative methods are utilized to investigate the practical application of Bitcoin technology in supporting renewable energy initiatives. Data from the Cambridge Bitcoin Electricity Consumption Index provided by the Cambridge Center for Alternative Finance (CCAF) (Alternative Finance 2021b), Bitcoin Mining Council (Council 2022), International Renewable Energy Agency (International Renewable Energy Agency 2022), the International Energy Agency (International Energy Agency 2022), Overview of Global Energy (Ritchie and Roser 2021), and other reliable sources were used to estimate the current and projected electricity consumption of Bitcoin mining, average household energy needs, as well as potential savings in carbon emissions, and renewable energy percentages. These calculations aim to provide a realistic and comprehensive assessment of the environmental performance and benefits of Bitcoin mining in relation to renewable energy and reducing CO_2 levels.

Despite the growing body of research on the topic, there are still some gaps and

limitations in the existing literature. First, most studies focus on the technical and economic aspects of Bitcoin mining and sustainable energy sources, but few examine the policy and regulatory implications of this emerging phenomenon. Second, there is little empirical evidence on how Bitcoin mining affects the development and adoption of renewable energy projects, especially in developing countries and regions. Third, there is uncertainty about how the upcoming halving event, which will reduce the reward for Bitcoin mining by half, will affect the sustainability of mining, as it is projected that the price will dramatically increase based on historical price trends and factors such as supply and demand. Higher prices tend to draw new mining operations and without policies and regulations in place to ensure conscious use of electricity, there are potential negative effects on Bitcoin's carbon footprint.

To ensure the quality and clarity of the writing, AI tools such as ChatGPT (OpenAI 2023) and Bing AI (User and Assistant 2022) were utilized to check for grammar and punctuation mistakes and to aid in paragraph formulation. These tools provided suggestions and feedback on the content, structure, and style of the text, which were then reviewed and revised by the author.

1 Blockchain Technology

Blockchain technology is one of the key innovations that enables Bitcoin and other cryptocurrencies to function as decentralized and trustless systems. Many people have heard of blockchain and blockchain technology, but very few understand what blockchain actually is. Introduced in 2008 during the global financial crisis as the underlying technology of Bitcoin, blockchain has since then shown that it is so much more than just the groundwork for digital money (Pratt and Gillis 2021). Blockchain is a technology that creates a distributed, shared, decentralized, and immutable ledger of data, also known as distributed ledger technology DLT, that can be used and accessed by a network of participants. The data on the ledger can be information of any kind, for example, transactions, smart contracts, assets, or even the carbon footprint of a given step in the fabrication and supply chain of a product (Harrington 2022). With blockchain technology, the recording and storage of information can be done with reduced costs and risks, while also being more efficient because the data is much more transparent and verifiable (RushRadar 2022).

One of the main advantages of blockchain is that it is immutable, meaning that once a block is created and verified, it can no longer be altered or tampered with. Being immutable ensures the integrity and reliability of data and prevents any possible fraud or corruption. Traditional databases are much more easily subject to manipulation and hackers as they enable easy changing or erasing of data entries. Another benefit is its transparency, any network member with access can see the same information at the same time, providing full accountability and auditability. Members have the ability to view the entire history of a transaction or an asset and verify its origin (Blockchain 2021). Blockchain also supports decentralization because it does not rely on a single authority or intermediary to validate or control the data. Instead, it uses a consensus mechanism among network participants to agree on the state of the ledger. Users also gain increased autonomy and sovereignty as the need or third parties or middlemen can be eliminated.

With DLT comes enhanced security and faster, more efficient data transactions. Cryptographic techniques such as hashing and digital signatures prevents data from being accessed or modified by anyone without authorization. This also provides protection from cyberattacks and physical damage by storing it across a network of computers rather than a single server. The processes involved in transactions can now be streamlined as DLT eliminates paperwork and errors, and reduces costs and delays. In addition, Decentralized Finance, or DeFi, harnesses blockchain technology to recreate traditional finance systems in a noncentralized manner.

Blockchain technology also has tremendous potential to support sustainability in various ways. It can be used to track and verify the origin and impact of products along a supply chain, ensuring sustainable production and consumption of goods (Harrington 2022). Blockchain can also be used to incentivize and reward environmentally friendly behavior, for example, recycling, energy conservation, or reducing carbon emissions. It can provide services to marginalized and vulnerable communities, such as access to financial services, identity verification, and digital

rights. For example, Indigenous People can use blockchain technology enabled digital rights to maintain ownership and control over their lands, water sources, and traditional knowledge by registering and managing their assets. This allows them to protect their intellectual property rights, and benefit from the fair and equitable sharing of benefits that may come from their use (U. N. E. Programme 2020).

Distributed ledger technology can facilitate the implementation and monitoring climate goals and agreements from all over the world such as the Paris Agreement, or the Sustainable Development Goals (Parmentola et al. 2021). Enhanced trust, accountability, and collaboration with stakeholders would result in more transparent and verifiable reporting of greenhouse gas emissions and climate actions by different companies or countries. Climate finance from different sources would be easier to mobilize and track to ensure it reaches the intended projects and beneficiaries. Along with smart contracts that are able to execute enforceable agreements between entities, holding them accountable to their climate promises. Blockchain is not just a technological innovation, but a social innovation that can contribute to a more sustainable future.

1.1 How Does Blockchain Work

Blockchain works via a multi-step process which begins with a transaction. Once an authorized participant inputs the transaction, it is then authenticated by the technology creating a block that represents the specific transaction or data (Pratt and Gillis 2021). A block header is the part of the block that contains important information such as the hash of the previous block, the timestamp, the nonce, and the Merkle root of the transactions. The Merkle root is a hash that summarizes all the transactions in the block.

This block is then sent to every node (computers or servers that store or process data) within the network. Using a consensus protocol, the nodes then validate the block and then it is added to the existing chain of blocks, forming the blockchain. The longest blockchain is then replicated and synchronized across the network of nodes, ensuring that everyone has access to the same information and prevents individual nodes from corrupting or tampering the data (Pratt and Gillis 2021).

The consensus protocol is a critical part of every blockchain network. It provides a set of rules and parameters that define how a transaction will be processed in a blockchain network, and how communication will be done between the nodes in the network (RushRadar 2022). Without a consensus protocol some nodes may have varied versions of the ledger, possibly allowing fraudulent or invalid transactions. Therefore, it is essential that all nodes agree on only valid transactions and will have the same version of the block (Pratt and Gillis 2021). Different blockchain networks use different consensus protocols depending on their design goals and trade-offs. Some of the most common consensus protocols are Proof of Work (PoW), Proof of Stake (PoS), and Proof of Authority (PoA).

1.1.1 Consensus Protocol Mechanisms

One of the most widely used consensus protocols is Proof of Work. PoW requires nodes to solve complex mathematical problems, called hashes in order to create new blocks. The first node to solve the problem, called a miner, is rewarded in newly minted cryptocurrency tokens. PoW is used by Bitcoin and other types of crypto that aim to achieve high security and decentralization. The high level of security comes from the massive amount of computing power needed (over 50% of all the computing power in the entire network) if someone wanted to falsify the ledger (Arcane Research 2022). This method is very energy intensive and slow compared to other protocols, but on the other hand, it's this energy that goes into the mining that gives the currency its value. It transforms one valuable asset (energy) into another, similar to when the USD was backed by gold, whereas the other protocols don't maintain any sort of value backing the currency. However, Proof of Work has some limitations that other protocols try to address.

Proof of Stake is a consensus mechanism that assigns nodes a "stake" or a fraction of a cryptocurrency that is locked up as collateral in order to participate in the validation process (*Consensus Mechanisms - Proof of Stake*). Selecting validators, or participating nodes, is based on the amount and duration of their stake. The greater the amount of staked currency, the higher the probability of being selected to create new blocks (RushRadar 2022). Validators are rewarded similarly to Proof of Work, except rewards are proportional to their stake and performance. On the other hand, validators can lose their stake if they act maliciously or dishonestly, such as creating invalid blocks, double spending, or going offline (*Consensus Mechanisms - Proof of Stake*). This creates incentive for participating nodes to act in the best interest of the network because they risk financial loss. As PoS consensus doesn't require solving complicated problems, it has higher scalability, and a lower environmental impact than PoW because the validation process uses less energy.

Proof of Authority has a different approach to achieve consensus on a blockchain network. PoA doesn't involve any computations or stake based participation, but as its name indicates, through authority. This means that in the network, a limited number of designated nodes are pre-approved based on their expertise, reputation, or authority within the network. The validators are typically entities or individuals who are established and well known, and the consensus mechanism is reliant on their authority to validate transactions and create new blocks (Antolin 2023). While Proof of Authority offers a faster and cheaper consensus, it sacrifices decentralization and security, as the network depends on a small number of nodes that could be corrupted of compromised (Antolin 2023).

This was just a short overview of three commonly used consensus protocols used in blockchain networks. To compare and contrast their main features and trade-offs, the table below summarizes their performance in terms of security, scalability, energy efficiency, and decentralization.

Consensus Protocol	Security	Scalability	Energy Efficiency	Decentralization
PoW (Proof of Work)	High	Low	Low	High
PoS (Proof of Stake)	Medium	High	High	Medium
PoA (Proof of Authority)	Low	High	High	Low

Table 1: A comparison of different blockchain consensus protocols.

As the table shows, PoW offers the highest level of security and decentralization, but at the cost of low scalability and high energy input. PoS improves on these aspects by using a stake based mechanism, but it reduces the security and decentralization of the network. PoA achieves the highest level of scalability and energy efficiency, but it sacrifices security and decentralization more than the others by relying on a small number of trusted authorities. Each protocol has its own advantages and disadvantages depending on the design goals and requirements of the blockchain network. However, for the purpose of this thesis, the focus will be on the benefits of Proof of Work mining for Bitcoin and its potential to reduce carbon emissions and aid the transition to renewable energy.

1.2 What is Bitcoin

In 2008 the world experienced the collapse of the traditional banking system. It was during this financial crisis that an unknown person or group under the pseudonym Satoshi Nakamoto published a white paper describing the concept of a peer-to-peer electronic cash system (Nakamoto 2008). This paper was the first ever mention of the blockchain and a financial system that wouldn't rely on any sort of central authority. The technology behind Bitcoin is a decentralized public ledger that containing its transactions. Nakamoto himself mined the first block of transactions in January of 2009 (Pinkerton and Davis 2023). On this first block a message was embedded that referenced a headline from The Times: "The Times 03-Jan-2009 Chancellor on brink of second bailout for banks" (Pinkerton and Davis 2023). This message was a clear indication of Nakamoto's motivation and vision for creating Bitcoin: a system that would not depend on or be affected by the failures of the traditional banking system.

Bitcoin operates in a decentralized manner, independent of centralized authorities such as banks or governments who can exert control over an individual's funds. Bitcoin mining is the process of validating transactions and creating new coins by solving complex mathematical problems. Miners are rewarded with freshly minted Bitcoin and earn transaction fees for their contribution to the network's security and functionality. Bitcoin, sometimes referred to as digital gold, is a novel and innovative form of money, that is scarce and durable like gold, but unlike the precious metal, it is portable, divisible, and programmable.

To use Bitcoin, users send and receive payments using software called a wallet, which generates a unique address for each transaction. Each payment is broadcasted to the network and verified by other nodes using cryptographic techniques (Hodl 2022a). Transactions are then recorded in blocks that are linked together to form the blockchain, which serves as a permanent and immutable record of all Bitcoin transactions.

A store of value, an everyday currency, or a hedge against inflation, however it is used, Bitcoin is a fair and accessible form of money for the world. It offers a new paradigm of money that is decentralized, transparent, unchangeable, and censorship resistant. It empowers its users with more freedom, control, and opportunity to participate in a global, open, and inclusive network that transcends borders and barriers. It challenges the existing standards of currency and creates new possibilities for economic and social development.

1.2.1 The Halvening

The halvening is one of the most important and anticipated events in Bitcoin, as it affects the supply and demand dynamics of the cryptocurrency, as well as the incentives and behavior of miners. During a halvening, the reward for correctly validating a new block in the process of Bitcoin mining is cut in half, reducing the reward for miners. This process is designed to ensure that Bitcoin follows a predictable and transparent monetary policy that is independent of any central authority or manipulation. The initial reward was 50 bitcoins per each block mined, and from there the reward is halved after every 210,000 blocks are mined, which is approximately every four years. Once Bitcoin hits the maximum supply, miners will still be able to make money by receiving rewards through transaction fees paid from users. In this way they will have incentive to continue to confirm transactions (Axi 2023). The block validation reward is calculated by this equation:

$$\text{block reward} = \frac{\text{initial reward}}{(\text{number of halvings})^2}$$

it will continue to decrease every four years until the final halvening event in 2140, when the block reward will become zero and all 21 million Bitcoin will have been mined (Conway 2023). By gradually reducing the amount Bitcoin rewarded for each block over time, the halvening ensures that the inflation rate of Bitcoin will decrease until it approaches 0%. The strict limited supply and the diminishing circulation of new coins over time gives Bitcoin its deflationary nature and helps to preserve its value over time, making it a hedge against inflation.

Deflationary assets tend to increase in value over time as their scarcity increases and their purchasing power goes up. This is unlike fiat currencies, for example, the US dollar US Dollar (USD) where the money supply can be adjusted and expanded monthly by central banks depending on the monetary policy of the Federal Reserve and the demand for money in the economy. The fixed supply cap ensures that the total number of BTC will never go beyond 21 million, creating an asset with intrinsic scarcity.

The halvening also has implications for the environmental impact of Bitcoin mining. As the block reward decreases, some miners may lose their profitability and will be forced to either find cheaper sources of energy, such as isolated or excess renewable energy, or exit the market reducing the overall energy consumption of mining. However, there are potential risks for the security and decentralization of the Bitcoin network if only the most efficient and wealthy

miners can survive. Although, renewable sources of energy are becoming more and more accessible with cheaper and cheaper operating costs.

1.2.2 Bitcoin Energy Usage Argument

The issue of Bitcoin's energy consumption has been a subject of intense debate and scrutiny. Many critics argue that the PoW mining process, which requires substantial computational power and results in excessive and unnecessary energy consumption and carbon emissions. However, it is crucial to approach this debate with a balanced and informed perspective, taking into account the broader context and benefits Bitcoin can bring to society.

Critics contend that Bitcoin is wasteful and a harmful activity that consumes an excessive amount of scarce and precious resources for no social benefit or even for negative purposes. They argue that bitcoin is mainly used for speculative, illicit, or criminal activities, such as money laundering, tax evasion, ransomware, or terrorism. They also claim that bitcoin undermines the efforts and authority of governments and international organizations to regulate the financial system and combat climate change.

Now it is true that Bitcoin's energy consumption has undeniable environmental impacts that cannot be ignored or dismissed. The carbon footprint of Bitcoin mining does contribute to global greenhouse gas emissions and competes for scarce resources such as water and electricity, which may create conflicts or tensions with other users or sectors. In addition, Bitcoin mining is still partially dependent on fossil fuels, especially coal, which are highly polluting and contribute to global warming. Bitcoin mining also faces regulatory uncertainty and hostility from some governments or authorities, who may impose bans, restrictions, or taxes on mining activities.

However, Bitcoin's energy consumption also provides a unique value when compared to traditional financial systems. Bitcoin offers a decentralized, transparent, and secure way of transferring value across borders, without intermediaries or censorship. Bitcoin enables financial inclusion and empowerment for people who are excluded or marginalized by the traditional financial system. Bitcoin also fosters innovation and competition in the digital economy, by creating new business models and opportunities.

This high energy usage also creates positive aspects and opportunities that can outweigh or mitigate its negative impacts. Bitcoin mining provides an incentive to use renewable and surplus energy sources that would otherwise be wasted or underutilized. Bitcoin is a complex and controversial issue that has both positive and negative aspects. Its energy consumption is a reflection of its value and utility as a decentralized and secure digital currency that can empower and benefit millions of people around the world. Bitcoin can overcome this challenge by using more efficient and sustainable mining protocols and practices, and by harnessing the potential of renewable and surplus energy sources. Additionally, better policies and regulations can also help BTC become more sustainable by providing incentives and guidelines for miners to adopt greener practices, and through facilitating cooperation and coordination among stakeholders to address the environmental and social challenges of Bitcoin.

1.2.3 Bitcoin Lightning Network

Another one of the major criticisms of Bitcoin is that it is difficult to scale up due to its limited capacity to handle a high amount of transaction data in a short period of time. The Lightning Network is a layer-2 solution that aims to increase the scalability of Bitcoin by creating a second network of payment channels that can operate off of the main Bitcoin blockchain (Young 2023). This network facilitates fast and cheap transactions between users without having to broadcast each one to the network and wait for the validation of the next block.

The Lightning Network functions through allowing users to open and closes payment channels with each other using smart contracts. Each payment channel is a two-way connection between two users, and other than the initial and final transaction, it allows them to completely send and receive payments without involving the main blockchain (Young 2023). Users can route payments through multiple channels to reach any other user on the network, establishing a web of interconnected nodes, making it a viable solution for reducing the carbon footprint of Bitcoin transactions. However, with this deviation from the central blockchain comes challenges and limitations. It introduces centralization to the decentralized currency by authorizing third-party services or software to manage transaction routing through channels or to find routes. Lightning wallet holders can be required to monitor the activity of their funds in payment channels to prevent fraud or theft, or risk losing them if there were to be technical errors, malicious attacks, or a power outage. There can also be difficulties in finding optimal payment routes across the network if there is too much distance between nodes or the the amount of payment is too large (Kraken 2021).

The Lightning Network is still in development and experimentation, but it is still a very promising innovation in the Bitcoin ecosystem that can contribute to its environmental sustainability. With its focus on improving its scalability and usability, it provides an opportunity to address the environmental concerns associated with Bitcoin transactions and mining. Although further enhancements are required for handling large payments on the second layer network, lightning transactions are perfectly suited for everyday micro transactions such as buying a coffee or refueling at a gas station. By creating faster, more cost efficient, and scalable payments, this technology has the potential to alleviate the environmental impact of Bitcoin and promote a greener future.

1.3 Other Types of Cryptocurrencies

Bitcoin is not the only cryptocurrency that exists in the market. Since its inception, Bitcoin has inspired and spawned thousands of other cryptocurrencies that aim to provide different features or values. All these other cryptocurrencies are collectively known as altcoins (alternative coins), which are based on the technology behind Bitcoin. Altcoins can be classified into different types or categories depending on their characteristics, design, or purpose. Some of the main types of altcoins are:

- Forks: Forks are alternative coins that are created from splitting from or modification of an existing codebase or blockchain of a currency. Examples of

forks are: Litecoin, Bitcoin Cash, and Bitcoin SV.

- Stablecoins: Stablecoins are pegged to or backed by a stable asset such as fiat currency, gold, or another cryptocurrency. Tether USDT, USD Coin USDC, and Dai all aim to maintain a stable value relative to the US dollar. This particular type of altcoin aims to provide a reliable substitute to the high volatility of other popular cryptocurrencies. As the name indicates, it remains stable and very rarely deviates from 1 USD. Despite this inherent stability, stablecoins also pose some risks, such as regulatory uncertainty, lack of transparency, centralization, and potential insolvency (Catalini and Massari 2021).

- Tokens: When an altcoin is issued on top of another cryptocurrency's platform or protocol, it is called a token. Tokens are digital assets that represent a value or utility such as currency, a reward, a share, or anything else a creator could define. An example of these of non-fungible tokens (NFTs) which are unique and indivisible tokens that can represent digital art, collectibles, gaming items, or other forms of creative expression (Investopedia 2023). Tokens can enable new forms of innovation and participation in the digital economy, but they can also raise legal and ethical issues regarding ownership, authenticity, and intellectual property rights (Zetzsche et al. 2020).

- DeFi Coins: The goal of decentralized finance coins is to provide financial services such as lending, borrowing, trading, investing, or saving without intermediaries or centralized institutions. Examples of DeFi coins are Uniswap, Aave, Compound, and Maker (Y. Zhang et al. 2021). DeFi coins aim to democratize and disrupt the traditional financial system by offering more accessible, transparent, and efficient alternatives. However, DeFi coins also face some challenges such as technical complexity, security vulnerabilities, regulatory compliance, and user education (Y. Zhang et al. 2021).

There are many aspects in how Bitcoin differs from the other types of cryptocurrencies such as its underlying technology, its consensus mechanism, the governance model, and the environmental impact. The technology behind BTC is relatively mature and stable compared to other currencies that use more complex or experimental technology.

For storing value Bitcoin has the advantage over the other cryptocurrencies due to its scarcity, deflation, and security as previously mentioned. The disadvantage that altcoins have is that they are often subject to inflation, and have more volatility, and vulnerability compared to Bitcoin. Altcoins also can have an unlimited or variable amount of currency with a flexible or adaptive supply schedule.

Alternative cryptocurrencies are a diverse and dynamic phenomenon that offer different features and values to different users and markets, while Bitcoin is the first and most popular cryptocurrency that has established itself as a reliable and resilient form of digital money. On the other hand, Bitcoin also faces some competition and criticism from other types of cryptocurrencies that aim to improve or challenge some aspects of its technology, economics, or environmental impact.

1.3.1 Ethereum

Next to Bitcoin, the most popular crypto is Ethereum. It differs from the first blockchain currency in many ways, such as its purpose, functionality, inflation rate, consensus mechanism, and transaction speed (Foundation 2021). Ethereum was designed as a platform that can support smart contracts and decentralized applications (dApps) that run on its network (Foundation 2021). While Bitcoin aims to be a global, decentralized, and censorship-resistant alternative to fiat money, Ethereum differentiates by being a programmable platform for innovation and development. This programmability allows users to build and deploy decentralized applications on the ETH network.

Smart contracts are irreversible, self-executing agreements that are written into code that runs on the ETH blockchain network. They are very beneficial as they can automatically perform predefined actions when certain conditions are met, without the need for intermediaries or third parties. For example, smart contracts can be used to facilitate peer-to-peer transactions, enforce contractual obligations, automate business processes, and create digital tokens (Foundation 2021). While ETH smart contracts have been established since 2015, in 2020 Bitcoin re-enabled its capabilities for performing smart contracts. While still a work in progress Bitcoin smart contracts have enormous potential due to increased security, performance, and cost effectiveness over Ethereum contracts (Liu 2021).

Ethereum also has environmental implications, but unlike Bitcoin, it is taking major steps in how it functions to reduce its carbon footprint. On September 15, 2022 Ethereum experienced an update that transitioned it from Proof-of-Work mining to Proof-of-Stake (Foundation 2021). This cuts the energy consumption of the ETH blockchain by 99.9%. Prior to this change, the network was using millions of mega watt hours per year, now it is under 3 thousand mega watt hours (*Consensus Mechanisms - Proof of Stake*).

This first chapter served as an introduction into what blockchain is, how it works, what are its advantages and potential for climate friendly change. It has also examined the most prominent cryptocurrencies, namely Bitcoin and Ethereum, providing the necessary background and context for understanding their importance and potential for helping the transition to renewable energy and reducing carbon emissions. The next chapter will focus on renewable energy for Bitcoin mining, and how mining can help renewable energy in return.

2 Renewable Energy Mining

Renewable energy sources like wind and solar have been growing rapidly in the past four years, both in terms of capacity, and consumption. According to the International Energy Agency IEA (International Energy Agency 2022), the capacity of renewable energy increased worldwide by 45% from 2018 to 2022, reaching 3,162 gigawatts GW globally (International Energy Agency 2022). Wind and solar power accounted for almost 90% of this increase, growing by 150% in four years. Data from the US Center for Climate and Energy Solutions (Center for Climate and Energy Solutions 2021) shows that in just the US, consumption of renewables is expected to grow over the next 30 years at an average annual rate of 2.4%, which is higher than the overall growth rate in energy consumption (o.5% per year). In addition, the growth of renewable energies is expected to increase even more rapidly due to recent government policies in the US and EU such as the Inflation Reduction Act IRA, and the EU Solar Energy Strategy as part of its REPowerEU plan (European Commission 2022). However, despite these positive trends, renewable energy still faces a huge challenge in competing with fossil fuels, which dominate the global energy market.

Renewable energy sources can also benefit from the integration of Bitcoin mining, which can create a new source of revenue and demand for excess or stranded power (Shan and Sun 2019). Bitcoin mining is the process of using specialized computers to solve complex mathematical problems that secure the bitcoin network and generate new bitcoins as a reward (Arcane Research 2022). BTC mining requires a lot of electricity, and therefore can have a significant environmental impact depending on the source of power used. However, if it is powered by renewable energy sources, it can reduce its carbon footprint and support the development and adoption of green energy.

This chapter investigates how renewable energy mining for bitcoin can help achieve these goals in different contexts and scenarios. First the current growth rates of renewable energy expansion and usage compared to fossil fuels will be examined. Then, how using excess energy to mine bitcoin can help reduce curtailment and fund new renewable projects. Followed by the benefits of hydroelectric mining, and how it can help disadvantaged citizens in Kenya. Finally, a discussion on how renewable energy certificates can provide verifiable evidence of being produced with green energy, and how they can be used to incentivize and reward renewable energy mining for Bitcoin.

2.1 Renewable Energy vs. Nonrenewable

Energy sourced from wind, solar, and hydro have several advantages over fossil fuels, such as lower environmental impact, higher efficiency, and lower cost in the long run (Center for Climate and Energy Solutions 2021). Despite this, sustainable energy sources still face a huge challenge in competing with coal, gas, and oil. Many argue that Bitcoin energy use is harmful to the environment and that mining uses more energy than some small countries, but they don't take into account that less than half of the energy comes from fossil fuels sources. Through examining the global capacity and consumption of renewable energy and fossil

fuels, and comparing the energy mix of Bitcoin mining, it can be shown that Bitcoin has transitioned to green energy more rapidly than the rest of the world.

There are two ways to look at the global energy capacity to compare fossil fuels and renewables. One way to measure is to look at primary energy consumption, which is the amount of energy that final consumers use from all sources. The other way to measure it is to examine the generation of electricity from all the different sources. The International Renewable Energy Agency (IRENA), has published that the generation capacity of renewable energy in 2022 reached over 3000 GW accounting for 11% of global primary energy consumption (International Renewable Energy Agency 2022). Fossil fuels on the other hand, accounted for 79% of global energy used by consumers, with a much higher generation capacity of 22,600 GW (Ritchie, Roser, and Rosado 2022).

Looking at electricity generation, renewable energy sources reached 8,300 terawatt-hours TWh globally in 2021, accounting for 29% of the energy generated around the world (Ritchie, Roser, and Rosado 2022). Yet, fossil fuels produced 17,000 TWh resulting in 62% of the world's electricity generation. In both cases fossil fuels have a much larger capacity than green energies, and despite the increased usage of solar and wind electricity, the usage of oil and gas continues to grow.

These statistics show that renewable energy sources have a long way to go before they can match or surpass the dominance of fossil fuels in the global energy market. However, Bitcoin mining can play a role in accelerating this transition by creating demand and incentives for renewable energy sources and solutions. According to various studies and estimates, Bitcoin mining is powered by a high percentage of renewable energy, ranging from 58.5% (Council 2022) to 74.1% (CoinShares 2022), making it "more renewables-driven than almost every other large-scale industry in the world" (CoinShares 2022). This is mainly due to the fact that Bitcoin miners seek out the cheapest available electricity sources, which are often hydroelectric, solar, and wind power plants in isolated regions. Compared to the global energy usage statistics, Bitcoin consumes more than double the percent of green energy than the world average (Ritchie, Roser, and Rosado 2022).

However, this does not mean that Bitcoin mining has no environmental impact or carbon footprint. As some researchers have pointed out, Bitcoin mining can also contribute to local pollution and greenhouse gas emissions by displacing other uses of renewable energy or increasing the demand for fossil fuels (Arcane Research 2022). Therefore, it is important to consider not only the percentage of renewable energy used by Bitcoin mining, but also the opportunity cost and trade-offs involved in using that energy, and how sustainable energy can be used for Bitcoin without competing with regular consumers.

2.2 Utilizing Excess Renewable Energy

According to a study done by (Adjeleian, Jurjica, and Kim 2018), Bitcoin and blockchain technology have the potential to be disruptive to the solar energy industry. Currently there are several issues plaguing the solar industry which

prevent it from being as efficient as fossil fuel energy. Because the sun only shines during the day there is often a mismatch between supply and demand, creating an excess, or over-generation of energy during the day, and an absence of solar energy available when it is dark out. During periods with over-generation of photovoltaic PV power, generators are often shut off because there are difficulties in storing the excess energy supply due to the high costs and technological difficulties of energy storage solutions. This reduction in PV power generation is what's known as curtailment (Niaz, Liu, and You 2022). The abundance of solar energy creates challenges for grid balancing and also limits the potential of renewable sun energy to meet demand during the night, not to mention that this surplus normally goes to waste due to the lack of storage capacity. However, this curtailment is necessary to prevent blackouts and electrical grid instability (Niaz, Liu, and You 2022).

Now imagine there is a way to have a steady and predictable demand for this excess of solar energy, one that can be turned on and off when necessary, a way that could transform the power into an easily storable digital asset. Research done using mathematical modeling and data from solar and wind energy farms in Texas, show that through using the surplus of green energy to mine Bitcoin, energy providers can reverse the loss in revenue from curtailment, and increase profitability and competitiveness of renewable energy projects (Niaz, Liu, and You 2022). This also benefits producers by allowing them to reduce their dependence on subsidies or contracts.

With the price of Bitcoin being projected to substantially increase this can be a very attractive solution, creating incentives and opportunities to further the green energy transition by creating a more profitable source of clean energy with all excess energy being turned into a profit instead of curtailing production. Consumers, especially those with lower income or developing countries can benefit from increased availability and reduced prices of PV power. It also doesn't negatively affect the current available supply of renewable electricity to consumers as Bitcoin mining can be turned on and off as needed. In addition, it reduces the carbon emissions of the Bitcoin mining that would have alternatively been done using fossil fuels-based power sources.

2.2.1 Co-Located Data Centers to End Curtailment

If solar energy producers want to end their curtailment, but not invest in mining equipment, there are companies like Aspen Creek Digital Corp that have created co-located data centers located at new renewable energy project sites. These crypto mining data centers are powered only from the green energy purchased from these project sites (Ashraf 2023; ACDC 2023). This helps to lower the price volatility of renewable energies and helps new renewable projects bring their energy to the grid with financial aid. Another startup called Arkon Energy (*Arkon Energy*) has a similar business plan of bringing sustainably powered data centers to the energy sources, except they focus on introducing the mining facilities to local consumers in areas where the grids are physically constrained (Shan and Sun 2019).

Physically constrained grids are power grids that cannot transfer power from one

region to another due to limitations in the structure of the network, or topology. In these localized grids balancing supply and demand of electricity can be problematic, especially with fluctuating renewable energy sources like wind and solar. Often grid operators ask generators to reduce their output or increase their consumption when they need to maintain system stability, and they pay them for doing so in what are known as constraint payments. In 2022 renewable energy generation in the United Kingdom (UK) reached an all-time high, however, during this year the UK National Grid paid 204 million pounds in constraint payments to wind farm operators alone just to have them temporarily deactivate their wind turbines (Barrett 2023). Arkon Energy solves this and would not only save the spending of grid operators around the world, but also removes the extra costs that constraint payments end up passing onto consumers. Similar to Aspen Creek Digital Corp, it helps increase the speed and viability of newer renewable energy projects, which in turn further accelerates the global renewable energy transition.

2.3 Hydroelectric Mining

Hydroelectric Bitcoin mining is the process of using electricity generated from waterpower, such as dams, rivers, or waterfalls, to power the computers that run the Bitcoin network and validate transactions (Hersman 2023). Hydroelectric power is an efficient and environmentally friendly alternative to fossil fuels, as it does not produce greenhouse gases or air pollutants, and it often produces excess amounts of energy that would otherwise be wasted if not used. It is also a renewable, clean, and abundant source of electricity that does not deplete natural resources or depend on weather conditions. By using hydroelectric energy for mining Bitcoin, miners can reduce their operational costs and environmental impact, while also contributing to the development and stability of the local energy grid.

The Cambridge Bitcoin Electricity Consumption Index estimates that if Bitcoin was mined with 100% hydro energy, then the annual carbon dioxide emissions would be reduced down to 3.13 megatons of CO_2 from the current annual estimated amount of 75.50 megatons (Alternative Finance 2021b). In addition, hydroelectricity is often one of the cheapest sources of electricity in the world due to geographically isolated locations and the difficulties of transporting energy over long distances.

There are many examples of successful hydroelectric mining projects around the world, especially in regions with abundant water resources and low electricity prices. Some of these projects use existing or abandoned hydroelectric facilities that have been repurposed for Bitcoin mining, giving them a second life and a new source of income. Some of these projects also aim to use excess or stranded power to mine Bitcoin and help provide affordable electricity to rural communities or support other economic activities.

2.3.1 Africa

Africa has a large untapped potential for hydroelectric power generation, with only 11% of its technically feasible capacity exploited (International Renewable Energy Agency 2015). Hydroelectric mining projects in Africa could help harness

this potential and increase the share of renewable energy in the continent's energy mix. Through using excess or stranded power from rivers to mine Bitcoin, affordable and reliable electricity can be provided to rural communities that lack access to the grid or face high energy costs (Khalil 2023). Not only would this reduce the price of electricity for their homes, but it creates new income opportunities.

An example of hydroelectric mining project in Africa is the Gridless Compute project in Kenya, which uses excess electricity generated by mini-hydropower plants to mine bitcoin and subsidize the cost of electricity to users in rural areas (Hersman 2023). The project has successfully powered three rural settlements and lowered their existing prices of electricity by more than 50%, benefiting 2,000 people or 500 families (Hersman 2023). New mining operations also help to secure the Bitcoin network and enhance decentralization through diversifying the geographic distribution of mining power. This project is projected to be successful and has recently raised $2 million in seed investment led by Blocks, a subsidiary of Square, the company founded by Twitter CEO Jack Dorsey (Zimwara 2021). Gridless plans to expand its operations across Africa and other regions with abundant water resources and low electricity access (Hersman 2023).

2.4 Renewable Energy Certification

Another way to promote and incentivize the usage of renewable energy for Bitcoin mining is by providing verifiable proof that the coins were created using green energy. Energy attribute certificates (EACs) are certificates that represent the environmental attributes of one megawatt hour of renewable electricity generation (Forum 2023). They can be used to verify that the electricity consumed by a blockchain network and cryptocurrency transactions come from renewable sources such as wind, solar, and hydro energy. EACs help to reduce the carbon footprint of blockchain and crypto activities by encouraging the use of clean energy for crypto mining. There are different types of EACs depending on the region or market where they are issued and traded. In North America there are Renewable Energy Certificates (RECs), in Europe they are known as Guarantees of Origin (GOs), and in emerging markets there are International Renewable Energy Certificates (I-RECs).

2.4.1 Energy Web Solutions

Energy Web (EW) is a nonprofit organization that develops and operate open-source Web3 technologies that aid companies to navigate the energy transition (Web 2021). Their vision is to unleash the potential of clean and distributed energy resources by creating a decentralized platform for the energy sector. Energy Web has created their own blockchain called the Energy Web Chain. The EW Chain is a public, proof-of-stake blockchain designed to have a low carbon footprint, high scalability, and the ability to exchange data and value across different blockchain networks and traditional IT systems (Web 2021). This blockchain is specific to the energy sector and provides the baseline for timestamped immutable data sets and the states of their smart contracts.

Energy Web has many projects using the Energy Web Chain to issue and track

energy attribute certificates. EW Zero and more recently, Green Proofs for Bitcoin are two of the projects powered by the Energy Web Chain. EW Zero is an open-source application built on the EW Chain to help individuals, businesses, or even entire blockchain ecosystems to shift towards verified zero-carbon electricity by connecting them with renewable energy projects around the world (Web 2021).

Currently, renewable energy markets and their underlying EACs are very fragmented due to the diversity of renewable energy sources, lack of harmonized definitions and standards, and numerous different tracking systems all over the world (OECD 2016). Fragmentation can reduce the efficiency and competitiveness of renewable markets and limit their potential to contribute to climate change mitigation by reducing affordability, accessibility, and reliability for consumers (Web 2020). EW Zero fixes this by providing a common platform and standard for issuing, tracking, and trading energy attribute certificates across the world. As a global search engine, it streamlines the life cycle of EACs and allows buyers to link their certificate purchases to their transactions of blockchain accounts (Web 2020). According to Energy Web, EW Zero has already enabled more than 1.6 million transactions to avoid emitting carbon dioxide and other greenhouse gases (Web 2020).

2.4.2 Green Proofs for Bitcoin

Energy Web Green Proofs use its blockchain technology to register and track low-carbon mining operations to prove that they are using renewable sources for their mining operations (Web 2021). By tokenizing the RECs, Green Proofs provides a decentralized, trustworthy mechanism for the issuance, verification, and trading of renewable energy certificates. There are 18 different projects currently using Green Proofs solutions, two of which are specific to greening the cryptocurrency mining process. They are called Proof of Green Mining, and Green Proofs for Bitcoin (Web 2021).

The Green Proofs for Bitcoin platform consists of three main components: the producer of renewable energy, the crypto miner, and the verifier. The producers use smart meters to register data about their generation of renewable electricity on the Energy Web blockchain (Web 2021). The producers also apply for a certification from an issuing body that validates its renewable energy attributes, such as its location, type, and quality of the green energy source. Issuing bodies provide digital certificates to producers, and this digital certification is recorded on the blockchain. Miners in the network use the renewable energy supplied by the producer to participate in the Bitcoin network and register their data on the EW Chain, detailing their consumption of electricity in a similar way, through using a smart meter, or a device that can measure and record electricity input.

The validity and consistency of the data and certificates recorded on the blockchain by the producer and the miner are verified by an independent third party such as an auditor, regulator, or stakeholder. They access and analyze certificates on the blockchain using the open-source software tool from Energy Web known as Green Proofs (Web 2020). They can also check to ensure the compliance of the producer and miner's sustainability claims and issue rewards or penalties based on their performance.

Through using this platform producers and miners create verifiable links between their renewable energy generation and consumption and prove their contribution to the decarbonization of Bitcoin mining (Web 2023). The Proof of Green Mining solution works in a very similar way. Miners can purchase verified renewable energy certificates from producers using EW Zero making it easier for a miner to give proof of green mining (Web 2021). In the future they hope to apply this solution across any blockchain creating certificates for miners of all types of crypto.

3 Carbon Emissions Reduction Through Bitcoin and Blockchain

There is more to environmentally friendly Bitcoin than just reducing the amount of fossil fuels used in crypto mining. The urgent need to address carbon emissions and combat climate change has led to innovative solutions in various industries. This chapter will explore the potential of harnessing Bitcoin and blockchain technologies to significantly reduce carbon emissions and contribute to a more sustainable future. Three key areas will be investigated for their high potential to significantly decrease carbon emissions globally: the recovery and use of the heat generated from Bitcoin mining, reduction of methane emissions from oil drilling through mining, and the enhancement of supply chain visibility through blockchain.

The recovery of heat from Bitcoin mining presents a unique opportunity to not only optimize energy use, but also offset the energy that would've been used for traditional heating. Blockchain enabled supply chain visibility holds immense potential for reducing greenhouse gas emissions (Harrington 2022). Blockchain based platforms enable stakeholders to gain real-time insights into the environmental impact of each of the various stages in the supply chain of a given product (U. N. E. Programme 2020).

Through an exploration and case studies into these focal areas, this chapter aims to bring to light the transformative potential of Bitcoin and blockchain technologies in the reduction of carbon emissions. If harnessed effectively, these technologies can pave the way to a more sustainable future and make a significant impact in combatting climate change.

3.1 Utilizing Heat from Mining

During the energy intensive Bitcoin mining process, a lot of the energy is transformed into heat by the mining machines. In order to prevent overheating and equipment damage, mining operations often rely on expensive cooling systems that consume substantial amounts of energy themselves. These cooling systems employ methods such as air or liquid to remove the heat from the mining equipment, but both of these methods require energy to operate things like fans and pumps. Cooling systems alone can account for up to 40% of the total energy consumption of a Bitcoin mining operation (Shilov 2021).

Heat is a form of thermal energy and can be converted into other forms of energy such as mechanical work or electricity. If the heat energy from Bitcoin mining was turned into another type of energy that could be used instead of coal or gas, not only would that help to offset the total consumption of energy and emissions, but it would also eliminate the high energy costs of cooling systems (Mellerud and Helseth 2022). To put it into numbers, Bitcoin mining emits 65.85 megatons of CO_2 annually while consuming on average 129.95 terawatt hours (TWh) of energy according to the Cambridge Center for Alternative Finance (CCAF)(Alternative Finance 2021b). If zero changes are made to the mix of energy currently being used, and all of the cooling systems were no longer

necessary, that 40% reduction in energy usage would result in a reduction of 51.98 TWh per year, and an estimated 26.34 megatons less of emitted CO_2 per year.

The following chapter subsections will delve into various practical applications that the recovered thermal energy from the Bitcoin mining process is already being effectively implemented. These real-life examples highlight the innovative methods and technologies that harness the excess heat generated during mining operations, and show the potential that these use cases have to contribute to reducing carbon emissions.

3.1.1 Heating Homes and Entire Cities

In urban areas, buildings each have an individual heating and cooling systems and currently, 75% of buildings globally are estimated to rely on fossil fuels as their energy source for heating (Ritchie and Roser 2021). However, these individual systems are not only costly and not efficient, but also significantly consume large amounts of energy, accounting for 55% of building energy consumption worldwide (Danfoss 2021). By replacing these individual systems with a shared underground network of hot and cold water pipes known as a district energy system, buildings can profit from a cheaper, more reliable heating and cooling that has higher efficiency (Danfoss 2021). District energy systems not only require less energy and emit lower levels of carbon dioxide, but can connect to renewable sources such as waste heat, effectively replacing the need for oil and gas (U. E. Programme 2019).

In the city of North Vancouver, Canada, a company that mines Bitcoin using renewable energy sources called Mintgreen (MintGreen 2021b), has partnered with the Lonsdale Energy Corporation (LEC), in a 12 year contract to provide heat to the city. Lonsdale Energy Corporation is a district energy utility owned by the City, with the goal of providing a low carbon heating solution and by partnering with Mintgreen, they will reduce greenhouse gas emissions by 90% compared to the use of natural gas (MintGreen 2021b).

Mintgreen has developed a groundbreaking technology that uses the heat produced from the Bitcoin mining process and transfers it to a water-based heating system, which they call Digital Boilers (Ashraf 2021). These Digital Boilers are able to recover 96% of electricity using in mining and transform it, providing hot water and heat for 50,000 residents (Prospero 2022). By combining energy recycling technology with district energy systems, each megawatt of renewable energy would save 1,300 tons of CO_2 emissions in the process of crypto mining and cooling systems, as well as an additional 1,800 tons of CO_2 by replacing fossil fuels with the recovered green electricity for district energy heating systems in urban areas (MintGreen 2021a). While LEC has stated that the low carbon waste heat recovery is only a small part of the corporation's total energy generation, it is still estimated that over the 12 years, it will prevent 20,000 tons of CO_2 emissions from being released into the atmosphere (Prospero 2022). This collaboration serves as a testament to the capability of recovered heat from Bitcoin mining to provide sustainable heating solutions for entire cities, significantly reducing carbon emissions and progressing the transition to renewable energy.

To demonstrate the significant potential for reducing CO_2 emissions in North

Vancouver, the following calculations were done to show the value of a citywide implementation of using waste heat for district energy. Through data extrapolation, the estimated annual energy consumption for buildings and residences in North Vancouver is approximately 742 megawatts (International Energy Agency 2022; Regulator 2021). Considering data provided by Mintgreen (MintGreen 2021b), the amount of greenhouse gasses saved by utilizing their technology for district energy and industrial processes is 3,100 tons of carbon for every 1 megawatt. Taking these two data points the predicted annual reduction in carbon emissions using 100% recovered heat energy for district energy heating systems, the Canadian city of just 146,288 residents would save 2,300,200 tons of CO_2. This is just one city for just one year, imagine if this were implemented in major cities with millions of residents. This calculation demonstrates the considerable environmental impact achievable through widespread integration of this energy system.

3.1.2 Heating Water

Another valuable application of the recovered heat from Bitcoin mining is providing hot water for homes. Water heating is a large part of residential energy consumption, and traditional methods rely on electricity from fossil fuels. By repurposing the excess heat from the mining process, a more energy efficient and sustainable water heating solution can be realized.

Immersion cooling for Bitcoin mining is more complicated and expensive, but results in higher efficiency and performance over the simpler air-to-water heat exchange (Braiins 2021). The BTC specific ASIC mining devices are submerged in a liquid that is non-conductive, meaning it can absorb the heat without completely diffusing it. Heated liquid is then pumped to a water heater tank or heat exchanger where the energy in the liquid gets transferred to water. The cooled liquid continues to circulate and the cycle begins again. This method is also better for homes as it eliminates the noise pollution of traditional mining operations because loud fans are no longer required.

A French company called Hestiia has implemented this innovative technology to create a revolutionary water boiler that is heated from computer cards that mine Bitcoin (Hestiia 2023). This allows consumers to mine their own bitcoin while also heating their household water using electricity instead of fossil fuels. While the price is expensive for a water boiler, the initial investment and electricity usage will eventually pay for itself with the mined Bitcoin. From the company's online calculator, it is estimated that a family home with 2,000 square meters and four people living there can earn over 2 Bitcoin with one Sato boiling kit containing 5 hashboards during a period of 4 years (Redman 2021). One Bitcoin is currently over 30 thousand USD, and in 2021 the price of a Sato was around 9,000 USD making it a very feasible investment of approximately 15,000 USD per year.

3.1.3 Heating Greenhouses

Global climate change is posing a serious threat to food security and water availability. Agriculture faces major consequences, therefore, finding ways to adapt and mitigate the impacts of climate change on the food supply is crucial for

maintaining food security and sustainability around the world. A potential solution is to use greenhouses for crop production. Greenhouses are structures that create a controlled environment to allow plants to grow in optimal conditions regardless of the external climate. They offer many benefits to agriculture, such as extending growing seasons, increasing crop yield and quality, reducing water consumption, and reducing the amount of carbon emitted (Huete 2020).

However, there are some drawbacks to greenhouses such as high initial investments, high electricity consumption. Maintaining a suitable temperature inside a greenhouse can be costly, especially in regions with cold winters. A more recent and innovative energy source that can be used to heat greenhouses is recycling the waste heat from Bitcoin mining. This creates a win-win situation for both crypto miners and farmers, as it removes the energy needed for cooling systems and allows farmers to reduce the costs of supplying heat, all while producing food and income. In addition, this can also have environmental benefits, as it reduces the carbon footprint of both activities and promotes local food production.

There are several examples of such projects around the world, such as a company in the Netherlands called Bitcoin Bloem, and Genesis Mining, which heats greenhouses in Northern Sweden (Nasdaq 2020; Meyer 2020). Bloem has partnered with Dutch farmers to heat greenhouses and cultivate flowers in the province of North Brabant. The company mines BTC for the farmers and pays the electricity bill, giving the cultivators free heat to grow their crops (Meyer 2020). Genesis Mining provides warmth from their data centers via a specially fitted air duct system that connects it to nearby greenhouses. This allows farmers to keep their crops at 25°C (77°F) year round, which is incredibly valuable in a region where temperatures can fall as low as -30°C (-22°F) in the winter (Nasdaq 2020).

These projects demonstrate that heating greenhouses with cryptocurrency mining is not only feasible but also beneficial for both parties involved.

3.2 Reduction of Methane Emissions

The oil and gas industry is one of the largest sources of methane emissions, accounting for about 23% of global methane emissions (GAO 2022). Due to it being one of the least reactive molecules, methane doesn't break down in the atmosphere, making it 80 times more harmful than carbon dioxide in its first 20 years in the atmosphere (GAO 2022). During oil extraction there is often excess gas that gets produced, and very frequently these oil sites lack the infrastructure to utilize it. Flaring or venting helps oil miners comply with safety or regulatory reasons, but both are just releasing large amounts of methane and CO_2 into the atmosphere, and wasting valuable energy resources that could be used for other things (W. Bank 2020).

That's where Bitcoin mining comes in, instead of venting the methane into the atmosphere, it gets funneled to an engine that provides electricity to Bitcoin data centers. This allows oil producers to significantly reduce not only their methane emissions, but also their CO_2 emissions by replacing the fossil fuels that could be

consumed by traditional crypto mining (K33 2022). According to (K33 2022), mitigating gas flaring is one of the most powerful ways to reduce greenhouse gas emissions. Per megawatt, a Bitcoin mining system using flared gas reduces 9,482 tons of CO_2 equivalent emissions, compared to 1,917 tons with wind energy, and 1,278 tons with solar (K33 2022).

There are already several ongoing projects working to utilize this wasted natural gas. Crusoe Energy is a company based in the US offering a cheap and simple alternative to flaring the gas, that can be deployed in oil fields very rapidly (Robertson 2021). They install mobile data centers at drilling sites to capture the vented gas, and they are one of the largest Bitcoin miners in North America (K33 2022). Another company, Giga Energy Solutions, deploys their equipment in East Texas. They have been so successful in using the flared natural gas to mine Bitcoin, that they pay the electricity bill for oil producers, providing them with free heat for their operations (Sigalos 2022). In Canada, Upstream Data has over 300 mobile data center units that can be transported by truck to remote locations where there is no pipeline or grid connection (Data 2021). These projects demonstrate that utilizing flared gas for Bitcoin mining is an innovative and promising solution to help reduce methane emissions from the oil and gas industry.

Despite all this, using flared gas for Bitcoin mining is not a fix all for the environmental problems caused by the oil and gas industry. While it can help oil companies reduce their emissions and profit from the gas that would otherwise be wasted, it does not discourage the use of fossil fuels. Oil drilling will still contribute to global warming and air pollution, even if it has reduced emissions. Therefore, gas flare BTC mining should be seen as temporary and transitional solution, not a permanent one. The ultimate goal should still be to phase out fossil fuels and shift to clean and renewable energy sources as soon as possible.

3.3 Supply Chain Visibility

Blockchain also enables traceability of goods in a supply chain business. It can be used to build a system that tracks the origin, movement, and quality of products from source to destination (U. N. E. Programme 2020). This can benefit producers, suppliers, vendors, and consumers by providing more information, trust, and value.

Moreover, supply chain traceability can also help reduce carbon emissions by enabling more efficient and transparent resource management, waste reduction, and optimization of a product's life cycle (Harrington 2022). By tracking the environmental impact of each product and its components, businesses can identify opportunities to improve their sustainability performance and align with their carbon reduction goals (Blockchain 2021). Traceability can also help businesses comply with environmental regulations and standards, communicate their sustainability credentials to their customers and stakeholders, and enhance their reputation and competitiveness in the market (U. N. E. Programme 2020).

As detailed in the previous chapter, Energy Web Green Proofs uses its blockchain to register and award trackable tokenized RECs, but it's not just for crypto

mining (Web 2021). Green Proofs is also available for organizations to help them to register and track their low-carbon products throughout a complex supply chain (Web 2023). This aids producers, suppliers, vendors, and even consumers to comply with environmental regulations and standards while creating new markets and opportunities for green commodities. Blockchain provides them with a transparent, immutable, and verifiable record of all transactions and data related to the origin, shipment, and quality of products along supply chains.

To better implement this technology, new policies with a clear and consistent legal framework for blockchain applications could help to develop standards, tools, and technologies that facilitate the adoption and verification of blockchain-based solutions for supply chain traceability and sustainability. They could also promote a system that no longer relies on trust, reducing information asymmetry, and increasing transparency among supply chain stakeholders, such as producers, suppliers, consumers, and regulators for a faster transition to sustainable production.

4 Regulation and the Future

As Bitcoin becomes more mainstream and influential, it also attracts more attention and scrutiny from regulators, policymakers, and stakeholders around the world. With growing institutional interest and adoption, as well as new and uncertain regulatory environment, Bitcoin faces both challenges and possibilities for further development and integration into the global financial system. This chapter examines recent regulations and trends affecting Bitcoin, as well as some of the potential scenarios and implications for its future. It also considers the relationship and future of central bank digital currencies, looking specifically into the coming digital euro.

While uncertainties lie ahead, the environmental sustainability of the digital payment systems can be improved with careful consideration, evaluation, and impact assessments by policymakers and stakeholders. Implementation of policies and practices that promote the adoption of green electricity sources and reduce CO_2 emissions of digital payment systems can mitigate the environmental risks of Bitcoin and other digital currency initiatives.

4.1 European Markets in Crypto-Assets Regulation

The Markets in Crypto-Assets Regulation MiCA was introduced by the European Union in September of 2020 to regulate the rapidly growing crypto-assets markets (Palma 2023). Going into effect in 2024, it aims to protect investors, preserve financial stability, prevent abuse of the market, and foster innovation and competitiveness in the crypto-asset sector through a harmonized regulatory framework (European Parliamentary Research Service 2022). Currently, policies and regulations regarding crypto assets either don't exist in some Member States, or are varied and not cohesive between them. The crypto industry is allowed to operate without taking into account any potential effects it has on the climate or energy industry, and users lack visibility into the potential environmental damage caused by widely used crypto-assets.

While not directly focused on protecting the environment, MiCA includes regulations that will require crypto asset firms to disclose their energy consumption and the impact of their digital assets on the environment (European Commission 2020). In addition, having enhanced and cohesive regulations will encourage the adoption of crypto assets, while also pushing for a higher percentage of renewable energy used in mining (Berger 2022).

During the approval process of the MiCA regulation, Bitcoin managed to avoid a near ban on PoW mining in the EU (Handagama 2022b). Some members of the European Parliament's Economic and Monetary Affairs Committee (ECON) offered amendments to the MiCA regulation that would prohibit the use of proof of work consensus protocols in Europe, or at least impose strict limits on their energy consumption (Handagama 2022a). This provision was heavily criticized due to being too radical and disproportionate because it would affect a vast number of crypto-assets and their users because they rely on proof of work for security and to remain decentralized (Handagama 2022b).

To improve the sustainability of crypto assets in the EU, incentives or subsidies should be offered for using renewable energy sources or reducing emissions, which the current MiCA regulation does not include (Berger 2022). This approach would help prevent migration of miners and crypto-asset companies to countries with less strict environmental regulations and aid Europe in its transition away from fossil fuels.

4.2 The Future of Bitcoin

Bitcoin, as the first and most valuable cryptocurrency has faced many challenges and uncertainties since its inception in 2009. Despite this, it has demonstrated remarkable resilience and innovation, attracting millions of users and investors worldwide. While the future of Bitcoin cannot be known with certainty, there are many indications that suggest its continued growth and relevance in the global economy.

Because Bitcoin is a global asset that transcends national borders and jurisdictions, it offers a universal and accessible way of storing and transferring value, particularly for individuals without access to traditional financial services or in regions experiencing political and economic instability. It serves as a deflationary asset, providing stability for citizens in countries grappling with rapid and substantial levels of inflation, preserving the value of their hard-earned money. Bitcoin is easily portable, allowing millions of dollars to fit easily in a pocket and be transported anywhere, or sent across the world quickly and easily. As more countries and regions embrace Bitcoin as a legitimate and useful asset, it could foster more trade, commerce and cooperation among diverse and distant communities as 1 BTC equals 1 BTC everywhere.

BTC has gained increasing recognition and acceptance by institutional investors, such as hedge funds, pension funds, and corporations. In June of 2023, a very significant application for a Bitcoin Exchange Traded Fund (ETF) was done by BlackRock, the world's largest asset manager and leader of the US ETF market (Reuters Staff 2023). In the past, the US Securities and Exchange Commission (SEC) has rejected every attempt to create a Bitcoin tracking ETF. This kind of investment allows investors to participate in BTC without buying it themselves and having to deal with the risks of custody, storage, and security. If approved, this would attract billions of dollars into the Bitcoin market, potentially reshaping its future and boosting its legitimacy. Just the news about application alone has already boosted the price of BTC to a one year high, and many other BTC ETF applications have since been filed (Katzeff 2023).

Institutional entities are seeing Bitcoin now as a valuable addition to their portfolios, offering diversification, hedging, appreciation and innovation potential (Kabaklarlı 2022). This type of adoption will boost the liquidity, stability and maturity of the Bitcoin market, as well as increase its exposure and influence among mainstream audiences.

The United States is one of the biggest and most influential markets for Bitcoin, both in terms of demand, and regulation. In the recent years, the US has seen a surge in adoption of Bitcoin by retail investors and institutions. This has been due

to factors such as inflation fears, digitalization trends, and financial inclusion. The US government and regulators have also shown a more open and supportive stance towards Bitcoin and other cryptocurrencies, recognizing potential benefits and challenges, and providing more clarity and guidance for its legal and tax treatment (OSTP 2022).

Although very recently, President Biden has proposed a new tax on crypto mining called the Digital Asset Mining Energy (DAME) tax. This proposal, set to begin in January of 2024, would charge up to 30% in taxes on the electricity costs incurred by mining operations in the US (Torpey 2023). Biden cites environmental concerns surrounding crypto mining as the reason behind this tax, but fails to acknowledge that a majority of mining relies on renewable energy sources, and claims that if that were the case, it would still be diverting green electricity away from consumers. As other major crypto currencies have transitioned to PoS, this proposal would mainly affect Bitcoin, but as this research shows, it's the amount of energy needed for mining that helps increase capacity and funding of renewable energy production.

As the 2024 halvening event approaches, it is expected that the price of Bitcoin will increase dramatically. This price surge will heighten its popularity and the number of those aspiring to successfully partake in the mining operations. Because mining can be done anywhere, miners will go to the cheapest sources of electricity. If governments want to lower greenhouse gas emissions, policies should be made to incentivize miners to set up operations in areas with high levels of renewable energy generation.

Policy changes that could facilitate renewable energy Bitcoin mining may include providing incentives or subsidies for miners using renewable energy sources, the establishment of standards or certifications for verifying the origin and type of energy used by miners, creation or utilization of regional or global platforms for trading renewable energy credits or certificates among miners and energy producers such as Green Proofs, and developing regulations that balance the environmental, economic, and social impacts of Bitcoin mining.

4.3 The Future of Centralized Digital Currency

As the world is racing towards financial digitalization, digital currencies are becoming more prevalent and prominent in various forms and functions. In addition to decentralized cryptocurrencies like Bitcoin, there are efforts to create centralized or hybrid digital currencies that are issued or backed by governments or central banks. These are known as central bank digital currencies (CBDCs) or sovereign digital currencies (SDCs), and aim to provide a digital alternative to cash or bank deposits that can be used for payments or savings.

One of the most advanced examples of CBDCs is the digital yuan or e-CNY, which has been developed by the PBOC since 2014 (Wong 2022). The digital yuan is intended to be a legal tender that coexists with physical cash and bank deposits, but offers more convenience, efficiency, security, and inclusiveness for users. The digital yuan is also designed to impose China's monetary policy objectives, financial stability goals, cross-border payments integration, and digital

economy development (Broby 2021). However, some analysts have also raised concerns about the potential implications of the digital yuan for privacy rights, data security, financial surveillance, geopolitical influence, and global monetary order (Broby 2021).

While many countries are researching their own central bank digital currency, the potential environmental impacts of CBDCs are not well understood or studied, as most are still in the design or pilot stage (Masterson 2022). In addition, CBDCs could also pose challenges to the environmental sustainability of payment systems by creating new sources of risks and externalities that need to be identified, measured, monitored, and mitigated. For example, depending on the scale and scope of CBDC adoption and usage, they could have a positive or negative impact on the environment by reducing or increasing the demand for physical cash, bank branches, ATMs, or energy-intensive cryptocurrencies (Sahay et al. 2021).

Therefore, the environmental impacts of central bank digital currencies are not predetermined or inevitable, but depend on choices and trade-offs that need to be carefully considered and evaluated by policymakers and stakeholders. CBDCs can also offer an opportunity to improve the environmental sustainability of the payment system by leveraging digital technologies and innovations in their development that reduce energy consumption.

4.3.1 Digital Euro and Others

The digital euro project is a CBDC currently being investigated by the European Central Bank (ECB) since October 2020 (E. C. Bank 2021). The digital euro would be a digital form of central bank money that would offer greater choice to consumers and businesses in situations where physical cash cannot be used. It would complement cash, not replace it, and would be accessible, robust, safe, efficient and compliant with the law. The digital euro would also support the EU's digital finance and consumer payment strategies, as well as strengthen the monetary sovereignty of the euro area and foster competition and innovation in the European economy (E. C. Bank 2021).

Other examples of CBDC or SDCs that are being developed by various countries include the digital dollar in the US, the e-krona in Sweden, the sand dollar in the Bahamas, the e-hryvnia in Ukraine, and the e-CFA franc in West Africa (Masterson 2022). Each of these projects has its own objectives, challenges, opportunities and implications for their respective economies and societies. The emergence of these digital currencies could have significant effects on the global financial system (Masterson 2022). But even the best designed digital currency cannot force citizens to use it if they don't want the government controlling their money. Therefore, the success and adoption of digital currencies will depend not only on their technical features and policy frameworks, but also on their social acceptance and trust among the public.

The relationships between BTC and central bank digital currencies are complex and uncertain. Bitcoin appeals to users who value its decentralization, censorship-resistance, transparency, scarcity, and global reach. On one hand, they could be seen as complementary assets that offer different benefits and use cases to different users and markets. On the other hand, they could be seen as

competing assets that vie for market share and adoption among consumers, businesses, and governments. Bitcoin could challenge the monopoly and sovereignty of central banks over money creation and monetary policy, and potentially reduce the demand for fiat currencies and weaken their exchange rates (Sephton 2020).

The environmental impact of Bitcoin mining could be significantly worse than that of central bank digital currencies if no changes are made to the energy mix. However, BTC technology has demonstrated its potential to contribute to green energy projects, and effective lowering of carbon emissions. Moreover, the Bitcoin industry is leading the transition to 100% renewable energy usage at a faster pace compared to any other global industry (CoinShares 2022; Web et al. 2021).

As Bitcoin continues to evolve and regulators explore the future of digital currencies, it is important to consider their environmental impact and sustainability. Regulatory frameworks should strive to incentivize the use of renewable energy sources and reduce the carbon footprint associated with digital payment systems. This approach requires collaboration among policymakers, stakeholders, and industry participants. Through harnessing technology, innovation, and proper regulation, digital currencies, including Bitcoin and central bank digital currencies, can contribute to a greener and more sustainable financial future.

5 Conclusion

This thesis has explored the potential for Bitcoin to support the transition to renewable energy sources and reduce carbon emissions. Bitcoin is a revolutionary decentralized currency that offers a global, freely available, censorship resistant, and human rights preserving technology that runs on the blockchain network.

Applications such as using recovered waste energy to provide heat for entire cities and greenhouses, digitalization and transparency of supply chains, and renewable energy certificates have demonstrated the potential for Bitcoin to not only support renewable energy, but also contribute to the circular economy, resource efficiency, and elimination of CO_2 emissions.

One of the most promising areas where Bitcoin could have a positive impact is the transition to renewable energy. By providing a steady and profitable demand for underutilized or discarded energy sources such as excess solar or wind power, BTC mining can accelerate otherwise expensive but innovative renewable developments. Projects as solar farms in remote areas or wind turbines on floating platforms are more feasible with Bitcoin providing a storage of value for the excess energy and removing the need for curtailments (Masterson 2022). Furthermore, it improves energy affordability by lowering the cost of electricity for consumers and producers.

Bitcoin is driving the adoption and innovation of renewable energy sources, while renewable energy is providing a clean and abundant supply of electricity for Bitcoin mining. Together, they can create a cycle that benefits both the environment and the economy. Bitcoin is not only a revolutionary monetary technology, but also a powerful tool for social and environmental change. However, this potential is not without challenges and limitations, such as regulatory uncertainty and public perception. These issues need to be addressed and resolved in order to achieve wider adoption and acceptance of Bitcoin as a legitimate and beneficial form of money.

Policy changes that can be made to ensure renewable energy mining would be requiring things like verifiable energy certificates, and better integration of data centers to sustainable energy producers to avoid energy curtailment and curtailment payments. This will not only ensure the environmental and social benefits of Bitcoin mining, but also the economic and competitive advantages of the renewable energy sector. Moreover, incentives and subsidies for green mining and innovations, such as technologies that utilize mining heat energy or increase the efficiency of cooling systems can further accelerate the transition to a low-carbon economy.

Through implementing these policy changes, governments can encourage the adoption of clean and sustainable energy sources for Bitcoin mining and reduce the carbon footprint of the crypto industry. This would not only benefit the planet, but also Bitcoin miners, who would enjoy lower energy costs and higher profits, while increasing the security and resilience of the Bitcoin network. Therefore, renewable energy for Bitcoin mining is a win-win situation for all stakeholders involved, and a promising opportunity for the future of Bitcoin and the planet.

In conclusion, this thesis has demonstrated that Bitcoin is here to stay, and that it has a significant role to play in supporting renewable energy and reducing carbon emissions. However, this potential requires proper regulation, technological advancements, industry collaboration, public trust, and further research to overcome the challenges and limitations that Bitcoin faces. All in all, Bitcoin is not only a groundbreaking monetary technology, but also a catalyst for environmental and social progress.

References

ACDC. 2023. *Aspen Creek Digital Corporation,* February. https://acdigitalcorp.com/.

Adjeleian, Adrienne, Oana Jurjica, and Henry Kim. 2018. "Breaking the stagnant spell: How blockchain is disrupting the solar energy industry." *SSRN Electronic Journal,* https://doi.org/10.2139/ssrn.3207104.

Akin Gump Strauss Hauer & Feld LLP - EU Close to Introducing Groundbreaking Law to Regulate Crypto. https://www.akingump.com/en/insights/alerts/eu-close-to-introducing-groundbreaking-law-to-regulate-crypto.

Ali, R., A. Mikołajewicz-Woźniak, C. Beer, S. Nakamoto, A. Zohar, A. M. Antonopoulos, F. Tschorsch, et al. 2017. "Sustainability of Bitcoin and Blockchains." *Current Opinion in Environmental Sustainability* (May 29, 2017). Accessed March 21, 2023. https://www.sciencedirect.com/science/article/abs/pii/S1877343517300015.

Alshahrani, H., N. Islam, D. Syed, A. Sulaiman, M. S. Al Reshan, K. Rajab, A. Shaikh, J. Shuja-Uddin, and A. Soomro. 2023. "Sustainability in Blockchain: A Systematic Literature Review on Scalability and Power Consumption Issues." *MDPI,* https://www.mdpi.com/1996-1073/16/3/1510.

Alternative Finance, Cambridge Centre for. 2021a. "3rd Global Cryptoasset Benchmarking Study." https://www.jbs.cam.ac.uk/wp-content/uploads/2021/09/2021-ccaf-3rd-global-cryptoasset-benchmarking-study.pdf.

———. 2021b. *Cambridge Bitcoin Electricity Consumption Index.* Cambridge Centre for Alternative Finance. https://ccaf.io/cbnsi/cbeci.

Antolin, Mike. 2023. *What Is Proof-of-Authority?* https://www.coindesk.com/learn/what-is-proof-of-authority/. Accessed: 2023-07-03.

Arcane Research. 2022. "How Bitcoin Mining Can Transform the Energy Industry." Arcane Research, September 1, 2022. Accessed December 12, 2022. https://arcane.no/research/reports/how-bitcoin-mining-can-transform-the-energy-industry.

Arkon Energy. https://www.arkonenergy.com/. Accessed: July 18, 2023.

Ashraf, Aoyon. 2021. *Canadian Bitcoin Miner MintGreen to Heat City of North Vancouver,* October. https://www.coindesk.com/business/2021/10/14/canadian-bitcoin-miner-mintgreen-to-heat-city-of-north-vancouver/.

———. 2023. *Solar-powered bitcoin miner starts operations despite difficult market,* May. https://www.coindesk.com/business/2022/06/23/new-solar-powered-bitcoin-miner-launches-operations-despite-difficult-market/.

Axi. 2023. *What is Bitcoin Halving & How Does it Affect its Price?* https://www.axi.com/int/blog/education/blockchain/bitcoin-halving.

Bai, Chunguang, Patrick Dallasega, Guido Orzes, and Joseph Sarkis. 2020. "Industry 4.0 technologies assessment: A sustainability perspective." *International Journal of Production Economics* 229:107776. ISSN: 0925-5273. https://doi.org/https://doi.org/10.1016/j.ijpe.2020.107776. https://www.sciencedirect.com/science/article/pii/S0925527320301559.

Bank, European Central. 2021. *Digital euro.* https://www.ecb.europa.eu/paym/digital_euro/html/index.en.html.

Bank, World. 2020. *Gas Flaring Explained.* https://www.worldbank.org/en/programs/gasflaringreduction/gas-flaring-explained.

Barrett, Christopher. 2023. *When the wind blows: The terrible truth about constraint payment,* February. %5Curl%7Bhttps://accessaa.co.uk/when-the-wind-blows-the-terrible-truth-about-constraint-payment/%7D.

BÂTCĂ-DUMITRU, A.-M. I. R. I. M. E. S. C. U., and C.-G. 2022. "The Role of Cryptocurrency in the Sustainable Development of Businesses." *CECCAR Business Review* (January 1, 2022). Accessed March 21, 2023. https://ideas.repec.org/a/ahd/journl/v3y2022i10p9-13.html.

Beck, Benjamin, Jasmine Carolin Schimke, Marcel Hörauf, Dr. Patrick Scholl, and Svenja Schenk. 2022. *EU markets in crypto-assets (MICA) regulation expected to enter into force in early 2023,* December. https://www.lexology.com/library/detail.aspx?g=e8a26ed1-0513-411b-80c8-a8a7f14ee7fb.

Bendiksen, Christopher, and Samuel Gibbons. 2021. "The Bitcoin Mining Network - Trends, Marginal Creation Cost, Electricity Consumption & Sources." https://coinshares.com/assets/resources/Research/bitcoin-mining-network-june-2021.pdf.

Berger, Stefan. 2022. *Report on the proposal for a regulation of the European Parliament and of the Council on markets in crypto-assets and amending directive (EU) 2019/1937: A9-0052/2022: European Parliament.* https://www.europarl.europa.eu/doceo/document/A-9-2022-0052_EN.html#_ftn1.

"Bitcoin is Key to an Abundant, Clean Energy Future." n.d. Bitcoin Clean Energy Initiative. Accessed December 12, 2022. https://assets.ctfassets.net/2d5q1td6cyxq/5mRjc9X5LTXFFihIlTt7QK/e7bcba47217b60423a01a357e036105e/BCEI_White_Paper.pdf.

"Bitcoin Wiki." n.d. Accessed January 10, 2023. https://en.bitcoin.it/wiki/Main_Page.

Bitcoin?, What Is. 2019. *Mining Bitcoin with Flared Gas,* April. https://www.whatisbitcoin.com/mining/mining-bitcoin-with-flared-gas.

Blockchain, IMI. 2021. "Advantages of Blockchain Technology (Top 7 Benefits 2021)." Accessed June 30, 2023. https://imiblockchain.com/advantages-of-blockchain/.

Bosch Sarquella, M. 2022. "Bitcoin Mining, the Clean Energy Accelerator." Pàgina inicial de UPCommons, December 13, 2022. Accessed March 21, 2023. https://upcommons.upc.edu/handle/2117/377967.

Boudette, Neal E. 2021. "Tesla stops accepting Bitcoin as payment for its cars." *The New York Times,* https://www.nytimes.com/2021/05/12/automobiles/tesla-bitcoin.html.

Braiins. 2021. "Green Innovation in Bitcoin Mining: Recycling ASIC Heat." Braiins, February 25, 2021. Accessed December 12, 2022. https://braiins.com/blog/green-innovation-in-bitcoin-mining-recycling-asic-heat.

Broby, Daniel. 2021. "China's digital currency could be the future of money – but does it threaten global stability?" *The Conversation* (May). https://theconversation.com/chinas-digital-currency-could-be-the-future-of-money-but-does-it-threaten-global-stability-160560.

Catalini, Christian, and Jai Massari. 2021. "Stablecoins and the Future of Money." *Harvard Business Review* (August). https://hbr.org/2021/08/stablecoins-and-the-future-of-money.

Center for Climate and Energy Solutions. 2021. *Renewable Energy.* https://www.c2es.org/content/renewable-energy/. Accessed: 2023-06-11.

CoinDesk. 2021. *People Are Mining Bitcoin to Heat Their Homes.* Accessed: 2023-07-01. https://www.coindesk.com/markets/2021/03/01/mining-bitcoin-for-heat-strawberries-and-chickens/.

CoinShares. 2022. *The Bitcoin Mining Network - Trends, Marginal Creation Cost, Electricity Consumption & Sources.* Accessed January 15, 2023. https://a.storyblok.com/f/155294/x/0c3f3837c8/coinshares_bitcoin_mining_report_jan_2022.pdf.

EU postpones final vote on MICA for the second time in two months. https://cointelegraph.com/news/eu-postpones-final-vote-on-mica-for-the-second-time-in-two-months.

Commission, European. 2021. *Digital euro.* https://finance.ec.europa.eu/digital-finance/digital-euro_en. Accessed: 2022-01-29.

Compass. 2021. *These are creative ways to repurpose heat from bitcoin mining.* Accessed: 2023-07-01. https://compassmining.io/education/repurposed-bitcoin-mining-heat-farming-water-whiskey/.

Conrad, Jennifer. 2022. "China's Digital Yuan Works Just Like Cash—With Added Surveillance." *WIRED* (November). https://www.wired.com/story/chinas-digital-yuan-ecny-works-just-like-cash-surveillance/.

Conway, Luke. 2023. *What is bitcoin halving? definition, how it works, Why it matters,* June. https://www.investopedia.com/bitcoin-halving-4843769.

Council, Bitcoin Mining. 2022. "Bitcoin Mining Council Survey Confirms Year-on-Year Improvements in Sustainable Power Mix and Technological Efficiency in Q4 2022." *Bitcoin Mining Council,* https://bitcoinminingcouncil.com/bitcoin-mining-council-survey-confirms-year-on-year-improvements-in-sustainable-power-mix-and-technological-efficiency-in-q4-2022/.

Danfoss. 2021. *What is District Energy? See how it works and how it can help us decarbonize heating and cooling.* https://www.danfoss.com/en/about-danfoss/insights-for-tomorrow/integrated-energy-systems/district-energy/.

Data, Upstream. 2021. *Upstream Data Blog.* https://blog.upstreamdata.ca/.

EU Vote on MICA Regulation. 2023, April. https://dig.watch/updates/eu-vote-on-mica-regulation#:~:text=Parliament%20voted%20by%20517%20in,cryptoassets%20such%20as%20bitcoin%20cryptocurrency.

Consensus Mechanisms - Proof of Stake. https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/.

Eugenio, Martinez-Cruz Carlos. 2022. "Are El Salvador's Volcanoes Being Harnessed to Power Bitcoin Mining?" In *2022 IEEE 40th Central America and Panama Convention (CONCAPAN).* https://doi.org/10.1109/concapan48024.2022.9997792.

European Commission. 2020. *Proposal for a Regulation of the European Parliament and of the Council on Markets in Crypto-assets, and amending Directive (EU) 2019/1937.* COM(2020) 593 final. OJ C 66, 26.2.2021, p. 8, September.

———. 2022. *Solar energy to repower Europe.* https://ec.europa.eu/energy/sites/default/files/eu_solar_energy_strategy.pdf. Accessed: 2023-06-11.

European Parliamentary Research Service. 2022. *Markets in crypto-assets (MiCA) and pilot regime for market infrastructures based on distributed ledger technology (DLT).* Briefing EU Legislation in Progress, PE 739.221, January. https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/739221/EPRS_BRI(2022)739221_EN.pdf.

Fortis, S. 2022. "Bitcoin Mining Project in Kenya Helps Power Rural Community." *Cointelegraph* (December 9, 2022). Accessed December 12, 2022. https://cointelegraph.com/news/bitcoin-mining-project-in-kenya-helps-power-rural-community.

Fortis, Savannah. 2021. "Bitcoin mining project in Kenya helps power rural community." Accessed January 15, 2023. https://cointelegraph.com/news/bitcoin-mining-project-in-kenya-helps-power-rural-community.

Forum, World Economic. 2023. *Guidelines for Improving Blockchain's Environmental, Social and Economic Impact.* Technical report. World Economic Forum, April. https://www3.weforum.org/docs/WEF_Guidelines_for_Improving_Blockchain%E2%80%99s_Environmental_Social_and_Economic_Impact_2023.pdf.

Foundation, Ethereum. 2021. *What is Ethereum?* Accessed: 2023-06-30. https://ethereum.org/en/what-is-ethereum/.

Frankenfield, Jake. 2023. *Cryptocurrency Explained with Pros and Cons for Investment,* February. https://www.investopedia.com/terms/c/cryptocurrency.asp.

GAO. 2022. *Oil and Gas: Federal Actions Needed to Address Methane Emissions from Oil and Gas Development on Federal Lands,* April. https://www.gao.gov/products/gao-22-104759.

Gundaboina, L., S. Badotra, T. K. Bhatia, K. Sharma, G. Mehmood, M. Fayaz, and I. U. Khan. 2022. "Mining Cryptocurrency-Based Security Using Renewable Energy as Source." *Security and Communication Networks,* https://www.hindawi.com/journals/scn/2022/4808703/.

Gundaboina, Lokesh, Sumit Badotra, Sarvesh Tanwar, and Manik. 2022. "Reducing Resource and Energy Consumption in Cryptocurrency Mining by using both Proof-of-Stake Algorithm and Renewable Energy." In *2022 International Mobile and Embedded Technology Conference (MECON),* 605–610. https://doi.org/10.1109/MECON53876.2022.9752365.

Handagama, Sandali. 2022a. *MICA could still be delayed by EU parliamentarians over proof-of-work provision,* March. https://www.coindesk.com/policy/2022/03/23/mica-could-still-be-delayed-by-eu-parliamentarians-over-proof-of-work-provision/.

———. 2022b. *Proposal Limiting Proof-of-Work is Rejected in EU Parliament Committee Vote,* March. https://www.coindesk.com/policy/2022/03/14/proposal-limiting-proof-of-work-is-rejected-in-eu-parliament-committee-vote-sources/.

Harrington, E. 2022. "ServiceNow brandvoice: Could Blockchain Be Sustainability's Missing Link?" Forbes, April 11, 2022. Accessed January 11, 2023. https://www-forbes-com.cdn.ampproject.org/c/s/www.forbes.com/sites/servicenow/2022/04/08/could-blockchain-be-sustainabilitys-missing-link/amp/.

Hart, Robert. 2021. "El Salvador Makes History As World's First Country To Make Bitcoin Legal Tender." *Forbes* (June). https://www.forbes.com/sites/roberthart/2021/06/09/el-salvador-makes-history-as-worlds-first-country-to-make-bitcoin-legal-tender/?sh=5313aaa7eaa3.

Hersman, Erik. 2023. "A Blueprint for Bitcoin Mining and Energy in Africa." Accessed January 15, 2023. https://gridlesscompute.com/2023/05/17/a-blueprint-for-bitcoin-mining-and-energy-in-africa/.

Hertig, Alyssa. 2023. *What Is Proof of Work?,* January. https://www.coindesk.com/learn/what-is-proof-of-work/.

Hestiia. 2023. *The incredible story of our water heater SATO.* Accessed: 2023-07-01. https://hestiia.com/en/blog/the-incredible-story-of-our-water-heater-sato.

Hodl, J. 2022a. "Bitcoin Is an Energy Solution, Not an Energy Problem." What Is Bitcoin?, November 15, 2022. Accessed January 11, 2023. https://www.whatisbitcoin.com/mining/bitcoin-is-an-energy-solution-not-an-energy-problem.

———. 2022b. "Using Surplus Heat from Bitcoin Mining." What Is Bitcoin?, November 15, 2022. Accessed January 11, 2023. https://www.whatisbitcoin.com/mining/using-surplus-heat-from-bitcoin-mining.

Hosseini, Seyed Ehsan, and Hesam Kamyab. 2022. "Sustainable Energy and digital currencies: Challenges and future Prospect." *Future Technology* 1 (1): 26–32. https://doi.org/10.55670/fpll.futech.1.1.4.

Howson, Peter. 2019. "Tackling climate change with Blockchain." *Nature Climate Change* 9 (9): 644–645. https://doi.org/10.1038/s41558-019-0567-9.

Huang, Jon, Claire O'Neill, and Hiroko Tabuchi. 2021. "Bitcoin Uses More Electricity Than Many Countries. How Is That Possible?" *The New York Times,* https://www.nytimes.com/interactive/2021/09/03/climate/bitcoin-carbon-footprint-electricity.html.

Huete, J. 2020. *Advantages of a greenhouse,* May. https://jhuete.com/advantages-greenhouse/.

MICA Regulation: The EU Parliament's Position on Proof-of-Work Mechanism. https://www.gtlaw.com/en/insights/2022/7/mica-regulation-the-eu-parliaments-position-on-proof-of-work-mechanism.

Intergovernmental Panel on Climate Change. 2023. *Climate Change 2023: Synthesis Report.* Edited by Hoesung Lee et al. In press. Cambridge, UK and New York, NY, USA: Cambridge University Press.

International Energy Agency. 2022. *Renewables 2022.* https://www.iea.org/reports/renewables-2022. Accessed: 2023-06-11.

International Renewable Energy Agency. 2015. *Africa 2030: Roadmap for a Renewable Energy Future.* Accessed January 15, 2023. https://www.irena.org/publications/2015/Oct/Africa-2030-Roadmap-for-a-Renewable-Energy-Future.

———. 2022. *Renewable Capacity Statistics 2022.* Technical report. Accessed: 2023-06-11. IRENA. https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022.

Investopedia. 2023. "Non-Fungible Token (NFT): What It Means and How It Works," April. https://www.investopedia.com/non-fungible-tokens-nft-5115211.

K33. 2022. *Bitcoin mining using stranded natural gas is the most cost-effective way to reduce flaring.* https://k33.com/research/archive/articles/bitcoin-mining-using-stranded-natural-gas-is-the-most-cost-effective-way-to.

Kabaklarlı, E. 2022. "Green Fintech: Sustainability of Bitcoin." *Digital Finance* 4 (4): 265–273. https://doi.org/10.1007/s42521-022-00053-x.

Katzeff, Paul. 2023. "BlackRock's Bitcoin ETF: What You Need To Know." Accessed July 7, 2023. https://www.forbes.com/advisor/investing/cryptocurrency/spot-bitcoin-etf/.

Khalil, Abubakar Nur. 2023. "Africans Are Pioneering The Bright, Yet Complicated, Green Future Of Bitcoin Mining." Accessed January 15, 2023. https://www.forbes.com/sites/abubakarnurkhalil/2023/05/24/africans-are-pioneering-the-bright-yet-complicated-green-future-of-bitcoin-mining/.

Kraken. 2021. *The Lightning Network: What is it and what are the challenges?,* August. https://www.kraken.com/learn/what-is-the-lightning-network.

Liang, Yingqi, Can Berk Saner, Bryan Min Kwang Lim, Kai Tseng Hong, Jeffrey Wei Chong Lim, Keeve Juin Hwee Ho, Li Zheng Lim, and Yun Ying Loh. 2022. "Sustainable Energy-based Cryptocurrency Mining." In *2022 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia),* 789–793. https://doi.org/10.1109/ISGTAsia54193.2022.10003517.

Liu, Xiaohui. 2021. "Bitcoin vs Ethereum smart contracts." *CoinGeek,* https://coingeek.com/bitcoin-vs-ethereum-smart-contracts/.

Lyn Alden. 2023. "Bitcoin's Energy Usage Isn't a Problem. Here's Why." Lyn Alden, January 5, 2023. Accessed January 11, 2023. https://www.lynalden.com/bitcoin-energy/.

Masterson, Victoria. 2022. "What are central bank digital currencies?" World Economic Forum. Accessed June 11, 2023. https://www.weforum.org/agenda/2022/08/what-are-central-bank-digital-currencies/.

Mayer Brown. 2022. *MICA Regulation: The EU Parliament's Position on Proof-of-Work Mechanism,* July. https://www.mayerbrown.com/en/perspectives-events/publications/2022/7/mica-regulation-the-eu-parliaments-position-on-proof-of-work-mechanism.

McDonald, M. T., K. S. Hayibo, F. Hafting, and J. M. Pearce. 2022. "Economics of Open-Source Solar Photovoltaic Powered Cryptocurrency Mining." SSRN, September 15, 2022. Accessed March 21, 2023. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4205879.

Mellerud, J., and A. Helseth. 2022. "Repurposing Waste Heat from Bitcoin Mining Can Lower Heating Costs and Mitigate Emissions." Arcane Research, September 19, 2022. Accessed December 12, 2022. https://arcane.no/research/repurposing-waste-heat-from-bitcoin-mining-can-lower-heating-costs-and.

Mengelkamp, Esther, Johannes Gärttner, Kerstin Rock, Scott Kessler, Lawrence Orsini, and Christof Weinhardt. 2018. "Designing microgrid energy markets: A case study: The Brooklyn Microgrid." *Applied Energy* 210:870–880. https://doi.org/10.1016/j.apenergy.2017.06.054.

Meyer, Christoph. 2020. *Bitcoin Miner Used to Heat a Greenhouse in Netherlands,* May. https://www.btctimes.com/news/bitcoin-miner-used-to-heat-a-greenhouse-in-netherlands.

MintGreen. 2021a. *MintGreen.* https://mintgreen.co/.

———. 2021b. "North Vancouver to be World's First City heated by Bitcoin." *PR Newswire* (October). https://www.prnewswire.com/news-releases/north-vancouver-to-be-worlds-first-city-heated-by-bitcoin-301400596.html.

Miśkiewicz, R., K. Matan, and J. Karnowski. 2022. "The Role of Crypto Trading in the Economy, Renewable Energy Consumption and Ecological Degradation." *MDPI* (May 22, 2022). Accessed March 21, 2023. https://www.mdpi.com/1996-1073/15/10/3805.

Here Are Six New Projects Looking to Mitigate Bitcoin Mining's Energy Footprint. https://www.msn.com/en-us/money/other/here-are-six-new-projects-looking-to-mitigate-bitcoin-mining-s-energy-footprint/ar-AA1ac0cs.

Mustafa, Fairouz, Suman Lodh, Monomita Nandy, and Vikas Kumar. 2021. "Coupling of Cryptocurrency Trading with the Sustainable Environmental Goals: Is It on the Cards?" *Business Strategy and the Environment* 31 (3): 1152–1168. https://doi.org/10.1002/bse.2947.

Nakamoto, Satoshi. 2008. *Open source P2P money.* https://bitcoin.org/bitcoin.pdf.

Napoletano, E. 2023. *Proof of Work Explained,* February. https://www.forbes.com/advisor/investing/cryptocurrency/proof-of-work/.

Nasdaq. 2020. *How Heat From Crypto Mining Farms Could Be Recycled Into Energy for Greenhouses,* December. https://www.nasdaq.com/articles/how-heat-from-crypto-mining-farms-could-be-recycled-into-energy-for-greenhouses-2020-12-23.

Niaz, H., M. H. Shams, J. J. Liu, and F. You. 2022. "Mining Bitcoins with Carbon Capture and Renewable Energy for Carbon Neutrality across States in the USA." *Energy & Environmental Science* 15 (9): 3551–3570. https://doi.org/10.1039/d1ee03804d.

Niaz, Haider, Jay J. Liu, and Fengqi You. 2022. "Can Texas mitigate wind and solar curtailments by leveraging bitcoin mining?" *Journal of Cleaner Production* 364:132700. https://doi.org/10.1016/j.jclepro.2022.132700.

OECD. 2016. *Fragmentation in clean energy investment and financing.* OECD Business and Finance Outlook 2016. Accessed: 2023-07-05. https://www.oecd.org/daf/inv/investment-policy/BFO-2016-Ch5-Green-Energy.pdf.

Orban, Milan. 2022. *Stand for Financial Freedom: Our Position on MICA's Proof of Work Ban,* March. https://www.ledger.com/blog-stand-for-financial-freedom-our-position-on-micas-proof-of-work-ban.

OSTP. 2022. *Climate and Energy Implications of Crypto-Assets in the United States.* White House Office of Science and Technology Policy, Washington, D.C., September.

Palma, Federico Di. 2023. *An Overview of the EU Crypto-Asset Regulatory Framework (MICA),* February. https://news.law.fordham.edu/jcfl/2023/02/06/an-overview-of-the-eu-crypto-asset-regulatory-framework-mica/.

Parmentola, Adele, Antonella Petrillo, Ilaria Tutore, and Fabio De Felice. 2021. "Is Blockchain Able to Enhance Environmental Sustainability? A Systematic Review and Research Agenda from the Perspective of Sustainable Development Goals (SDGs)." *Business Strategy and the Environment* 31 (1): 194–217. https://doi.org/10.1002/bse.2882.

Person. 2022. "Why Is Cryptocurrency Important? How Is It Revolutionizing the World?" Worldcoin, December 14, 2022. Accessed January 10, 2023. https://worldcoin.org/articles/why-is-cryptocurrency-important.

Pinkerton, Julie, and Aaron Davis. 2023. "The History of Bitcoin, the First Cryptocurrency," May. https://money.usnews.com/investing/articles/the-history-of-bitcoin.

Pirus, Benjamin. 2021. "Crypto Has Entered Its Fourth Stage Of Adoption, Industry Exec Says." *Forbes,* https://www.forbes.com/sites/benjaminpirus/2021/01/29/crypto-has-entered-its-fourth-stage-of-adoption-industry-exec-says/.

Pratt, Mary K., and Alexander S. Gillis. 2021. *What is blockchain and how does it work?,* June. https://www.techtarget.com/searchcio/definition/blockchain.

Programme, UN Environment. 2019. *District energy: a secret weapon for climate action and human health,* March. https://www.unep.org/news-and-stories/story/district-energy-secret-weapon-climate-action-and-human-health.

Programme, United Nations Environment. 2020. "Blockchain Technology and Environmental Sustainability." Accessed June 30, 2023. https://wedocs.unep.org/bitstream/handle/20.500.11822/34106/FB19.pdf.

Prospero, Eduardo. 2022. "Bitcoin Mining Rigs Could Heat Vancouver Homes Next Year. Take That, ESG FUD." *Bitcoin Insider* (May). https://bitcoininsider.org/article/131491/bitcoin-mining-rigs-could-heat-vancouver-homes-next-year-take-esg-fud.

Redman, Jamie. 2021. "The Wisemining Sato Boiler- A Product That Aims to Heat Your Home and Offset Costs by Mining Bitcoin," March. https://news.bitcoin.com/wisemining-sato-boiler-product-heat-your-home-offset-costs-mining-bitcoin/.

Regulator, Canada Energy. 2021. *Provincial and Territorial Energy Profiles - British Columbia.* Accessed: 2023-07-01. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-british-columbia.html.

Reuters Staff. 2023. "BlackRock close to filing for bitcoin ETF - CoinDesk." *Reuters* (June). https://www.reuters.com/business/finance/blackrock-close-filing-bitcoin-etf-coindesk-2023-06-15/.

Ritchie, Hannah, and Max Roser. 2021. "Overview of Global Energy." Accessed: 2023-06-11, *Our World in Data,* https://ourworldindata.org/energy-overview.

Ritchie, Hannah, Max Roser, and Pablo Rosado. 2022. "Energy." Https://ourworldindata.org/energy, *Our World in Data.*

Robertson, Harry. 2021. *Meet the company mining bitcoin using the flare gas from oil drilling — and drawing investment from Coinbase and the Winklevii,* June. https://markets.businessinsider.com/currencies/news/bitcoin-mining-flare-gas-btc-energy-crusoe-energy-coinbase-winklevoss-2021-6-1030537177.

RushRadar. 2022. "Consensus Protocol." Accessed June 30, 2023. https://rushradar.com/consensus-protocol/.

Sahay, Ratna, Ulric Erik von Allmen, Amina Lahreche, Purva Khera, Sumiko Ogawa, Majid Bazarbash, Kimberly Beaton, et al. 2021. *Central bank digital currencies in emerging markets.* Accessed: 2023-07-16. https://business.cornell.edu/hub/2021/08/11/central-bank-digital-currencies-emerging-markets/.

Sarkar, A. 2022. "Repurposing Bitcoin Mining Heat Can Solve Global Energy Crisis: Arcane." Cointelegraph, September 4, 2022. Accessed December 12, 2022. https://cointelegraph.com/news/repurposing-bitcoin-mining-heat-can-solve-global-energy-crisis-arcane.

Sarkodie, Samuel Asumadu, Maruf Yakubu Ahmed, and Thomas Leirvik. 2022. "Trade volume affects bitcoin energy consumption and carbon footprint." *Finance Research Letters* 48:102977. ISSN: 1544-6123. https://doi.org/https://doi.org/10.1016/j.frl.2022.102977. https://www.sciencedirect.com/science/article/pii/S1544612322002264.

Scanlon, Luke. 2022. *What EU's MICA Regulation Means for Crypto-Asset Service Providers,* October. https://www.pinsentmasons.com/out-law/analysis/eu-mica-regulation-crypto-asset-service-providers.

Sephton, Connor. 2020. "Digital dollar vs Bitcoin: which is better?" *Currency.com* (October). https://currency.com/digital-dollar-vs-bitcoin.

Shan, Rui, and Yaojin Sun. 2019. "Bitcoin Mining to Reduce the Renewable Curtailment: A Case Study of Caiso." *SSRN Electronic Journal,* https://doi.org/10.2139/ssrn.3436872.

Shekhar Gehlot, D. A. D. n.d. "Evaluating the Sustainability of Bitcoin." *Mathematical Statistician and Engineering Applications,* accessed March 21, 2023. https://www.philstat.org/index.php/MSEA/article/view/120.

Shilov, Anton. 2021. "Bitcoin Miners Adopt Liquid Immersion Cooling." Accessed June 20, 2023. https://www.tomshardware.com/news/cryptominers-adopt-liquid-immersion-cooling.

Sigalos, MacKenzie. 2022. *23-year-old Texans made $4 million mining bitcoin off flared natural gas,* February. https://www.cnbc.com/2022/02/12/23-year-old-texans-made-4-million-mining-bitcoin-off-flared-natural-gas.html.

Stoll, Christian, Lena Klaaßen, Ulrich Gallersdörfer, and Alexander Neumüller. 2023. "Climate Impacts of Bitcoin Mining in the U.S." *MIT CEEPR Working Paper Series,* https://ceepr.mit.edu/files/papers/2023-011.pdf.

Torpey, Kyle. 2023. "Biden Wants 30% Crypto Mining Tax, But Can It Work?" https://www.investopedia.com/biden-wants-30-percent-crypto-mining-tax-but-can-it-work-7488297.

Uddin, Shekh S. et al. 2023. "Next-generation blockchain enabled smart grid: Conceptual framework, key technologies and industry practices review." *Energy AI* 12:100228. ISSN: 2666-5468. https://doi.org/https://doi.org/10.1016/j.egyai.2022.100228. https://www.sciencedirect.com/science/article/pii/S266654682200074X.

User and Assistant. 2022. *A chat conversation with Microsoft Bing search.* Online chat. https://www.bing.com/search?form=NTPCHT&q=What+can+the+new+Bing+chat+do%3f&showconv=1&ntref=1.

Velický, M. 2023. "Renewable Energy Transition Facilitated by Bitcoin." *ACS Sustainable Chemistry & Engineering* 11 (8): 3160–3169. https://doi.org/10.1021/acssuschemeng.2c06077.

Volyntseva, Yulia. 2023. "Which Countries Have Adopted Bitcoin as Legal Tender?" *Businesstechweekly.com* (February). https://www.businesstechweekly.com/finance-and-accounting/cryptocurrency/which-countries-have-adopted-bitcoin-as-legal-tender/.

Warrick, Ambar. 2022. *Live News: EU Votes on MICA, Proof-of-Work (POW) Ban Amid Heavy Crypto Backlash,* May. https://coingape.com/eu-mica-vote-pow-ban/.

Web, Energy. 2020. *Energy Web Awarded Good Energies Foundation Grant for New Global Renewables Marketplace.* Accessed: 2023-07-05, December. https://medium.com/energy-web-insights/energy-web-awarded-good-energies-foundation-grant-for-new-global-renewables-marketplace-794eaa7e14e0.

———. 2021. *Projects - Energy Web.* Accessed: 2021-12-15. https://www.energyweb.org/projects/.

———. 2023. *Solutions - Green Proofs - Energy Web.* https://www.energyweb.org/solutions-green-proofs/.

Web, Energy, Alliance for Innovative Regulation, RMI, and World Economic Forum. 2021. *Home - Crypto Climate Accord.* Accessed: 2023-07-16. https://cryptoclimate.org/.

Wong, Wilson. 2022. "What's behind China's cryptocurrency ban?" *World Economic Forum,* https://www.weforum.org/agenda/2022/01/what-s-behind-china-s-cryptocurrency-ban/.

Young, Colin. 2023. *What is the Lightning Network?* https://decrypt.co/resources/what-is-the-lightning-network. Accessed: 2023-07-03.

Zetzsche, Dirk A., Ross P. Buckley, Douglas W. Arner, and Linus Föhr. 2020. "The Distributed Liability of Distributed Ledgers: Legal Risks of Decentralized and Smart Contracts." *University of Illinois Law Review* 2020 (3): 1361–1416. https://illinoislawreview.org/wp-content/uploads/2020/08/Zetzsche.pdf.

Zhang, D., E. Symitsi, C. Stoll, M. U. Rehman, E. Platanakis, T. Klein, A. Kajtazi, et al. 2021. "Bitcoin Investments and Climate Change: A Financial and Carbon Intensity Perspective." *Finance Research Letters* (November 20, 2021). Accessed March 21, 2023. https://www.sciencedirect.com/science/article/abs/pii/S1544612321005262.

Zhang, Yulong, Ethan Cecchetti, Yan Ji, Ahmed Kosba, Ari Juels, and Elaine Shi. 2021. "DeFi Protocols for Loanable Funds: Interest Rates, Liquidity and Market Efficiency." *Proceedings of the ACM Conference on Computer and Communications Security,* 1–18. https://doi.org/10.1145/3460120.3484759.

Zimwara, Terence. 2021. "Kenya-Based Bitcoin Mining Company Raises $2 Million in Seed Investment Led by Jack Dorsey-Owned Firm." Accessed January 15, 2023. https://news.bitcoin.com/kenya-based-bitcoin-mining-company-raises-2-million-in-seed-investment-led-by-jack-dorsey-owned-firm/.

———. 2022. *EU Parliament to "Vote on Adopting the Regulation on MICA" - Expert Says Industry Needs Legal Clarity – Regulation Bitcoin News,* December. https://news.bitcoin.com/eu-parliament-to-vote-on-adopting-the-regulation-on-mica-expert-says-industry-needs-legal-clarity/.