Current and Future Implications of Cryptocurrency Mining on Energy and Climate Change

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

I dedicate this thesis to my loving parents, my lifelong inspirations, who taught me to fight life's struggles. My father's unwavering support and my mother's lessons in patience and hard work have been invaluable, encouraging me to pursue my goals with unwavering dedication. I am also deeply grateful to my teachers, whose wise counsel and guidance have been instrumental in helping me reach the position I am in today.

ABSTRACT

Blockchain technology has been adopted at a significant pace in the recent years. It's a peer-to-peer technology and anyone is free to join this network. The major blockchain technologies for instance, bitcoin consume massive amount of energy during its mining and transaction processes and hence overburdening the power sector. Furthermore, due to these processes significant amount of carbon emissions are emitted which are known to contribute towards climate change. Consequently, they make it difficult to achieve sustainable development goals to combat climate change.

In this study the energy consumption, carbon emissions, and carbon credits for United States, China, India, and Pakistan have been calculated. Furthermore, the hash rate, energy consumption, and carbon emissions for Pakistan have been forecasted to check the future cryptomining potential in Pakistan. To calculate the energy consumption, and energy required to produce one USD worth of bitcoin is derived utilizing the methodology from available literature. Furthermore, the carbon footprint and carbon credits are calculated using the Department of Environment, Food and Rural Affairs (DEFRA) methodology. For forecasting hash rate, energy consumption, and carbon emissions, Machine Learning Convolutional Neutral Network (CNN) model has been used.

After Chinese government crackdown, United States has become the country housing most of miners. Meanwhile, India and Pakistan have a least contribution compared to other crypto mining countries due to various reasons including unregulated government policies. The hash rate from Pakistan is expected to remain lower until December 2024. Overall, most of emissions due to crypto mining are emitted from United States and more energy is required to mine a coin in United States than in Pakistan. Hence, mining can be more beneficial in Pakistan but due to unclear policies, limited resources and technologies it cannot prosper.

Overall, findings will assist in determining the adoptability of cryptocurrency and how the energy sector can be reshaped, and its carbon footprint be reduced.

Keywords: Cryptocurrency mining, Energy consumption, Climate change, Environmental impacts, Bitcoin

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LIST OF ABBREVIATIONS

IoT	Internet of Things
PoW	Proof of Work
GHG	Green House Gas
SDG	Sustainable Development Goals
Mt	Million tonnes
kWh	Kilowatt hour
MWh	Megawatt hour
TWh	Terawatt hour
CO_2	Carbon dioxide
CBECI	Cambridge Bitcoin Electricity Consumption Index
PE	Power Efficiency
EC_c	Energy cost of coin
EF	Emission factor
DEFRA	Department for Environment Food and Rural Affairs
GWP	Global warming potential
EU ETS	European Union Emission Trading System
EPA	Environmental Protection Agency
CNN	Convolutional Neutral Network
$SC\text{-}CO_2$	Social cost of carbon dioxide

LIST OF PUBLICATIONS

Current and Future Implications of Cryptocurrency Mining on Energy and Climate Change

Energy and Environment (Under Review)

Chapter 1

Introduction

1.1. Background

In recent years, a lot of attention has been focused on the fundamental mechanism that underpins cryptocurrency as well as blockchains technology. A peer-to-peer [1] digital exchange system known as cryptocurrency is characterized by the generation and distribution of currency units via the use of cryptography [2]. Cryptography is a method that ensures the confidentiality of messages. The goal of employing cryptography in the process is to offer fundamental security features: Only the owner can spend the money, and only once [3]. Anyone is free to join this network and contribute the computing power of their own devices to the process of adding new blocks of transactions to the blockchain [4]. The technique by which is used to add new blocks to a blockchain is known as Proof of Work (POW) algorithm [5].

There have been many virtual or digital currencies named cryptocurrencies for instance, Bitcoin, that have risen to prominence as a medium of exchange and are being used as an alternative to money [6]. Bitcoin as a cryptocurrency concept was first introduced by Satoshi Nakamoto in 2008 [1]. While, bitcoin mining actually started in 2009 [4, 7]. In the early days of Bitcoin, mining was carried out with the help of the central processing units (CPUs) of various computer systems. In the latter part of that same year, however, it was found out that graphical processing units (GPUs), could be used for mining Bitcoin [8]. Bitcoin uses proof of work algorithm to add new block to the chain. While other blockchain systems (such as Ethereum, the second biggest cryptocurrency) aim to shift away from Proof of Work and toward less energy-intensive consensus methods like Proof of Stake. A unique transaction called coinstake serves as proof-of-stake in the new variant of blocks. The block owner pays oneself in the coinstake transaction, consuming his coin age while obtaining the advantage of creating a network block and forging for proof-of-stake [9]. Cryptocurrencies differ from traditional currencies in various prospectives.

Cryptocurrencies are different from traditional currencies, such as the U.S. Dollar and the Euro, are strongly reliant on local and global economic situations, such as politics, inflation, crises, trade, and so on, making them more specific to compute. Cryptocurrency's price and fluctuations, on the other hand, are more difficult to predict. In addition to listening to the rumors that contribute to the fluctuation of Cryptocurrency prices, demand and supply are essential factors in the formation of Cryptocurrency pricing [10]. Hence, cryptocurrencies have become more popular.

The trend of regulating cryptocurrency in many countries demonstrates that the usage of Bitcoin is beginning to grow. Blockchain is generally regarded as one of the most alluring and appealing technologies for a variety of industries, including supply chain finance, logistics management, production operations management, and the Internet of Things (IoT). This is primarily attributable to key aspects such as anonymity, auditability, and decentralization, which Blockchain possesses [11-13]. However, these cryptocurrencies are not bound to central banks, fiats, sovereigns, or national borders. With all these benefits there are also few concerns associated with cryptocurrencies/ blockchain technologies.

The fact that cryptocurrency lacks a central administrator sets it apart from traditional forms of currency. The term "governance decentralization in bitcoin protocols" refers to the degree to which it is possible and likely for individuals to engage in activities and conduct transactions with one another without the oversight or authorization of a centralized authority [14].

Moreover, Bitcoin mining requires a lot of power [15-17]. Bitcoin mining's rising energy usage and accompanying carbon emissions might jeopardize global sustainability practices [18]. Over the last few years, as public and professional interest in Bitcoin has grown, complexity of Bitcoin mining, the value, Blockchain networks, and the power needed for Bitcoin mining have all increased significantly, both yearly and per transaction [19]. Every Bitcoin transaction is built into a 'block,' which needs the resolution of a computationally difficult proof-of-work, which consumes a lot of power [20]. The amount of electricity required to generate one coin every day is calculated using the blockchain's network hash rate, which is an available publicly. The hash rate is a metric that measures the amount of energy used by all processes in a cryptocurrency network in order to mine blocks and collect the money reward [16]. Hash rate increase as the computational competition becomes more intense [21]. However, the researchers' suggestions for reducing this effect disproportionately emphasize miners [22]. The number of Bitcoin miners in the corresponding places is represented in Bitcoin nodes. Miners, having a greater influence in how Bitcoin develops, aren't interested in getting rid of the algorithm since it's so important to their business. As a result, Bitcoin is expected to remain the greatest energy user among global blockchain systems, and it will continue to consume a significant amount of energy [23]. Moreover, the mining of cryptocurrencies, nowadays, consumes a lot of resources [24-27]. Extra refrigeration equipment, air conditioners, and fans are required because of the significant quantity of waste heat, demanding additional resources [24]. But the problem is not just limited to massive power consumption.

Digital currencies such as Bitcoin also have a substantial environmental impact due to the amount of energy required to run the algorithms that enable them. Though this might theoretically be done renewable energy is used, it isn't done in actuality. According to a detailed study conducted by Cambridge researchers, crypto-mining consumed the majority of the power utilized in the country is fueled by inefficient coal energy plants [28]. GHG emissions from Bitcoin transactions are dispersed across the world, regardless of where they are sent. Estimates of Bitcoin mining's carbon footprint are computed by considering the whole global Bitcoin mining supply chain. Researchers concur that regulations are required since the environmental effect has been growing over time, despite diverse estimating techniques and presumptions [22]. Furthermore, mining also produces electronic waste. Disposed electronic or electrical equipment is referred to as "electronic waste." Due to the fact that bitcoin mining now takes place on very specialized gear that is centralized in huge mining farms or pools [21, 25, 29]. Because it may cause harmful compounds and heavy metals to leak, electronic waste poses a concern to the environment. Ineffective recycling may contaminate the land, the air, and the water [7, 24]. Estimating the number of mining devices in the network and the speed at which this equipment is discarded is one approach for calculating the amount of electronic waste that results from bitcoin mining [8]. If the present pace of adoption is equivalent to some of the slowest widely adopted technologies, cumulative emissions from Bitcoin use will surpass the 2°C barrier in 22 years, or in 11 years if spread at the quickest rate at which various technologies have been adopted [30].

1.2. Problem Statement

Climate change is the most pressing issue today [3]. The carbon footprint of bitcoin is unignorable and so contributing to the climate change. The Sustainable Development Goals (SDGs) of the United Nations (UN) describe the key concerns confronting humanity. The world can be a much better place if these goals could be tackled in a methodical manner [31].

Bitcoin mining is an energy intensive process it consumes a lot of energy and hence overburdening the power sector.

Hence, these issues need an attention and immediate measures must be taken to address these issues.

1.3. Research Objectives

The objective of this study is to analyze the massive energy consumption, carbon emissions in select countries and future projections of cryptocurrency mining in Pakistan. In December 2015, 196 countries endorsed a worldwide strategy to prevent climate change in the next years under the Paris Agreement, which proposed limiting global warming to below 2^{o}C [32]. According to the calculations, the entire cryptocurrency industry can result in roughly $0.66 worth of health and environmental harm for every new cryptocurrency value created [33]. So, this study aims to analyze the impacts of cryptocurrencies' mining on climate change that somehow prevent the world meeting these goals. After reviewing the problems associated with the mining of bitcoin, this research will analyze the mining techniques used in various regions such as developed countries, developing countries and economies in transition. And future potential of cryptocurrencies' mining in Pakistan. So, this research aims to:

- Understand current implications of cryptocurrency mining on the energy and environmental sphere at national and international level.
- Forecast the future implication of cryptocurrency mining on existing energy infrastructure and its carbon footprint via machine learning.

It will provide insights regarding the current and future impacts of growing cryptocurrency mining on energy sector. Likewise, the study will highlight the climate change concerns of cryptocurrency mining and means to reduce them for sustainable development.

1.4. Scope and limitations of research

This study will help us understand the current trends and future projection of cryptocurrency to mitigate the alarming concerns of cryptocurrency. There are many types of cryptocurrencies like Bitcoin, Ethereum, and Avalanche etc. but this study focuses on Bitcoin. The power consumption, and power required for one USD worth of bitcoin during the mining process, and future projections of cryptocurrencies will be studied. Furthermore, the GHG emissions, and carbon credits, and climate damages due to the energy intensive process of bitcoin mining will be studied and its climatic impacts will be observed.

This study is expected to aid the policy makers and environmentalist to formulate effective energy system planning while meeting the sustainable development goals (7,13) [34]. Moreover, this study is to suggest the possible solutions to reduce the adverse effects of cryptocurrency mining on the climate change using the different kind of energies and comparing the scenarios from developed countries, economies in transitions and developing countries. And after detailed analysis the best solutions can be proposed.

The limitation of the study is researchers are seeking for novel ways to give all of the advantages of digital currency without the massive carbon footprint, as concerns about the environmental impact of blockchain-based currencies have grown. Keep an eye out for a new generation of environmentally friendly cryptocurrencies that use renewable energy sources to lessen transactional environmental impact [35].

There are few studies done related to this study i.e. carbon emissions linked with cryptocurrency mining in developed countries have been documented and energy utilization of major bitcoin mining countries have also been studied. Not much work has been reported on addressing the negative impacts of cryptocurrency mining on the sustainability of energy sector (especially for Pakistan) with regards to environment aspects.

1.5. Thesis Structure

The organizational structure of the thesis has been shown in Figure 1.1. The goal of the research was to analyze the current implications of cryptocurrency mining in select countries and forecast the future implications of cryptocurrency mining in Pakistan.

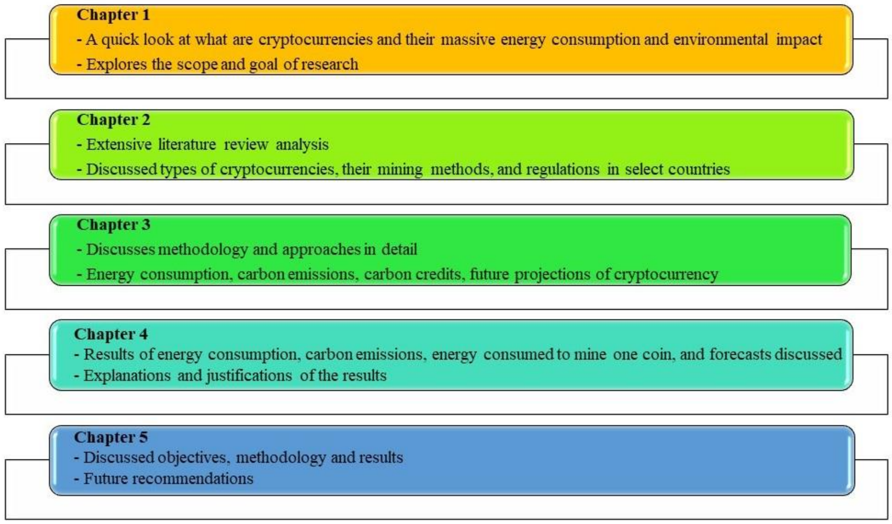

Figure 1.1 Thesis flow diagram

1.6. Summary

As the number of crypto miners have increased significantly in the last few years, there are lot of problems being raised due to its mining. With the increase in the number of miners across the globe, massive amount of energy is required to fulfill the cryptocurrencies' mining requirements. Climate change is a major problem arising from crypto mining using cheap and inefficient fossil fuel energy, for instance. coal energy. Due to greater carbon footprint of emissions from crypto mining it has been estimated that the global temperate of the earth can be increased to 2^{o}C in the next few years. Lot of climate damages associated with the massive carbon emissions and creating humanitarian crisis and climates harms. Hence, the immediate measures are required to be taken in order to tackle these problems.

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Chapter 2

Literature Review

2.1. Types of Cryptocurrencies

Among many different types of cryptocurrencies some are minable and while others are not minable. Mining is a term used to describe the process of solving puzzles [1]. Some of minable cryptocurrencies for example Bitcoin, Ethereum and Avalanche are the most popular in the universe of crypto. Market capitalization and the overall worth of all coins of these virtual currencies currently in circulation are discussed next [2]:

2.1.1. Bitcoin

Bitcoin (BTC) is the first cryptocurrency, having been created in 2009 under the pseudonym Satoshi Nakamoto [3, 4]. BTC, like most cryptocurrencies, is based on a blockchain [5], which is a distributed ledger that logs transactions over a chain of thousands of computers. Bitcoin is maintained secure and safe from scammers because updates to the distributed ledgers must be confirmed by solving a cryptographic problem, a process known as proof of work.

Bitcoin's value has soared as it has grown in popularity. In May 2016, a Bitcoin could be purchased for around $500. The price of a single Bitcoin reached above $46,300 on April 1, 2022. That's an increase of almost 9,000%. The market cap of BTC is $880 billion [2].

2.1.2. Ethereum

Ethereum (ETH) is a peer-to-peer blockchain in which every node follows the same set of instructions. Because of the tremendous parallelism, the network as a whole is slower and more computationally intensive. It does, however, make the blockchain highly secure against attackers, and it has extremely high fault tolerance. Unlike Bitcoin, Ethereum uses accounts rather than addresses. To establish a contract, users must first create an account. By uploading the appropriate code to the account, a decentralized applications (dAPP) is formed [6].

Ethereum is a favorite of programmers because of its potential uses, such as smart contracts that run automatically when conditions are satisfied and non-fungible tokens (NFTs). Ethereum is both a blockchain platform and cryptocurrency [7, 8].

Ethereum has a market cap of $415 billion. Ethereum has also exploded in popularity. Its price increased by more than 31,000% from April 2016 to the beginning of April 2022, from around $11 to over $3,450 [2].

2.1.3. Avalanche

Avalanche (AVAX), like Ethereum and Cardano, offers blockchain software that allows users to write and execute smart contracts using a native coin (in this case, AVAX). Avalanche has developed significantly since its introduction in 2020, owing in no little part to its low gas prices and quick transaction processing speeds.

AVAX's price has climbed more than 2,000% from $4.63 to $97.58 between July 12, 2020, and April 1, 2022. Its market is over $26 billion [2].

2.2. Cryptocurrencies' mining approaches

As there are many types of cryptocurrency, they have different mining methods. According to the available literature the mining approaches of these cryptocurrency are discussed below:

2.2.1. Mining approach for Bitcoin

Bitcoin mining is the process of adding transaction records to the blockchain, which is Bitcoin's public database of previous transactions. Bitcoin is mined with the help of mining rigs. The individuals known as miners protect the Bitcoin network [9]. Miners constantly monitor Bitcoin transactions and attempt to verify them [10]. Users have mined Bitcoin blocks using a variety of devices over time. A mining can be done be any machine connected to the Bitcoin network. Bitcoin mining hardware includes Central Processing Unit (CPU) mining, Graphics processing unit (GPU) mining, Field Programmable Gate Array (FPGA) mining, and Application-Specific Integrated Circuit (ASIC) mining. All hardware mining is plagued by low profit margins, excessive heat, and expensive power costs. Cloud mining can be another answer to these issues since it avoids the difficulties of excessive heat and expensive power costs. It does, however, have certain shortcomings. The miner solves the challenge and broadcasts it on the network using the computing power [9].

When the sender signs a transaction, it is considered legitimate by proof of work algorithm. As more miners join the network, the challenge becomes incredibly difficult, to the point where a new block containing a transaction is added to the blockchain in the network every 10 minutes on average. Only when a block has evidence of work is it regarded authentic. A reward is given to the miner who mines the block. Miners receive fresh Bitcoins as a reward, as well as transaction fees from any transactions contained in the block. This encourages miners to keep competing in the race to locate valid blocks [10]. Figure 2.1 depicts the overall procedure of how the Bitcoin blockchain operates.

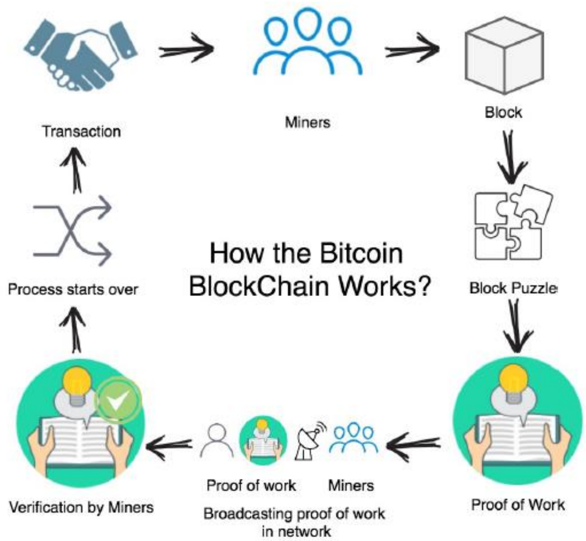

Figure 2.1 How the Bitcoin Blockchain Works [10]

The following are the steps to running the network [11]:

- All nodes are notified about new transactions.
- Check to see if the transactions are genuine.
- New transactions are bundled into blocks by each node.
- Each node tries to discover a challenging proof-of-work for its block.
- When a node discovers a proof-of-work block, it broadcasts it to all other nodes.
- Only if all transactions in the block are genuine and have not previously been spent do nodes accept it.
- Nodes signal their approval of the block by working on the next block in the chain, with the previous hash being the hash of the approved block.

There must be standards in order for everyone to be able to send transactions and mine more bitcoins in a fair and safe manner. These standards are [12]:

- **Fast verification:** This implies that the puzzle must take a fair amount of time to complete, but anybody should be able to check whether a solution obtained is indeed a legitimate. This validation must be as quick as feasible in order to be efficient. If validation took greater time and everyone had to perform it, the efficiency would be greatly reduced.
- **Adjustable difficulty:** The puzzle must have a modifiable difficulty level. The environment is always changing, and machine computing power is rapidly improving. As a result, the ability to vary the problem's difficulty or indeed the puzzle itself is required. This is done to ensure that a puzzle solution can be found in a fair length of time. This takes about ten minutes when using Bitcoin.
- **Progress-freeness:** This means that everyone who participates must have a chance to solve the challenge. This probability should be relative to the quantity of hash power utilized to solve the puzzle by the user.

2.2.2. Mining approach for Ethereum

Ethereum is a smart contract-based distributed blockchain platform [1]. It is different from Bitcoin for it allows for more flexibility in contract management, has a faster block generation rate, and has different mining incentives. Ethereum is based on a blockchain that is also protected by proof of work [13].

Clients are the people who use Ethereum. A client can use transactions to establish new contracts, transfer Ether (Ethereum's internal coin) to contracts or other clients, or trigger some of a contract's capabilities. Valid transactions are grouped into blocks, which are linked together by a cryptographic hash value from the preceding block. Ethereum does not have a centralized authority to authenticate blocks or perform smart contracts. Instead, a small number of customers (referred to as miners in the literature) validate transactions, build new blocks, and employ the proof of work (PoW) method to attain consensus, in exchange for Ethers [1].

A miner must discover a value for the nonce such that the new block's hash value is below a specific threshold dependent on the difficulty level—a system parameter that may be adjusted—in order to generate a new legitimate block in PoW. The mining complexity, basically, influences the likelihood of obtaining a new block in each attempt. The blockchain technology may maintain a consistent chain growth by regulating the mining difficulty. A new block will be disseminated to the whole network once it has been created [1].

2.2.3. Mining approach for Avalanche

Unlike the bitcoin network, which uses a proof-of-work system in which computer "miners" compete to proceed transactions and receive a reward, Avalanche uses a proof-of-stake blockchain in which users are given blocks to mine based on how many tokens they own. The native AVAX token of Avalanche is used to reward users [14].

2.3. Cryptocurrencies' mining impacts on energy and climate change

2.3.1. Cryptocurrencies and energy consumption

Cryptocurrencies mining is known to be very energy intensive process. According to a study, the rising demand for electricity to generate cryptocurrency could result in a consumption of energy that ranges from 196 TWh to 390 TWh, as another case illustrated a consumption of 293 TWh, which is equivalent to 1% of the electricity consumed in the United States in 2018 (EIA, 2019). According to a literature, when lower and upper bound forecasts are taken into consideration, this level of energy consumption would result in annual energy costs ranging anywhere from $23 billion to $57 billion [15].

Bitcoin is the most energy intensive among all cryptocurrencies. The total energy consumption from bitcoin network only reached approximately 10 TWh in May 2022 and cumulative energy consumption reached nearly 360 TWh during the period June, 2021 to May, 2022 as shown in Figure 2.2 [16]. This massive amount of energy is enough to power countries.

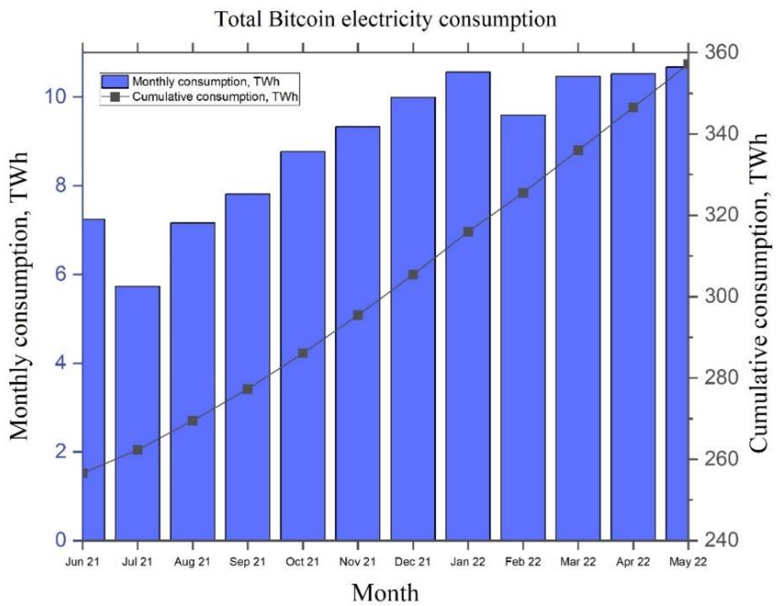

Figure 2.2 Bitcoin network energy consumption [16]

2.3.2. Cryptocurrencies and climate change

There is a greater interlinkage among Bitcoin and carbon emissions at greater quantiles than there is at lower ones [17]. Due to massive energy consumption, cryptocurrencies have a huge impact on climate change due to excessive carbon emissions associated with them. As of May 2018, it was observed that using Bitcoin releases 33.5 $MtCO_2e$ yearly, based on the premise that 60% of the economic return of the Bitcoin transaction verification process goes to power, at US$5¢ per kWh and 0.7 kg CO_2e emitted each kWh [18]. By adjusting emissions for a longer life cycle of energy generation, it was discovered that global emissions from using Bitcoin and Ethereum were 43.9 $MtCO_2e$ in 2017 [19]. In addition, another study investigated the implications of the environmental footprint left by cryptocurrencies, considering the anticipated shifts in the composition of the world's energy supply over the course of ten years. According to the findings, the anticipated levels of energy consumption would result in the production of carbon emissions that range between 53 and 63.6 MtCO2 [15].

When considering a global picture, China has the highest concentration of emissions. For instance, China accounts for 81% of worldwide emissions from Bitcoin mining, which also covers the mining supply chain in other countries. While the majority of Bitcoin holders are in the western world, primarily in North America and Europe, such as the Netherlands (5%), France (7%), Germany (20%), and the United States (22%), Bitcoin mining emission levels are primarily in China, with the United States accounting for 14% of total emissions in the year 2020 [20]. The geographic distribution of bitcoin users and carbon footprint of bitcoin is shown in Figure 2.3.

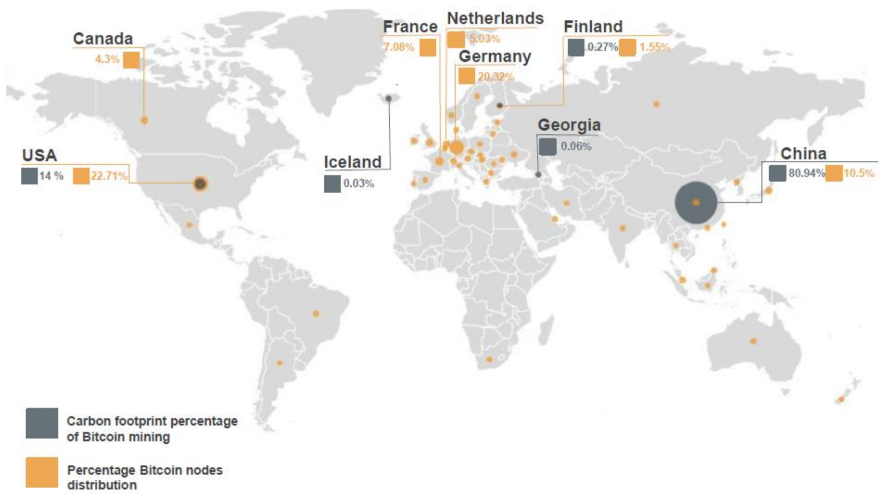

Figure 2.3 Geographic distribution of Bitcoin holders/users and Carbon footprint of Bitcoin [20]

There are climate damages associated with the excessive carbon emissions. For every extra tonne of carbon emitted into the atmosphere, there is a social cost for the damages it creates [21]. The social cost of carbon dioxide (SC-CO_2) is a crucial statistic guiding climate policy that assesses the monetized worth of the societal damages produced by each extra metric tonne of CO_2 emissions [22]. When humans release a tonne of carbon dioxide into the atmosphere, it stays there for a time and causes warming, which has consequences for humans. The social cost of carbon is the entire monetary harm caused by an extra tonne of CO_2 on outcomes. When assessing the social cost of carbon, the primary factors are what happens to the climate and how those changes impact economic results, such as changes in agricultural output efficiency, damages incurred by sea level rise, and declines in human health and labor productivity [21].

In addition to this, it brings to light the fact that regulatory frameworks pertaining to the crypto market should be improved in order to lessen the impact that cryptocurrencies have on the environment and combat climate change [17]. It is of the utmost importance to hasten the transition from mining cryptocurrencies using fossil fuels to using renewable sources of energy as the primary energy source. In order to cut down on CO_2 emissions and make headway against the problem of climate change, it is essential to spread awareness about how energy-efficient mining equipment and blockchain technology are. The advancement of blockchain technology will play a crucial part in ensuring the continued and sustainable growth of the cryptocurrency ecosystem. This will be accomplished by reducing the amount of energy that is consumed and increasing the decentralized consensus mechanism's environmental friendliness [23].

2.4. Cryptocurrencies’ mining regulations in select countries

Now, let's take a glance at the select countries’ mining scenarios in terms of the current regulatory structure for cryptocurrencies and related trading on crypto exchanges. How some of the world's largest economies are attempting to handle crypto assets will provide understanding of the need for and developing trends in crypto regulation [24].

2.4.1. Cryptocurrencies’ mining regulatory in United States

In the United States, cryptocurrency exchanges are lawful and regulated under the Bank Secrecy Act (BSA). This implies that cryptocurrency exchange network operators must get the necessary Financial Crimes Enforcement Network (FinCEN) license, execute an AML/CFT and Sanctions program, keep accurate records, and file timely reports with the authorities. However, the Securities and Exchange Commission (SEC) of the United States believes cryptocurrencies to be securities and applies securities regulations to digital wallets broadly, affecting both investors and exchanges [24]. The Commodities Futures Trading Commission (CFTC), on the other hand, has taken a more favorable stance, recognizing Bitcoin and Ethereum as "commodities" and permitting other virtual and cryptocurrency futures to trade openly on its regulated exchanges [25]. Moreover, FinCEN has stated that it wants cryptocurrency exchanges to cooperate with record-keeping requirements and the "Travel Rule" by providing data about the originators and stakeholders of cryptocurrency transactions after the Financial Action Task Force (FATF) released their instructions in June 2019 [26]. Virtual currency exchanges are regulated in the same way as traditional AML/CFT gatekeepers, money transmitters, and financial institutions in the United States. As a result, the same laws apply [24]. Hence, United States has observed a significant increase in the number of miners in the country due to government regulation and cheap sources of electricity.

Bitcoin miners rushed to the United States earlier in 2021, taking coal and natural gas with them. The cryptocurrency resurrected a natural gas plant in Dresden, New York, that had earlier stopped supplying electricity to the general public [27]. Moreover, a Bitcoin mining organization in Pennsylvania is using scrap coal to operate its machines [28]. Bitcoin miners in the United States rushed to regions with inexpensive hydropower, such as East Wenatchee, Washington, and Plattsburgh, New York. Mining consumed so much power that households' utility bills skyrocketed [29, 30]. Although, this was not the only problem the country faced.

Abrupt increase of crypto currency mining caused severe environmental impacts as well. A total of $1.5 billion (in 2020) in damages to the environment and human health were caused by the power usage of BTC mining in the United States. Most of the negative effects of bitcoin mining are focused on only a few states. The mining operations in Georgia and Kentucky are responsible for roughly half of the destruction (50%). Damages totaling 87% are concentrated in only eight states. Over $1.1 billion in losses were incurred throughout five states (Georgia, Texas, Kentucky, New York, and Nebraska) during this time period [31]. Environment concern was not the only reason for government to take immediate measures.

With environment damages, cryptocurrency regulations rooted aroused some criminal activities as well. To tackle national and international criminal activity, the US Treasury has underlined the immediate need for crypto legislation. FinCEN proposed a new data collection necessity for persons responsible for regulating cryptocurrency exchanges, digital assets, DTLs, and crypto payment personal digital wallets in December 2020, and Treasury Secretary Steve Mnuchin introduced a new FSOC (Financial Stability Oversight Council) working group to discover the oversaturated cryptocurrency marketplace in 2018. With all that, the Covid-19 dilemma, on the other hand, has hampered (though increased the urgency of) federal efforts to advance cryptocurrency legislation. Despite difficulties, US legislators are eager to regulate cryptocurrencies in anticipation of their possible disruptive influence on the world's most powerful currency, the US dollar, as well as the effects that private and centrally banked currencies may have [24].

2.4.2. Cryptocurrencies' mining regulatory in China

In 2013, the People's Bank of China (PBOC) prohibited financial institutions from conducting Bitcoin transactions, and in 2017, it went even farther by restricting initial coin offerings (ICOs) and local cryptocurrency exchanges. The PBOC justified the restriction by describing ICO funding (which creates virtual currencies like Bitcoin or Ethereum via the unscheduled sale and circulation of tokens) as unlawful public financing under Chinese law. China does not accept cryptocurrencies as legal cash, and the nation has a reputation for enforcing severe currency controls on the number of foreign currencies, especially cryptocurrencies. The government declared that state-approved cryptocurrencies have the status of ownership for the purposes of calculating inheritances under a 2020 revision to China's Civil Code [24].

Until 2021, China's electricity was mostly generated by a combination of coal and hydropower for bitcoin mining. During the rainy season in China's Sichuan province, miners used extra hydropower, taking advantage of inexpensive, carbon-free electricity. When it ran out, they traveled north to Xinjiang province, because coal was their primary source of energy [32].

There is no sign that China would withdraw or modify its cryptocurrency prohibition anytime soon, but recent moves imply that the government intends to position China as a crypto lead. The institutions, including online payment channels and banks, are prohibited from providing customers with any cryptocurrency-related services, particularly registration, settlement, trading, and clearing [24].

According to a Reuters story, China has barred financial institutions and payment providers from providing services connected to cryptocurrency transactions, and has advised investors against risky crypto trading in its latest move [33].

2.4.3. Cryptocurrencies' mining regulatory in Pakistan

Pakistan is among those countries where cryptocurrency mining is not fully legal and unregulated by the government and hence the negligible research has been done in Pakistan about cryptocurrency mining and therefore limited literature is available. Both cryptocurrency mining and trading are currently in legal grey area in Pakistan, and federal officials would have to give a clear route to legalization before the industry could be legally opened to investors. Despite this, cryptocurrency mining and trading is growing in Pakistan, with apps like Binance and Coinbase among the frequent downloads, according to SimilarWeb, to site analytics organization [34].

To take full advantage of a booming global cryptocurrency market, the government of Khyber Pakhtunkhwa, Pakistan, plans to develop two hydroelectric-powered trial "mining farms [34]."

Pakistan's government and central bank are considering prohibiting the usage of cryptocurrency in the neighboring state [35]. "The risks of cryptocurrencies considerably exceed the advantages for Pakistan," the SBP stated. "The only usage of cryptocurrencies in Pakistan appears to be speculative in nature, with people being tempted to invest in such coins for the sake of short-term capital gains [36]." The introduction of ban on cryptocurrencies in Pakistan has been advocated by a committee led by Sima Kamil, the deputy governor of the State Bank of Pakistan (SBP), the country's central bank. Officials from the Ministry of Finance, the Securities and Exchange Commission of Pakistan (SECP), and the Federal Investigation Agency of Pakistan (FIA) were among the other participants [35].

However, many Pakistanis believe that cryptocurrency is the answer to their financial troubles. Inflation is high, debt is high, and the country's foreign reserves are limited. Industry experts have slammed Pakistan's decision to prohibit cryptocurrency, believing that banning cryptocurrency is a bad idea and that Pakistan is going to make a huge mistake [35].

2.4.4. Cryptocurrencies' mining regulatory in India

Although cryptocurrency mining in India is not quite as widespread as it is in the United States, it is also not a minor cryptocurrency mining country in the world. As a result, it is not surprising that there are crypto aficionados in India. Highkart.com, an online store, was the first company to begin accepting Bitcoin as payment in the middle of the year 2013. Unocoin and Coinsecure are just two examples of the numerous cryptocurrency exchanges that sprung up to meet the need for somewhere to buy, sell, and keep track of digital money. Previously, in December 2013, February 2017, and December 2017, the Reserve Bank of India issued warnings to investors [37]. Respectively, authorities have also said that no financial institution or commercial enterprise has been approved to facilitate the trading of cryptocurrencies. The Reserve Bank of India has made it very clear that virtual currencies are not regarded legal cash, and that investors and anyone dealing in virtual currency do so at their own risk. On April 6, 2018, RBI issued a public notice banning all regulated entities from handling virtual currencies and from offering any services related to them [37-39].

Despite the fact that India's increasing adoption of digital technology in almost all spheres of life, the fact that the country does not yet have a regulatory framework to control the crypto assets market is a pressing issue that requires quick action. The Indian government made it clear in its Union budget for 2022–23 that any transaction involving the transfer of a cryptocurrency or virtual currency asset would be entitled to a 30% tax deduction. The recipient is responsible for paying tax on any gifts received in the form of virtual assets or cryptocurrency. The Reserve Bank of India (RBI) proposed a ban on cryptocurrencies in July 2022, citing their "destabilizing consequences" on the country's monetary and fiscal stability [40].

2.5. Summary

In this chapter, the three major types of cryptocurrencies i.e., Bitcoin, Ethereum, and Avalanche and their market shares have been discussed. Blockchain technology is used in all these cryptocurrencies and significant amount of energy is consumed during the mining process. Bitcoin mining uses proof of work algorithm to validate the transaction it is an energy intensive process, on the other hand Ethereum and Avalanche use proof of stake algorithm which consumes less energy than proof of work algorithm. Moreover, the amount of energy consumed in these cryptocurrencies is also not negligible especially for Bitcoin. The market cap of BTC, ETH, and AVAX are $880 billion, $415 billion, and $26 billion respectively.

China accounts for 81% of worldwide emissions from Bitcoin mining, which also covers the mining supply chain in other countries. While the majority of Bitcoin holders are in the western world, primarily in North America and Europe, such as the Netherlands (5%), France (7%), Germany (20%), and the United States (22%), Bitcoin mining emission levels are primarily in China, with the United States accounting for 14% of total emissions in the year 2020. After Chinese government put implemented crackdown on cryptocurrency mining, Bitcoin miners rushed to the United States earlier in 2021, taking coal and natural gas with them. As a result, the emission and energy consumption in the country soared.

Developing countries like India and Pakistan have very insignificant amount of mining as compared to the global scenario. Here the mining is not regulated by the governments and people do the mining based on their own limited resources and technologies. But to take full advantage of a booming global cryptocurrency market, the government of Khyber Pakhtunkhwa, Pakistan, plans to develop two hydroelectric-powered trial "mining farms. India does not yet have a regulatory framework to control the crypto assets market is a pressing issue that requires quick action. The Indian government made it clear in its Union budget for 2022–23 that any transaction involving the transfer of a cryptocurrency or virtual currency asset would be entitled to a 30% tax deduction.

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Chapter 3

Methodology

3.1. Data Availability

Available literature is utilized to create and model the scenarios to better understand the usage and accessibility of existing energy systems and carbon emissions of cryptocurrency mining. The findings will assist in determining the adoptability of cryptocurrency and how we can reshape the energy sector and reduce its carbon footprint.

The Cambridge Bitcoin Electricity Consumption Index (CBECI) provided the monthly hash rate statistics that are utilized for the period (September 2019 to January 2022) [1] in order to determine the quantity of energy that was used and the amount of carbon that was produced as a result of this consumption. When calculating the average daily energy consumption and carbon emissions for each country, the monthly hash rate average is one of the factors that is used. The power efficiency (PE) of the mining rig is taken as 0.15 J/GH as taken by Bevand et al. [2] and Vries et al. [3]. The block time and reward per block are also taken from the online data source [4]. As a part of the process that goes into the creation of Bitcoin's coin, miners are rewarded with a certain number of bitcoins each time a block is successfully mined (every 10 minutes approximately). When Bitcoin first started, miners received a reward of 50 bitcoins for each block they successfully mined. When every 210,000 blocks are mined, which occurs approximately once every four years, the block reward will initially begin to decrease and will continue to do so until it reaches zero (approximately by year 2140). The current reward for completing a block is 6.25 coins, but this amount will eventually be halved, bringing the reward down to 3.125 coins per completed block [5].

3.2. Bitcoin mining network energy consumption

The hash rate is multiplied by the amount of power that an average mining rig uses in order to calculate the amount of energy that is required by each cryptocurrency network, as computed by Bevand et al., Krause et al., and Niaz et al. [2, 6, 7]. In the Supplemental Data, the hash rate, energy consumption, and carbon emission calculations are given that were performed for the United States, China, India, and Pakistan.

The hash rate, also known as the processing capability of the network, has a direct correlation with the amount of power that Bitcoin consumes [8]. In turn, the rise in the hash rate is influenced by the intricate and interdependent linkages between mining incentives, hardware energy efficiency, power pricing, transaction fees, and the price of Bitcoin. Moreover, the price of Bitcoin also influences the amount of hash rate that is generated [9]. Multiplying the network hash rate by the power efficiency (PE) of the mining computer (rig) was the method that was used to calculate the total amount of energy that was consumed by the entire network for each country. This was done using the equation (1). Hash rate can be defined as the number of calculations that are carried out across the network in one second. The hardware that is used to mine coins is what determines both the number of computations that are carried out in a given second and the power efficiency with which those computations can be carried out [6].

$$\mathrm{P(MW)} = \mathrm{HR}\left(\frac{\mathrm{hashes}}{\mathrm{second}}\right) \times \mathrm{PE}\left(\frac{\mathrm{Joules}}{\mathrm{hashes}}\right) \times 2.78 \times 10^{-10}\left(\frac{\mathrm{MWh}}{\mathrm{J}}\right) \times 3600\left(\frac{\mathrm{seconds}}{\mathrm{hour}}\right) \quad (1)$$

Where P represents cryptocurrency network’s power requirement, HR denotes network hash rate, and PE indicates the power efficiency of mining rig.

3.3. Energy consumed to mine one coin and cost of energy

The energy cost and energy per coin is determined by the formula used by Krause [6] as shown in equation (2) and (3). The amount of energy required to produce one USD worth of bitcoin is represented by Equation (2), which was derived by multiplying the unit conversion factor from megawatt hours (MWh) to megajoules (MJ) by the network power (P), which was then divided by the velocity.

$$\mathrm{EC}\left(\frac{\mathrm{MJ}}{\mathrm{US\$}}\right) = \mathrm{P(MW)C} \div \mathrm{v}\left(\frac{\mathrm{US\$}}{\mathrm{h}}\right) \times 3600\left(\frac{\mathrm{MJ}}{\mathrm{MWh}}\right) \quad (2)$$

$$\mathrm{EC_c}\left(\frac{\mathrm{MJ}}{\mathrm{US\$}}\right) = \mathrm{A}\left(\frac{\mathrm{MJ}}{\mathrm{coin}}\right) \div \mathrm{B}\left(\frac{\mathrm{US\$}}{\mathrm{coin}}\right) \quad (3)$$

Where EC_c is the energy cost of the coin, A is the energy required to generate the coin, B is the market price of the coin.

3.4. Carbon footprint and carbon credits

Calculating the accurate carbon impact of cryptocurrencies is difficult because it requires justifying assumptions about the location of miners and the type of energy that powers them [10]. The carbon footprint and carbon credits have been calculated by using the methodology given by Department for Environment Food and Rural Affairs (DEFRA) [11]. According to DEFRA, these emissions fall under the scope 2 category, which is categorized as energy indirect. In order to calculate the average monthly greenhouse gas emissions, the average monthly energy consumption was used. Moreover, in order to calculate greenhouse gas emissions (CO_2e), the emission factor of three greenhouse gases (CO_2, CH_4, and N_2O) was multiplied with the energy consumption as expressed in equation (4) for calculating greenhouse gas emissions (CO_2e), the emission factor of three greenhouse gases.

$$\text{Activity data} \times \text{Emission factor} = \text{GHG emission} \quad (4)$$

The emission factor (EF) per MWh of CO_2 is 650.31 lbs, CH_4 is 0.03112 lbs, and N_2O is 0.00567 lbs [12]. Because of the disparity in the amount of impact that each of these gases has on climate change and damage, the next step was to determine each gas's global warming potential (GWP). Carbon dioxide has a warming potential of one for the entire planet. Nitrous oxide has a GWP of 298, which is equivalent to 298 units of carbon dioxide. Therefore, nitrous oxide has a capacity to warm the climate that is 298 times greater than that of carbon dioxide. On the other hand, the GWP for CH_4 is 25. Therefore, in order to represent all emissions as CO_2 equivalents, we multiplied each emission by the GWP that was listed in the EPA Greenhouse Emission Inventories. In the end, add up the total of the three emissions that resulted. Then, utilizing the following formula, we were able to convert the emissions from pounds to tonnes:

$$\frac{\text{Lbs of CO2e}}{2205} = \text{t CO2e} \quad (5)$$

To find the carbon credit price, the average monthly price from an online data source [13] and was then multiplied the average monthly prices with the monthly GHG emissions as per formula given by (DEFRA) [11] shown in equation (6). The European Union Emission Trading System (EU ETS) carbon market has been chosen for price estimates.

$$\text{Carbon credit price} = \text{Total CO2e} \times \text{Price per tonne of CO2e} \quad (6)$$

3.5. Climate damages assessment

In order to calculate the carbon damages due to GHG emissions emitted from the mining of cryptocurrencies the methodology from available literature was used. According to a study, each extra tonne of carbon dioxide released into the environment costs $185 per tonne to society [14] and represented in equation (7).

$$SSC = \$185 \times tCO2e \quad (7)$$

3.6. Forecasting approach for cryptocurrency mining in Pakistan

After that, the future mining potential of cryptocurrencies in Pakistan has been forecasted. In order to forecast the projections, machine learning with is used. In order to make accurate time series forecasts, univariate Convolutional Neutral Network (CNN) models was employed. Despite the fact that CNNs were initially developed for processing two-dimensional image data, it is possible to use them for problems involving the forecasting of univariate time series. A univariate time series is a type of dataset that is comprised of a single series of temporally ordered observations. In this type of time series, a model is required in order to infer the subsequent value based on the series of observations that came before it. Before a univariate series can be modelled, it must first be formatted in the appropriate manner. The CNN model learns a function that converts a series of previous observations from input to output. As a direct consequence of this, the string of observations needs to be segmented into various instances so that the model can gain insight from each one [15]. A convolutional neural network (CNN) model with a convolutional hidden layer that operates over a one-dimensional (1D) sequence is referred to as a one-dimensional CNN. The result of the convolutional layer is then condensed down to its most essential parts by a pooling layer, which in certain situations, such as when dealing with extremely lengthy input sequences, may be followed by a second convolutional layer. Pooling layers are used in artificial neural networks. After the layer that performs the convolutional analysis and the layer that performs the pooling analysis, there is a dense fully connected layer that performs an analysis on the characteristics that were collected by the convolutional section of the model. A flatten layer is placed between the dense layer and the convolutional layer. This layer is responsible for compressing the feature maps into a single one-dimensional vector [15-17].

The model is trained on 80% of the historic data and tested on 20% of data. In order to increase the accuracy to 98.8%, 2000 iterations are performed to fit the model on the data.

The main libraries that are imported in Python for this purpose are NumPy, Pandas, and matplotlib. NumPy is a Python library that is used for scientific computing with Python. It provides support for large, multi-dimensional arrays and matrices, along with a large collection of mathematical functions to operate on these arrays. NumPy is particularly useful for working with large datasets, as it provides functions for efficiently manipulating and analyzing data [18]. Pandas is a popular Python library for working with tabular data, such as data stored in a spreadsheet or a SQL database. It provides fast, flexible, and expressive data structures designed to make working with "relational" or "labeled" data both easy and intuitive. It is a great tool for data wrangling and preparation [19]. Matplotlib is a Python library that is used for creating static, animated, and interactive visualizations in Python. It provides a high-level interface for drawing attractive and informative statistical graphics [20].

Summary

This chapter provides information about the required sources of data collection and methods to calculate energy consumption, carbon emissions, energy to mine a coin, carbon tax for United States, China, India, and Pakistan. Furthermore, machine learning is used to forecast the cryptocurrency mining potential in Pakistan. The hash rate was multiplied by the amount of power that an average mining rig uses in order to calculate the amount of energy that is required by each cryptocurrency network, as computed by Bevand et al., Krause et al., and Niaz et al. [2, 6, 7]. Multiplying the network hash rate by the power efficiency (PE) of the mining computer (rig) was the method that was used to calculate the total amount of energy that was consumed by the entire network for each cryptocurrency. The energy cost and energy per coin is determined by the formula used by Krause [6]. In order to calculate the average monthly greenhouse gas emissions, the average monthly energy consumption was used. Furthermore, to calculate greenhouse gas emissions (CO_2e), the emission factor of three greenhouse gases (CO_2, CH_4, and N_2O) was multiplied with the energy consumption as expressed in equation (4) for calculating greenhouse gas emissions (CO_2e), the emission factor of three greenhouse gases.

Moreover, the future of cryptocurrency mining potential in Pakistan was forecasted with the help of machine learning. The main libraries used for this purpose are NumPy, Pandas, and matplotlib.

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Chapter 4

Results and Discussions

4.1. Current cryptocurrency mining implications on energy and climate change with respect to global scenario

To analyze the electricity consumption of overall bitcoin network overall electricity consumption in the world has been observed for the period June 2021 to May 2022 using the network's hash rate data as energy consumption and carbon emissions in mining process are dependent on network's hash rate. Energy usage has increased as a result of Bitcoin mining activities including continuous operating mining equipment [1].

In Figure 4.1 (A) it can be seen that the hash rate of total bitcoin network followed the increasing trend along with carbon emissions of the network. Because using the network hash rate and an anticipated average mining rig efficiency, power consumption of a proof of work (PoW)-based blockchain system can be estimated [2]. Despite the major crackdown in China in 2021 the mining emissions have already reached a significant higher level. In the Figure 4.1 (A) it can be seen that there is a downward trend in June - July 2021 due to the crackdown but again an upward trend can be seen which peaked in May 2022. It is clear from the situation that the circumstances are alarming if immediate measures are not taken. The power consumption in June 2021 was 7.24 TWh which significantly increased to 10.67 TWh by May 2022 while cumulative energy consumption reached 360 TWh in May 2022 [3]. The proof-of-work approach in cryptocurrency mining encourages miners to ramp up their operations as fast as possible, typically regardless of the energy source. Cryptocurrency mining is a highly energy-intensive operation that jeopardizes the capacity of governments all over the world to lessen our reliance on fossil fuels, which contribute to global warming [4]. According to a study, the market value of crypto assets required to support economic activity will increase from an expected $500 billion in 2019 to $3.6 trillion in 2028 [5].

The majority of bitcoin mining facilities have demonstrated minimal interest in investing in new sustainable energy, unlike other significant power consumers, and they have a limited time horizon. Cryptocurrency mining using fossil fuels has increased water, local air, and noise pollution, raised prices for others, and escalated environmental pollution at a time when we must do all in our power to go in the reverse direction to reduce the worst effects of the climate crisis [4]. The carbon footprint for this period is calculated using the formula from available literature [6, 7]. Exact estimates of the emissions of cryptocurrencies can be highly uncertain due to emission factors [8]. In Figure 4.1 (B) it can be seen that the total carbon emissions from only bitcoin network surpassed 2.27 Mt CO_2 in May, 2022 which is a huge number and the emissions from this network were 1.54 Mt CO_2 in June, 2021. Approximately, 22.9 Mt CO_2 emissions are produced during June 2021 to May 2022. According to estimates, only 39% of POW mining is fueled by renewable energy worldwide, with the majority being provided by non-renewable resources like fossil fuels [9]. Using a global estimate of where Bitcoin miners are located and the local energy mix in conjunction with regional CO2e emission coefficients by generation type, we find that a Bitcoin minted in 2021 is accountable for emitting 126 times the CO2e as a Bitcoin mined in 2016—an increase from 0.9 to 113 tonnes of CO2e per coin [10]. If adoption continues at its present pace, which is comparable to some of the slowest widely used technologies, the cumulative emissions from Bitcoin use will surpass the 2 °C barrier in 22 years, or in 11 years, if adoption proceeds at the level at which various technologies have been accepted [11].

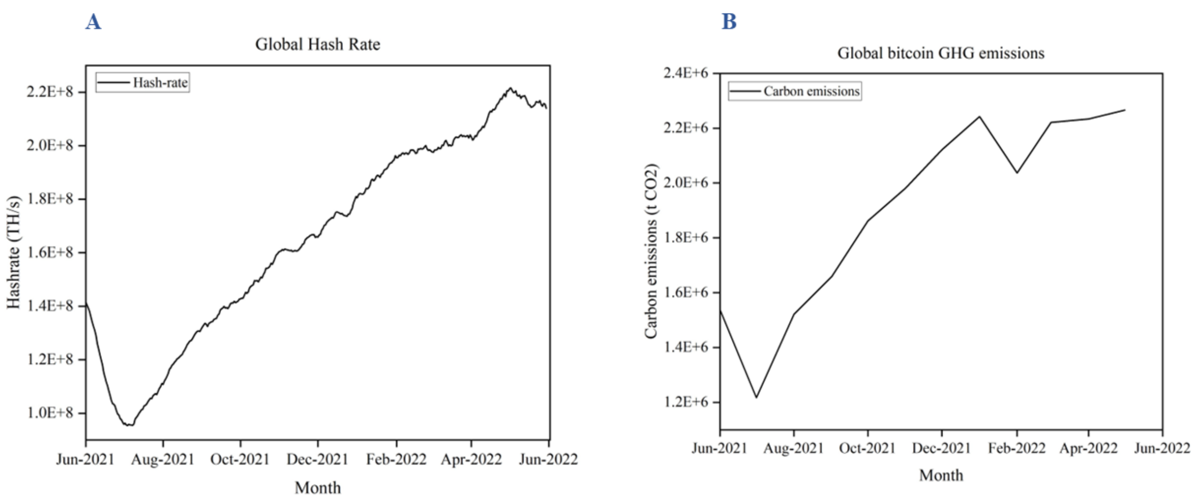

Figure 4.1 (A) Global bitcoin network hash rates [12] (B) carbon emissions

This clearly shows that if emissions from this source are neglected, the global sustainability practices to combat climate change will become so bleak. The United Nations (UN) sustainable development goals (SDGs) especially 7 and 13 will be more difficult to achieve as cryptocurrencies like bitcoin are engulfing a huge amount of energy and hence emitting massive amount of carbon emissions as shown in Figure 4.1 (B). Moreover, the current implications of cryptocurrency mining in select countries i.e., United States, China, India, and Pakistan are discussed next.

4.2. Current implications of cryptocurrency-mining on energy and climate change for select countries

4.2.1. United States

United States is one of the major crypto mining countries in the world. The bitcoin mining is done on large scale in the United States because of its legality in the country. Mining operations lead to the rise in energy demand, which activates more power generation resources. For instance, stranded fossil fuel plants have been revived in New York state to fuel Bitcoin mining operations. Environmentalists have expressed concern that 30 fossil-fueled power plants in New York state may be reactivated for mining activities [10, 13]. To maximize profit from mining, miners shift towards coal energy and hence the emissions soar [14]. The hash rate in the U.S. for the period (September 2019 to January 2022) are shown in Figure 4.2 (A).

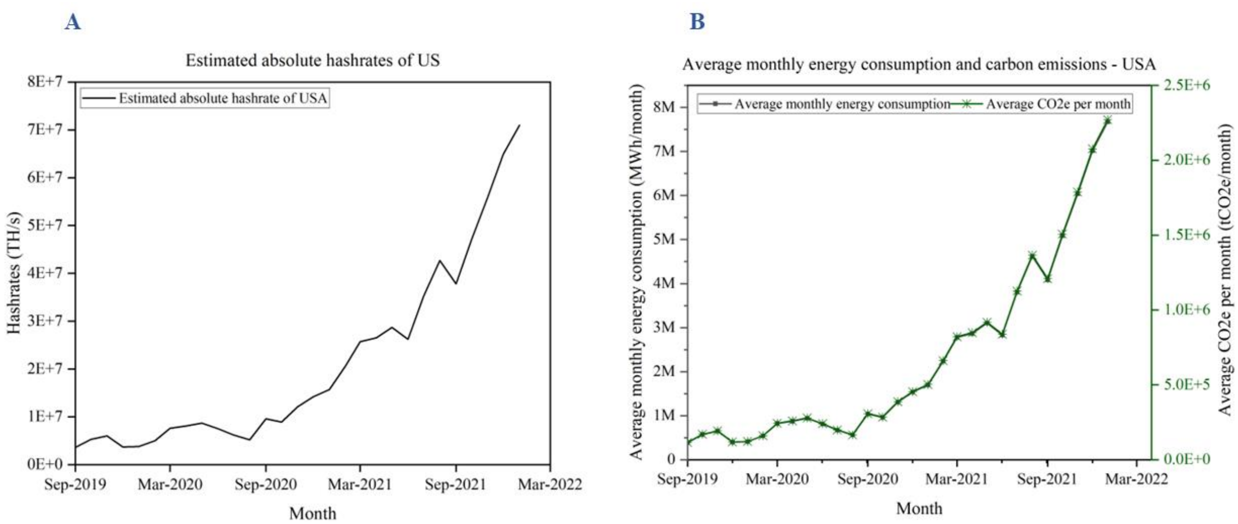

Figure 4.2 (A) Estimated absolute hash rates of US (B) Energy consumption, and CO_2e of US

The continuous upward trend with minor fluctuations can be observed in the figure. It can be seen that hash rate in 2019 i.e., 3600000 TH/s were far less than they are in 2022 i.e., 7.1E7 TH/s. It means that number of miners or crypto mining has significantly increased in the U.S. The energy consumption and the carbon emissions during this period are shown in Figure 4.2 (B). It's clear from the figure that the average monthly energy consumption and carbon emissions are proportional to the hash rate. The average monthly consumption in the beginning of period increased from 389100 MWh to 7.7 million MWh at the end of the period. Similarly, the monthly average GHG emission rose from 115194.1 tCO_2e to 2271883.7 tCO_2e during the period. The significant energy consumption and specialized hardware required by cryptocurrencies have an adverse effect on the environment [15]. Throughout the period, there is an increasing trend with little fluctuations for mining in the U.S., the reason behind this trend is that mining is totally legal in the country and the energy cost is less as compared to China. Another reason behind this situation is that after the mining crackdown in China, the miners rushed to the U.S. [16-19] because of lower electricity prices and mining freedom [19]. Consequently, the United States currently dominates mining, accounting for around 35.4% of the world's hash rate as of the end of August, according to the statistics, with Kazakhstan and Russia following it [20]. The situation has clearly become alarming and immediate measures are required.

After that, the energy consumed to mine one USD worth of bitcoin has been calculated. In Figure 4.3 it can be seen that the energy consumed to mine a bitcoin in the United States observed an upward trend throughout a period with minor fluctuations. The reason behind this increasing trend is because the computational complexity of the blocks mined determines how much energy is used [21-23]. As the bitcoin mining boomed in the United States and hence the energy consumption per coin reached 166.27 MWh/coin July 2021 and then there was a decreasing trend in energy consumed to mine a coin reduced to 101.4 MWh/coin in September 2021.

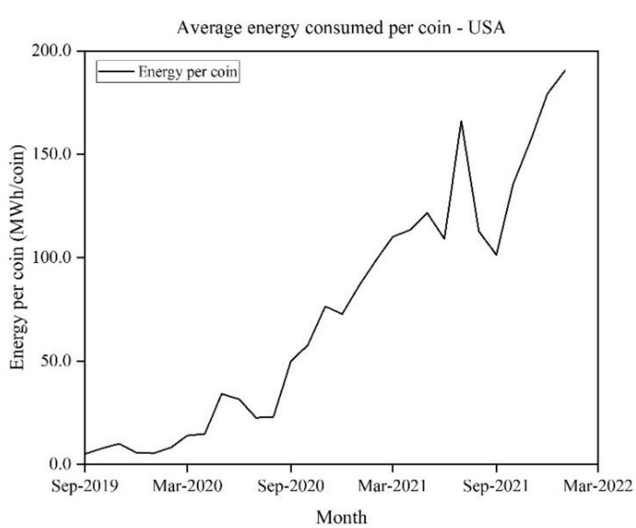

Figure 4.3 Energy consumed to mine one coin in US

But it again increased to all time high of 190.4 MWh/coin in January 2022. The reason behind this scenario is miners' fluctuating profit margin. Miners receive bitcoins as a reward for their successful creation of new blocks on the Bitcoin blockchain [24].

The calculated carbon credit price for the monthly carbon emissions shown in Figure 4.4. As per EU ETS market, the carbon credit price for USA followed the similar trend as carbon emissions graph. The price is dependent on the amount of carbon emissions emitted. As the market price for the tonne of CO_2e is fluctuating, there's difference between the trend of carbon emissions and carbon market price graphs.

During the start of the period the average monthly price for one tonne of carbon was about €25/tCO_2e [25] and the price for 115194.1 t CO_2e was about €2.9 million. The market price increased approximately €30/tCO_2e. The price for overall research period is shown in Figure 4.4. As the climate change is causing humanitarian crisis, world can't compromise on GHG emissions and as a result the average price per tonne of CO_2e reached €85 per tonne of CO_2e. As a result, the price for 2271883.7 tCO_2e reached €193 million. It is anticipated that a high rise in CO_2e emissions per coin minted as mining operations have grown over time [26].

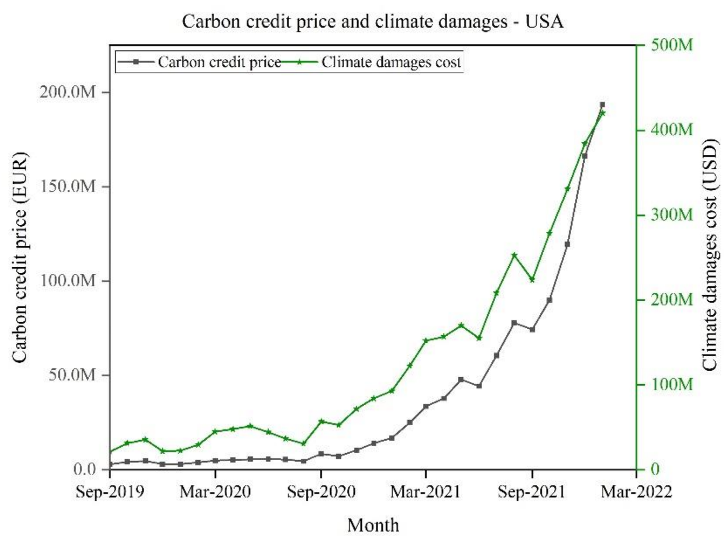

Figure 4.4 Monthly carbon credit and climate damages cost for USA

The climate damages in form of USD associated with all GHG emissions emitted due to cryptocurrency mining have also been depicted in Figure 4.4. It can be observed that the climate damages also increased with the increase in the carbon emissions and energy consumption in the country. During the start of the period as the energy consumption and carbon emissions were lower, the climate damages caused were only about $21 million which increased with the passage of time. A research estimates that for every dollar of BTC market value produced during the month, $1.56 in global climate damages were incurred [26]. As mining soared in the United States, the climate damages also soared and by January 2022, due to cryptocurrency mining only more than $420 million worth of harm had been caused in the country. As CO_2e emissions per coin minted grew over time, so did BTC production's climate damages [26].

4.2.2. China

China is among the countries with economies in transition. In China, about 55% of the energy comes from coal [27] and 7.7% from hydropower [28] and according to benchmark scenario about 40% of miners are mining in coal-based regions [1]. Despite of bitcoin mining crackdown in China in 2021, miners continues to mine in the country [29]. As the major source of energy in China is coal, lots of Greenhouse gas (GHG) emissions are already associated with it. Before 2021 crackdown, China was the country with largest number of crypto miners. Because of its accessibility to producers of specialized hardware and availability to cheap electricity, China had housed the majority of the mining, with Chinese miners accounting for over 75% of the Bitcoin network's hashing power [1]. In order to estimate the mining situation in China, hash rates, energy consumption, and carbon emissions can be seen in Figure 4.5. In Figure 4.5 (A) it can be seen that hash rate share of China was more than 66M TH/s in September 2019 which with some fluctuations reached its maximum of 91.1M TH/s in September 2020, with the total energy consumption of 9.85 TWh and the carbon emissions reached 2915051 tCO_2e as shown in Figure 4.5 (B). China had been a significant Bitcoin miner country, and coal contributes to 60% of the country's energy consumption [30]. Based on the benchmark simulation of Bitcoin blockchain carbon emission (BBCE) modelling, it is determined that the annual energy utilization of the Bitcoin sector in China will be at maximum in 2024 at 296.59 Twh. As a result, it was expected that the annual Bitcoin operation's carbon emissions would reach to maximum of 130.50 million metric tons per in 2024 [1]. As a result of Chinese government crackdown in 2021, the mining halted in the country and the energy consumption due to this purpose lowered to about 58.58 TWh with carbon emissions at a lower level of 1315133 tCO_2e. By August 2021, China's contribution to the global Bitcoin mining computer power had fallen to zero from over 80%. But since then, the country's contribution appears to be increasing once again [31]. In January 2022 it consumed about 4.3 TWh of power for crypto-mining purpose. According to CBECI, the China's share of the world's Bitcoin mining computer power surpassed 20% in January of in 2022 [31].

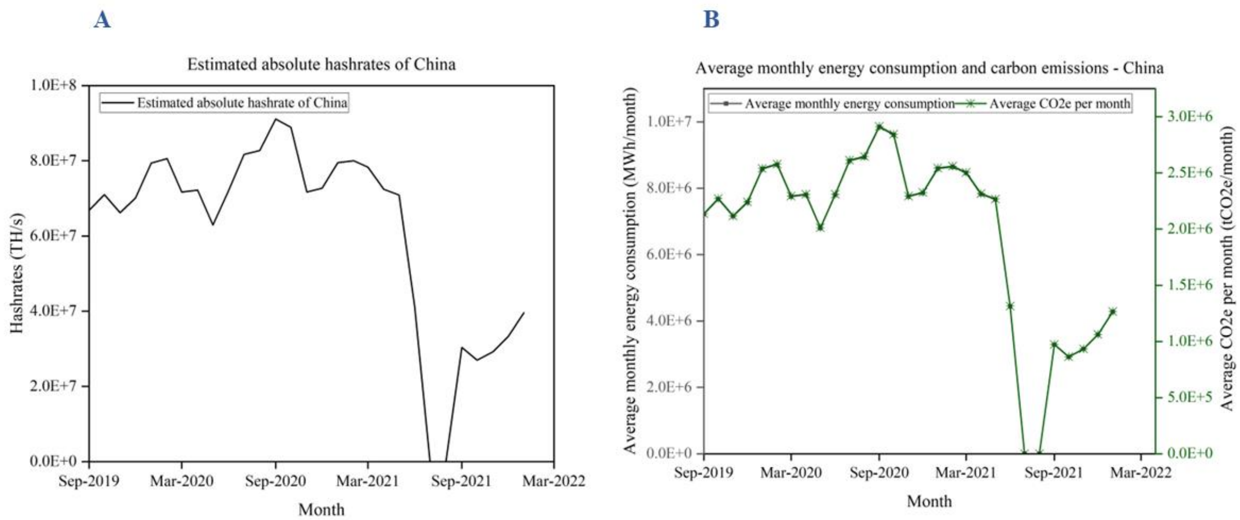

Figure 4.5 (A) Estimated hash rates of China, (B) Average monthly energy consumption and CO_2e of China

In Figure 4.6, the energy consumption to mine one coin can be seen for China. It can be observed that as the energy consumption was at a peak during the peak mining period in China i.e., from April 2020 – April 2021, the energy consumed to mine a coin in China also increased during this period and reached 576.5 MWh/coin in October 2020. Because bitcoin mining operations and continually running mining equipment increase energy consumption [1].

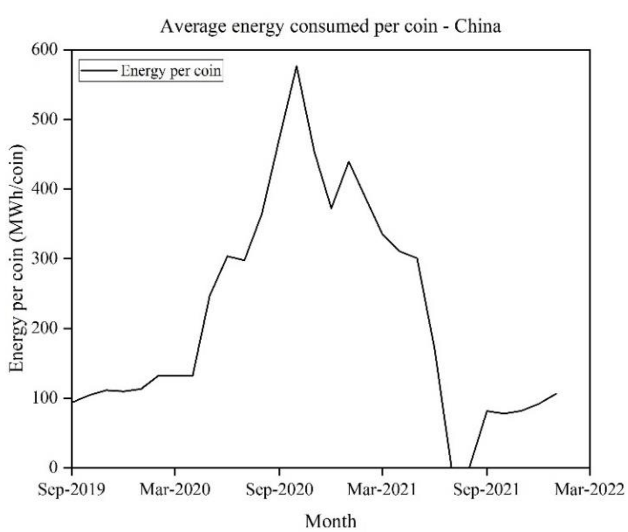

Figure 4.6 Energy consumed to mine one coin in China

But after the mining crackdown in China the overall energy consumption as well as the energy consumed to mine one bitcoin fell to zero. Later, the mining started again in China [31] with the slower pace which also increased the energy to mine a single coin to 106 MWh/coin.

The average price for the carbon emission trading for mining in China has also been shown in Figure 4.7. It can be seen that the price for 2137491 tCO_2e is only €54 million. Which increased to €118 million in May 2021 as the energy consumption and carbon emissions increased in China due to mining activities. The monthly carbon credit price for China peaked in this month because of higher average monthly price of about €52/tCO_2e. During the Chinese government crackdown, the graph fell to zero as there was no hash rate, energy consumption, or carbon emissions recorded in the country. Then, with the increase in mining activities in China, the carbon trading price also increased, and it reached to €107 million by January 2022.

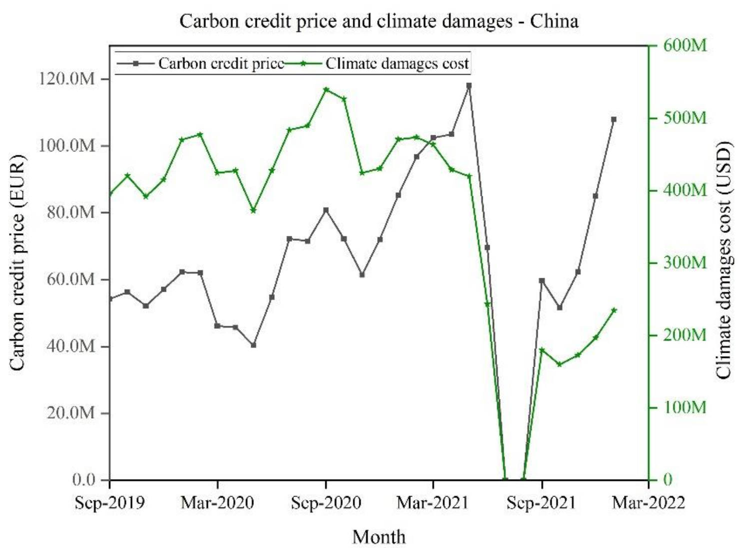

Figure 4.7 Monthly carbon credit and climate damages cost for China

The climate damages caused due to cryptocurrency mining in China have been depicted in Figure 4.7 in form of USD. As climate damages are proportional to the amount to GHG emissions, the trend is same as CO_2e emissions, discussed earlier. It can be observed that the climate damages were also higher during the peak mining period in China. The climate damages occurred during the beginning of the period were worth nearly $400 million with some fluctuations increased to approximately $540 million in September 2021. In May 2020, damages soared at 156% of the coin's value. Between 2016 and 2021, it is anticipated that worldwide BTC climate damages reached $12 billion worth of money. In 2021, 25% of market prices were attributable to mining-related climate damage as a result of BTC's end-of-2020 price hike [26]. The climatic implications of China's bitcoin mining account for a bigger proportion of overall damages (89 percent for climate vs 11 percent for human health effects) [32]. After the Chinese government crackdown on cryptocurrencies mining, the climate damages were also neglected as the carbon emission reduced to none. Later, as the cryptocurrency mining started again in China, the GHG emissions as well as the climate damages was started to increase and can be seen in Figure 4.7.

4.2.3. India

India is among those countries where the unregulated mining is done. Since, crypto-mining is unregulated in India, people do the mining depending on their own resources [33]. The cryptocurrency mining hash rate, energy consumption, and carbon emissions for India has been shown in Figure 4.8. In Figure 4.8, it can be seen that the mining followed the upward trend in India from September 2019 to April 2020. During this period the energy consumption reached the maximum level of 297.1 MWh in February 2020 with emissions level of 88 tCO_2e which can be seen in Figure 4.8 (B). As many people have invested in greatly in cryptocurrency [34]. After this period the downward trend can be observed in the crypto mining in India as can be seen in Figure 4.8.

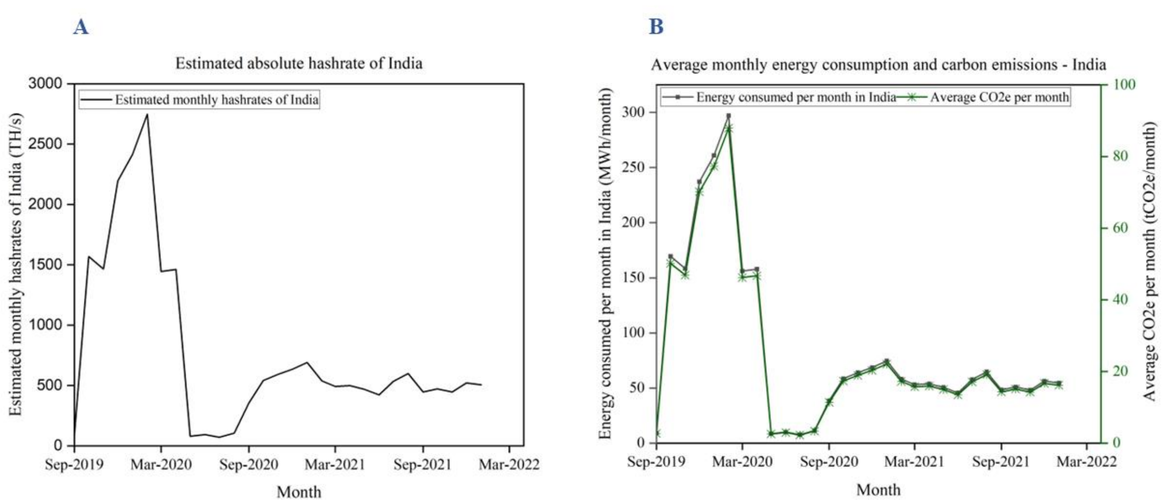

Figure 4.8 (A) Monthly hash rates of India, (B) Energy consumption and CO_2e of India

After that, the energy consumption and carbon emissions due to crypto mining lowered to 8.58 MWh and 2.54 tCO_2e respectively. This fall is due to Covid-19, as analyzed by previous literature [35, 36]. After this period the increment in crypto mining can be seen in the Figure 4.8, but it never reached the pre-pandemic level.

As mining is not regulated properly by government of India [37] and the world is coming out of the pandemic situation, mining can again reach its highest level in India and its maximum capacity. As in Figure 4.8 it can be seen that the mining in India followed an upward trend and with some insignificant fluctuations.

In Figure 4.9, the energy consumed to mine one coin in India is shown. It can be seen that on average energy consumed to mine a coin in September 2019 was around 118.04 Wh/coin and then abrupt increment can be observed in its trend which rose to maximum of 4511.9 Wh/coin in February 2020. As the mining is also done on the fossil fuel energy and it's cheap which attract more miners and hence consuming more energy [33]. After this period an abrupt fall in the graph can be observed where the energy consumed to mine a coin lowered to 258.7 Wh/coin, this fall be can be due to decreasing interest of the miners because the government could impose the ban on the cryo-mining at any time [37]. This definitively influence the confidence of the miners. After that, a sudden increase with the fluctuations can be observed in the energy consumption and it reached the maximum of 3813.4 Wh/coin in January 2021 and reason behind this scenario is advancement of technology and energy source in the country.

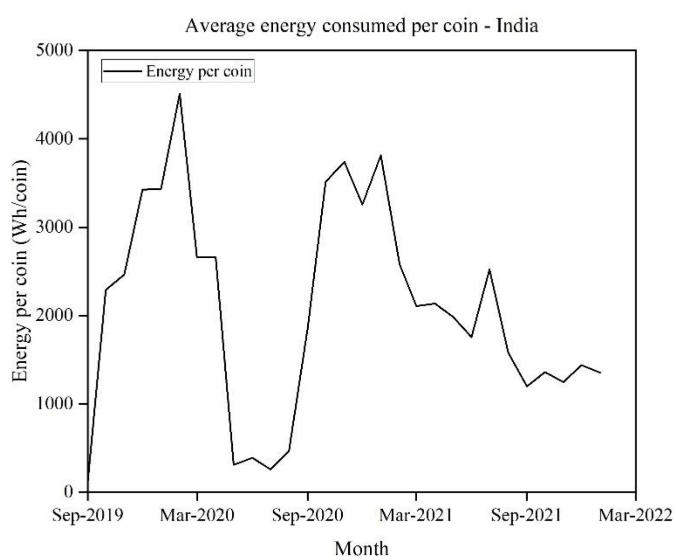

Figure 4.9 Energy consumed to mine one coin in India

After that the carbon credit price for emissions due to cryptocurrency mining in India has been calculated and can be seen in Figure 4.10. As the mining is done at a very lower level in India, there's a very low price for carbon credits in its case. It can be seen that the price was only €68 during the beginning of the period. With the increase in market price, energy consumption, and carbon emissions the carbon credit price reached €2118 in May for 87.96 tCO_2e.

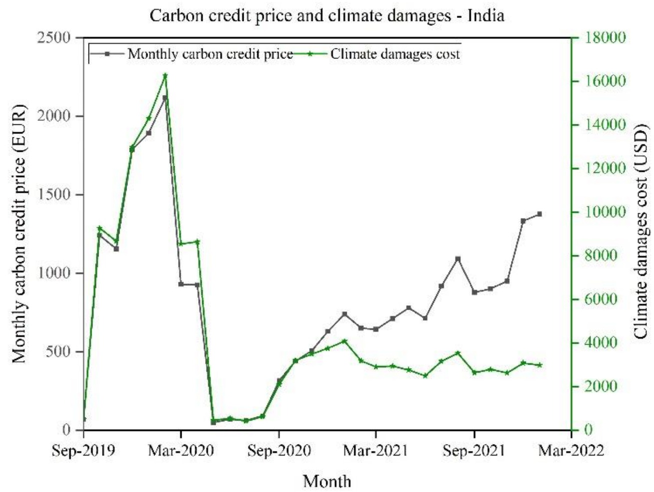

Figure 4.10 Monthly carbon credit and climate damages cost for India

After that there are fluctuation in the mining situation i.e., hash rate, energy consumption, and carbon emissions in India but the there's an increasing trend in the carbon credit price. This is because of the price increment in the EU ETS market which increased to €85/tCO_2e and hence the graph has shown a linear trend. The total price in the January 2022 for India is €1377.

The climate damages due to cryptocurrency mining in India have also been depicted in Figure 4.10. It can be observed that the worth of climate damages occurred is again proportional to total amount of GHG emissions due to crypto mining in the country. There's an increasing trend during the start of the period with minor fluctuations and the GHG emissions due to mining purpose caused only approximately $500 worth of damages which kept increasing in the upcoming month and reached at the peak in February 2020 causing climate damages worth more than $16000 in this month. According to a study, the social cost of mining the majority of currencies is not only rising, but for of Bitcoin and Ethereum, its growth rate is accelerating [38]. After that, as there was decline in the cryptocurrency mining in India as discussed before, the climate damages also started to decline and reached the minimum worth of $420 in July 2020 as shown in Figure 4.10. Later, the cryptocurrency mining started to rise again and so the carbon emissions and climate damages due to these emissions with fluctuations until the end of the period. As the mining across the country was accelerating, the worth of climate damages occurred during the end of period were worth approximately $3000. Moreover, the social cost of Bitcoin on a per-coin basis is rising fast with what looks a positive second derivative - a sign that the social cost might be alarmingly high in the future [38].

4.2.4. Pakistan

In Pakistan, cryptocurrency is not regulated by government. Up until April 2018, when the government outlawed trade and mining of the virtual currencies, bitcoin and other cryptocurrencies were booming in Pakistan [39, 40]. The mining sector is still expanding, even though several mining facilities have been closed since the implementation of this restriction [39]. Due to unregulated mining, people can mine the cryptocurrencies i.e., bitcoin, on the available source of energy.

The major source of energy in Pakistan is Gas i.e., 41.81%, followed by oil and coal as major sources of energy i.e., 26.44% and 17.42% respectively [41]. While other sources such as solar, wind, nuclear and other renewables are used at a very small scale. Share of hydropower as a source of energy is also significant but not as much as gas and coal. Mining being done on the government-provided energy source shares the same energy mix as discussed above. Hence, it imparts diverse impact on the climate and contributing towards the climate change.

In Pakistan, mining shows the varying trend throughout the period (September 2019 – January 2022). The ups and downs in the trend are due to different reasons including lack of resources, technologies, and policies. In Figure 4.11 (A) and (B) it can be seen that the hash rate, energy consumption, and carbon emissions due to mining in Pakistan increased from September 2019 to February 2020 i.e., hash rate increased to nearly 9.2 TH/s, while energy consumption and carbon emissions rose to approximately 1 MWh and 0.3 tCO_2e. This number is not negligible for a country where crypto mining is not fully legal. This rise in the mining situation in Pakistan was due to increasing awareness about cryptocurrency mining in the country [42]. After this period, an abrupt fall in the graphs in Figure 4.11 can be observed i.e., the hash rates, energy consumption, and carbon emissions declined to 0.044 TH/s, 0.0047 MWh, and 0.0014 tCO_2e respectively. The reason behind this scenario is covid-19. These results are supported by the findings from previous literature [43]. From November 2020 to February 2021 the mining started to revive, and the energy consumption and carbon emissions rose to approximately 0.5 MWh and 0.15 tCO_2e. During this period, the Covid-19 situation was better in the country and hence the crypto miners gained confidence to mine again. Later, there's another downfall in the after this period and the reason behind this fall was again 2nd Covid-19 wave. This fluctuating trend during Covid-19 is in line with the findings from available literature [44]. The increasing trend in the mining activities in Pakistan can be seen which is because of country started reverting back to pre-pandemic condition. Also the average bitcoin price rose to US$ 60000 in November 2021 [45] which also encourage the miners to confidently invest their resources in mining. Then there's a decreasing trend in January 2022. The reason behind this situation is the power shortage in the country which not only impacted the usual routine activities but also the miners who mined the cryptocurrencies with their resources. As Pakistan's energy demand has risen to 28,500 MW, but supply is just 22,000 MW. The deficit caused power disruptions that lasted four to six hours in urban regions and eight hours in rural ones [46].

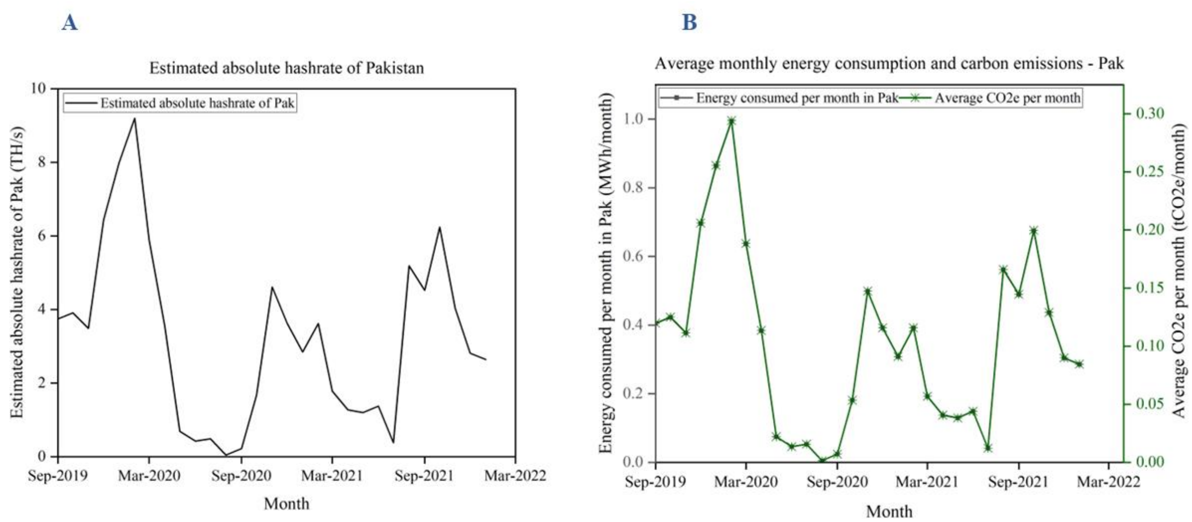

Figure 4.11 (A) Estimated hash rates of Pakistan, (B) Energy consumption and CO_2e of Pakistan

Figure 4.12 depicts the energy consumed to mine a coin in Pakistan. It can be observed that there are significant fluctuations throughout the period unlike United States and China. About 5.25 Wh/coin of energy was consumed on average during the beginning of the period which rose to 15.1 Wh/coin by February 2020. The reason behind this scenario is again same as described for energy consumption trend. This rise in the energy consumption per coin in Pakistan can be due to increasing number of miners in the country [42] and hence usage of more equipment and the resources. After that, there is a significant decline in the trend. The energy consumption per coin decline to as low as 0.19 Wh/coin by August 2020. The reason is again the same: Covid-19 [44]. In the next few months this number started to rise again and reached 29.2 Wh/coin by November 2020. The reason behind this growing trend is again similar to prior discussion about Pakistan's energy consumption i.e., better Covid-19 situation and the availability of advanced mining-equipment and resources. After that, there's again a abrupt fall in the energy consumption trend which declined to approximately 1.8 Wh/coin. The reason behind this scenario is 2nd Covid-19 wave in the country which affected lot of businesses and usual routines [44]. Another reason behind this declining trend is unregulated rules about crypto-currency mining by the government of Pakistan which make miners feel unsafe and unsure about their mining activities. Then there's an increase in the graph, the energy consumption jumped to approximately 18 Wh/coin which is because of rehabilitating situation from covid-19 and people started to mine again without any pandemic restrictions. Also, the price of one bitcoin jumped to US$ 57912 in October 2021 [45] which also encouraged the miners to mine with all of their resources and increase their profit margin. Then the decrement in the mining trend can be observed, which is because of shortage of electric power throughout the country [46] and it affected the miners as well.

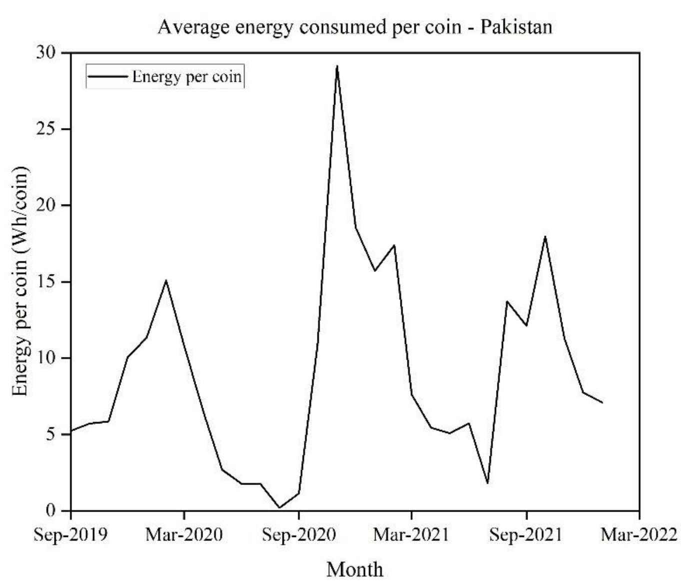

Figure 4.12 Energy to mine one coin in Pakistan

After that, the carbon credit price for the GHG emissions emitted specifically due to cryptocurrencies' mining in Pakistan has been calculated. The carbon credit market trend for Pakistan has been depicted in Figure 4.13. It can be observed that there's an overall fluctuating carbon credit pricing trend for Pakistan case, similar to hash rate, energy consumption, and carbon emissions. If compared to the global scenario, mining is done at a negligible scale as it is not fully legal in the country. In Figure 4.13 it can be seen that Pakistan's carbon credit price in overall period is negligible due to very small amount of crypto mining done in the country. The carbon credit price during the beginning of the period for Pakistan is only €3 as only 0.11 tCO_2e were emitted during this month. Later, this price increased to €7 as the mining increased in the country and overall significant fluctuations can be observed in the overall trend due to fluctuating mining condition in the country. The carbon credit price peaked to about €12 in October 2021 as the price had increased to approximately €60/tCO_2e. The change in carbon credit price in the international market is also a major reason behind this fluctuating trend.

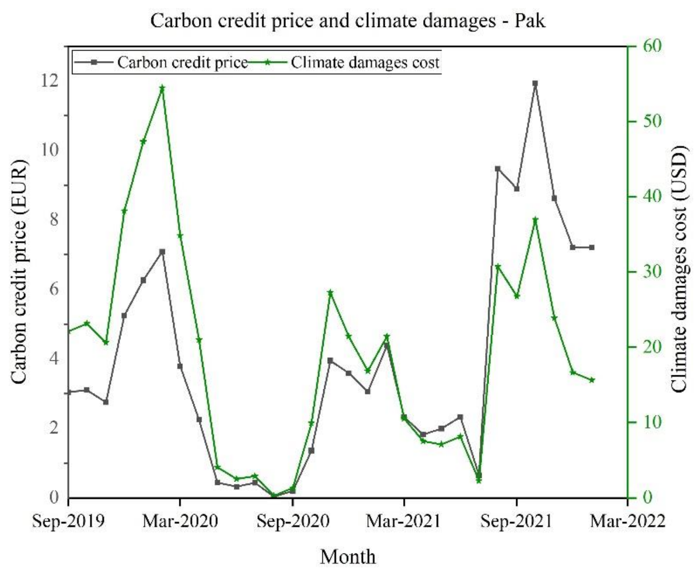

Figure 4.13 Monthly carbon credit and climate damages cost for Pakistan

The climate damages due to cryptocurrency mining in Pakistan have been depicted in Figure 4.13. Although, negligible amount of cryptocurrency mining is done in the country compared to the global scenario but there are climate damages associated with it. During the start of the period, the cryptocurrency mining seemed to be increasing and hence the carbon emissions associated with it. As a result, the climate damages also increased during this period and by February 2020 total damages occurred due to this purpose were worth nearly $55. The higher GHG emissions are emitted with the increasing cryptocurrency mining [26]. This amount is negligible again if compared with the major cryptocurrency mining countries like United States and China. After that, there's a significant decline in the climate damages as the cryptocurrency mining almost vanished from the country in August 2020 and total damages were worth less than a dollar. After that there's an increase in climate damages worth and further significant fluctuations until the end of the period, as these fluctuations are associated with the amount of miner or cryptocurrency mining in the country. Rather than decreasing as the industry grows, each new BTC currency minted is correlated with increased climate damages on average [26].

4.3. Future projections of cryptocurrency mining on energy and climate change for Pakistan

The crypto-currency mining is done in Pakistan despite not being regulated by the government. It is of no doubt that crypto mining being done in Pakistan is negligible if compared with the global scenario. Making precise predictions regarding the future of cryptocurrency mining in Pakistan is challenging since it relies on a number of variables, including governmental laws, prevailing economic circumstances, and technical advancements. Nevertheless, Pakistan has a large and expanding population of tech-savvy people, and the nation has the potential to play a significant role in the cryptocurrency mining sector. The Pakistani government has recently shown a greater openness to adopt new technology, which may eventually result in a more hospitable atmosphere for cryptocurrency mining. The future projections of mining for the period February 2022 to December 2023 for Pakistan have been shown below.

4.3.1. Hash rate projections

The hash rate forecast for bitcoin mining in Pakistan in future is depicted in Figure 4.14, it can be seen that there are fluctuations in the future trend as well. The hash rate in February 2022 expected to be 1.54 TH/s which reduced to minimum value of 0.025 TH/s in September 2022. This is due to massive fall in the cryptocurrency price and hence miners lost confidence in investing further in the mining [47]. After that it hash rate would reach the maximum value of approximately 3.7 TH/s in October 2022. This increasing trend is similar to the mining trend in the United States as crypto mining also increased in the country in during this period [48].

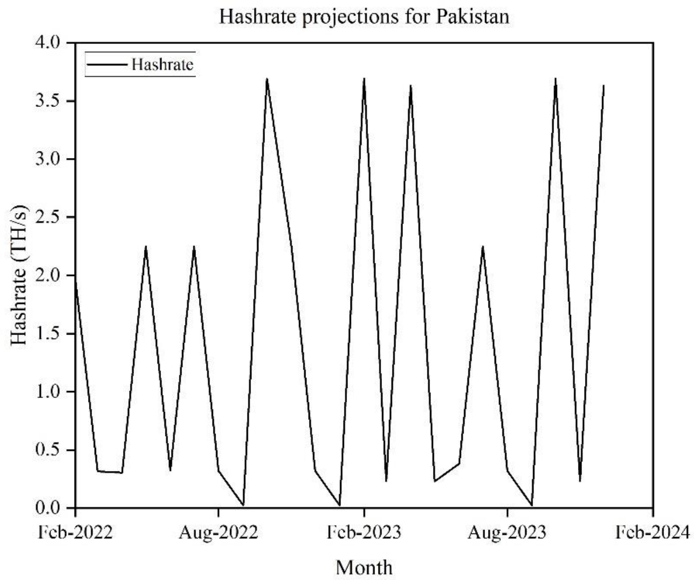

Figure 4.14 Hash rate projections for Pakistan

According to predictions, bitcoin hash rate will again reach the maximum value of approximately 3.7 TH/s in February 2023 and October 2023 and there would be lot of fluctuations during this period. These values are comparatively low because miners have already lost most of trust in mining the cryptocurrency due to the crypto crash in June 2022 [49]. Moreover, these major fluctuations will remain in the trend until cryptocurrency mining is not fully regulated by the government of Pakistan. The predicted hash rate value for December 2023 is 3.63 TH/s which shows that mining will thrive at similar rate in Pakistan and can be increased further in the future.

4.3.2. Energy consumption projections

Figure 4.15 depicts the forecasts for energy consumption due to cryptocurrency mining during the selected time period. It can be seen that energy consumption from February 2022 to March 2023 would reach maximum of 1.23 MWh/month with minor fluctuations during this period. The reason behind this scenario is major crypto crash in summer 2022. The cryptocurrency market saw a devaluation before extreme crash in June 2022. Not only has cryptocurrency experienced some of its cruelest months in terms of asset value, but it has also deceived crypto investors who were loyal to the investment market and believed that it could give them some economic security [49, 50].

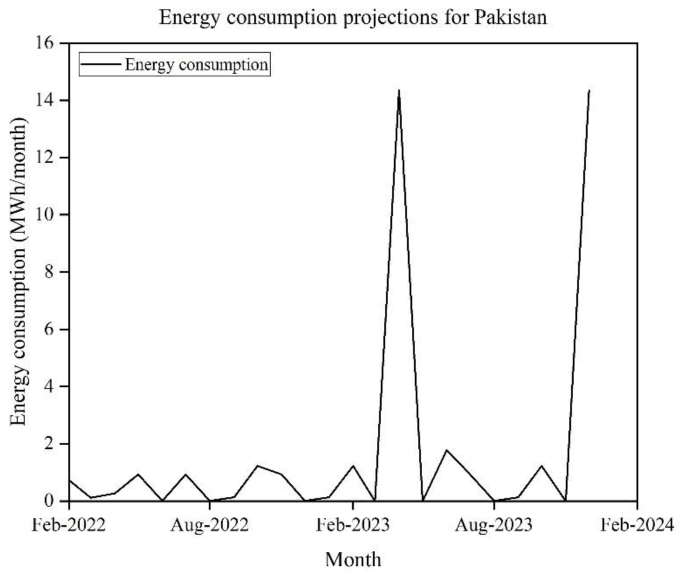

Figure 4.15 Energy consumption projections for Pakistan

The average monthly consumption of cryptocurrency mining is expected to reach as high as 14.35 MWh/month in April 2023. The forecasts about energy consumption due to bitcoin mining in mid-2023 are similar to the predictions given by Analytics Inside [51] that says as 2022 was a challenging year for crypto users, there is hopefulness that 2023 will be able to compensate for the damages that many people have experienced this year. Crypto mining in Pakistan would again be reduced due to lower confidence in digital assets and nonregulation of cryptocurrency by government.

4.3.3. Carbon emissions projections

Similarly, the forecasts for the carbon emission due to cryptocurrency mining in Pakistan for the selected time period are shown in Figure 4.16. The carbon emissions throughout the period are expected to be lower. It can be seen that in February 2022 the forecasted carbon emissions are 0.16 tCO_2e approximately. And majorly trend in the forecast is downward trend with some fluctuations. The reason behind the decreasing trend is again same i.e., unregulated policies and huge crypto crash in summer 2022. All the miners were harmed badly and lost their assets and trust in digital currency in this crypto fall [49, 50]. As miners has been reduced in the country and hence the carbon emissions. The carbon emissions are forecasted to reach 0.11 tCO_2e in July. Because miners still believe that they can recover their lost assets and hence the mining is expected to thrive [51].

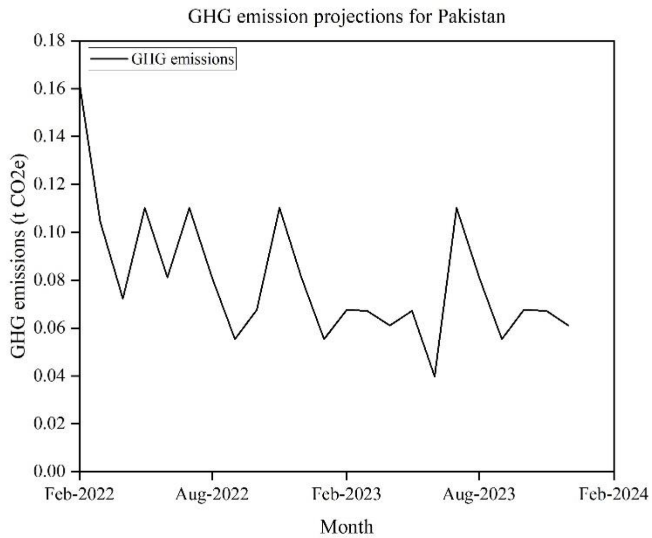

Figure 4.16 Carbon emissions projections for Pakistan

Summary

This chapter describes the detailed results of current and future implications of cryptocurrency mining on climate change. Total carbon emissions from only bitcoin network surpassed 2.27 Mt CO_2 in May 2022 which is a huge number and the emissions from this network were 1.54 Mt CO_2 in June 2021. Approximately, 22.9 Mt CO_2 emissions are produced during June 2021 to May 2022. The United States' average monthly consumption in the beginning of period increased from 389100 MWh to 7.7 million MWh at the end of the period and the price for 2271883.7 tCO_2e reached €193 million. About $420 million worth of climate damages were occurred in January 2022 due to crypto mining in US. The energy consumption trend to mine one coin in the US remained fluctuating due to fluctuating profit margin. Similarly, China's monthly average GHG emission rose from 115194.1 tCO_2e to 2271883.7 tCO_2e during the period. Cumulatively, in 2020, the annual energy consumption due to bitcoin mining reached approximately 100TWh. With this result, the prediction of bitcoin energy consumption reaching 296.59 TWh by 2024 [1, 52] seemed fulfilling. As a result of Chinese government crackdown in 2021, the mining halted in the country and the energy consumption due to this purpose lowered to about 58.58 TWh with carbon emissions at a lower level of 1315133 tCO_2e. Approximately $540 million worth of climate damages occurred due to cryptocurrency mining in China. During the Chinese government crackdown, the graph fell to zero as there was no hash rate, energy consumption, or carbon emissions recorded in the country. Then, with the increase in mining activities in China, the carbon trading price also increased, and it reached to €107 million by January 2022. Also, before the crackdown, the energy consumption was at a peak during the peak mining period in China i.e., from April 2020 – April 2021, the energy consumed to mine a coin in China also increased during this period and reached 576.5 MWh/coin in October 2020.

India's energy consumption reached the maximum level of 297.1 MWh in February 2020 with emissions level of 88 tCO_2e during the period September 2019 to April 2020. About $16000 worth of damages occurred in February 2020 during mining in the country. India's mining activities were harmed badly during the pandemic and unregulated government policies. Hash rate, energy consumption, carbon emissions, and carbon tax were lowered as well. India has increasing trend in case of energy consumption to mine one coin because of advancement of technology and faced decline during the severe conditions. Moreover, the hash rate, energy consumption, and carbon emissions due to mining in Pakistan increased from September 2019 to February 2020 i.e., hash rate increased to nearly 9.2 TH/s, while energy consumption and carbon emissions rose to approximately 1 MWh and 0.3 tCO_2e. So, the climate damages were also negligible. Pakistan's no regular government policies and lack of resources and technologies are the major reason behind the least mining in the country. And the energy consumed to mine a coin in Pakistan is also fluctuating because of non-availability of advance technology and resources and unregulated government policies. Furthermore, using machine learning it is predicted that the mining activities in the future also cannot increase due to different scenario discussed.

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Chapter 5

Conclusion and Recommendations

5.1. Conclusion

The impacts of bitcoin mining on energy consumption and the environment are alarming. The recent surge in bitcoin's mining has garnered a lot of attention, but it also requires more electricity and leads to more carbon emissions. However, in 2021 after China's crackdown on cryptocurrency, there was a significant decrease in the global hash rate and carbon emissions as a large number of miners were based in China and a majority of its power was generated from coal. Following the severe restrictions imposed by the Chinese government on cryptocurrency mining, many miners moved to the United States where electricity is cheaper, and regulations are more favorable. This led to the United States becoming the dominant country for mining cryptocurrency. However, as miners sought to maximize profits, carbon emissions in the country increased as they turned to coal-powered energy sources.

In developing countries such as India and Pakistan, where cryptocurrency mining is not widespread, overall energy consumption, carbon emissions, and energy required to mine one coin are lower compared to countries like the United States and China. Due to the lack of government regulation in India and Pakistan, miners have to rely on their own resources and use limited technology, which comes with a significant level of risk. This is a major reason for the low level of mining activity in these countries. However, predictions for cryptocurrency mining in Pakistan suggest that there is potential for growth in the industry within the country. Pakistan has a relatively low cost of electricity, which makes it a favorable location for cryptocurrency mining operations.

It is clear that the rapid growth of cryptocurrencies and the accompanying energy consumption will result in a significant increase in greenhouse gas emissions and other air pollutants. However, incorporating renewable energy into cryptocurrency mining [1] and using efficient equipment could potentially mitigate this impact. Moreover, cryptocurrencies can be considered an electric load because they require electricity to run the complex algorithms that enable them to function. They are also flexible in that they can be used for a wide range of purposes, including financial transactions. Additionally, the use of cryptocurrencies can potentially have an impact on the national load curve and increase the base load. Hence, it is crucial that appropriate demand side management (DSM) techniques are implemented and regulated properly [2, 3]. Furthermore, it is important to consider the potential impacts and carefully regulate the use of cryptocurrencies in order to ensure that they are used efficiently and in a way that benefits society as a whole.

Moreover, the use of excessive electricity for cryptocurrency mining has the potential to drive increased exports and revenue generation. This growing industry presents an opportunity for governments to capitalize on this revenue stream by including crypto miners in the taxation system. However, it is important to take a comprehensive approach when evaluating the impact of this industry on energy consumption, the environment, and regulatory considerations. To maximize the benefits and minimize the drawbacks, it may be necessary to adopt new policies, technologies and practices that ensure sustainable, responsible and profitable growth of the crypto mining industry.

5.2. Future recommendations

Recommendations for the future are given next:

- For the future work, in order to reduce the carbon footprint of the cryptocurrency mining, the hypothetical scenarios to integrate renewable energy sources to cryptocurrency mining plants can be modelled.
- Furthermore, future work can emphasize on the recommendations for the policy makers to reduce the overall impact of cryptocurrencies on energy and environment sector.
- More research can be done on how electricity prices in the developing countries impact the miners to invest their resources for cryptocurrencies mining purposes.

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Annex-A

Python code

The code for training the CNN model is given below:

```
# define model
model = Sequential()
model.add(Conv1D(filters=64, kernel_size=2, activation='relu',padding='same', input_shape=(n_
steps_in, n_features)))
model.add(MaxPooling1D(2))
model.add(Flatten())
model.add(Dense(32, activation='relu'))
model.add(Dense(n_steps_out))
model.compile(optimizer='adam', loss='mse',metrics=['mean_absolute_percentage_error'])
```

Code for importing the libraries is given below:

```
import os
import warnings
warnings.filterwarnings('ignore')
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import pandas_datareader as web
from sklearn.metrics import mean_squared_error, mean_absolute_error
import math
from numpy import array
from keras.models import Sequential
from keras.layers import Dense
from keras.layers import Flatten
from keras.layers.convolutional import Conv1D
from keras.layers.convolutional import MaxPooling1D
```

```
import datetime
```

The code to do the predictions on the test data is given below:

```
# split into samples
raw_seq = test_data
X_test, y_test = split_sequence(raw_seq, n_steps_in, n_steps_out)

y_pred_f = []
for i in range(0,len(X_test)):
    pred= model.predict(X_test[i].reshape((1,n_steps_in,n_features)))
    y_pred_f.append(pred)

Next_Months = 24
for i in range(0,10):
    raw_seq = y_pred_f
    y_pred_x, y_pred_y = split_sequence(raw_seq, n_steps_in, n_steps_out)
    for i in range(0,len(y_pred_x)):
        pred= model.predict(array(y_pred_x[i]).reshape((1,n_steps_in,n_features)))
        y_pred_f.append(pred)
        if len(y_pred_f) == Next_Months:
          break
    if len(y_pred_f) == Next_Months:
      break
```