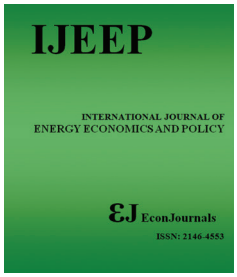

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(5), 564-578.

Digital Currencies, Energy Security, and Environmental Challenges: A G7 Perspective

Igor Britchenko*

University of the National Education Commission, 30-084, 2 Podchorążych Str., Krakow, Poland. *Email: igor_britchenko@pltch-sci.com

Received: 28 March 2025 **Accepted:** 05 July 2025 **DOI:** https://doi.org/10.32479/ijeep.19990

ABSTRACT

This article presents a comprehensive analysis of the impact of cryptocurrencies on the economic and environmental security of the G7 countries, exploring both the potential risks and prospects. The study focuses on the United States, Canada, the United Kingdom, France, Germany, Italy, and Japan, offering a detailed exploration of the increasing adoption of cryptocurrencies in these nations. Despite the benefits such as enhanced financial inclusion and cross-border transaction efficiency, cryptocurrencies pose significant challenges, including their use in illicit activities like money laundering and terrorism financing. The research critically examines the substantial energy consumption associated with certain cryptocurrency mining processes, particularly Proof-of-Work mechanisms, and their consequent environmental impacts, including carbon emissions, electronic waste, and air pollution. It investigates the corresponding energy policies and regulatory responses emerging within the G7 to address these concerns, alongside the development of more energy-efficient alternatives like Proof-of-Stake and the push for renewable energy in mining. The article critically examines these dual aspects, highlighting the measures implemented by regulators and policymakers to mitigate risks. It also delves into the evolving landscape of Central Bank Digital Currencies (CBDCs) and their potential role in enhancing financial system efficiency and security, including considerations for their energy footprint. The study employs a robust methodological framework, combining statistical analysis of market trends, case studies, and policy analysis to provide a balanced view of the current state and future trajectory of cryptocurrencies in the G7 countries. By offering a nuanced understanding of both the opportunities and threats posed by digital currencies, including their energy and environmental dimensions, this article contributes to the ongoing discourse on their integration into global financial systems and their implications for sustainable economic security.

Keywords: Cryptocurrencies, Economic Security, Energy Footprint, Proof-of-Stake, Renewable Energy
JEL Classifications: Q43, Q56, C33

1. INTRODUCTION

The emergence of cryptocurrencies, a significant innovation in the financial sector, has garnered increasing attention across the globe, particularly in the economies of the G7 countries: the United States, Canada, the United Kingdom, France, Germany, Italy, and Japan. This article embarks on a comprehensive examination of the impact of cryptocurrencies on the economic security of these nations, considering both their potential and the challenges they pose. According to the blockchain analysis firm Chainalysis, the total number of cryptocurrency transactions in 2021 grew to $15.8 trillion. This represents a significant increase from 2019, when there were approximately 1.1 billion cryptocurrency transactions with a total value of $2.0 trillion. The popularity of cryptocurrencies and blockchain technology has resulted in exponential growth in the market for digital assets over the past decade. This growth is expected to continue as more individuals and institutions recognize the potential benefits of cryptocurrencies, such as increased security, lower transaction fees, and greater privacy. As a result, the cryptocurrency market is poised for significant expansion in the coming years, with new use cases and applications emerging as the technology evolves (Chainalysis, 2023).

Originating from the concept of digital currency pioneered by Chaum et al. (1989) and gaining momentum with the advent of Bitcoin (Nakamoto, 2008), cryptocurrencies have evolved rapidly over the past decade. Their growth, as documented by Chainalysis (2023), highlights a burgeoning market that extends beyond traditional financial systems. This study aims to delve into the dichotomy of cryptocurrencies: their role in enhancing transaction security and efficiency, and the risks associated with their use, including market volatility and potential for illicit activities.

Beyond these well-documented aspects, a critical dimension that has profound implications for economic security and sustainable development is the energy footprint of cryptocurrencies. The computational processes underpinning many prominent cryptocurrencies, particularly those employing Proof-of-Work (PoW) consensus mechanisms like Bitcoin, are notoriously energy-intensive (Digiconomist, 2025; Bradley, 2025). This high energy demand translates into significant environmental concerns, including substantial carbon emissions, generation of electronic waste from specialized hardware, and potential impacts on local air and water quality (Wendl et al., 2023; Kumar and Balamurugan, 2024). As G7 nations grapple with commitments to climate change mitigation and energy transition, the unchecked growth of energy-demanding cryptocurrency mining presents a complex policy challenge. The economic security of nations is increasingly intertwined with prudent resource management and environmental sustainability. For G7 countries, many of which are significant energy importers or are undergoing delicate energy transitions, the substantial energy demands of certain cryptocurrencies can strain national grids, potentially influencing energy prices and availability for other vital economic sectors, thereby affecting overall economic stability (Karim et al., 2022; Bradley, 2025).

Furthermore, the environmental degradation associated with energy-intensive mining can lead to considerable long-term economic costs, such as increased healthcare expenditures due to pollution and the expenses of climate adaptation measures, while also potentially damaging their international reputation concerning climate commitments. Consequently, the energy dimension is not a peripheral concern but a central element in assessing the holistic impact of cryptocurrencies on the economic security of the G7. This paper will therefore extend its analysis to incorporate these energy and environmental considerations, examining how G7 countries are navigating the tension between fostering innovation in the digital asset space and upholding their energy security and environmental sustainability goals. This includes an exploration of emerging energy-efficient technologies, such as Proof-of-Stake (PoS), the potential for renewable energy integration in mining operations, and the nascent energy-related policy and regulatory frameworks within the G7.

To achieve comprehensive analysis, our methodology intertwines statistical analysis with case studies, thereby capturing a spectrum of perspectives on the adoption and impact of cryptocurrencies within the G7 countries. This approach enables an exploration of market trends, trading volumes, and specific impacts in various sectors, informed by the foundational work of Claeys et al. (2018) on the diversity of cryptocurrencies and their transactional dynamics. In addition to exploring the direct implications of cryptocurrencies, this paper also sheds light on the ongoing development of Central Bank Digital Currencies (CBDCs). We examine the efforts and strategies of G7 nations in navigating the landscape of digital currencies, as reflected in the actions of their central banks and regulatory bodies. This includes a critical assessment of the current state of CBDCs, their potential to reshape monetary policy, and their role in maintaining financial stability, with a specific G7 mandate that any CBDC ecosystem must be energy efficient. The G7's proactive stipulation for CBDC energy efficiency signals an awareness of the substantial energy challenges posed by some existing private cryptocurrencies and implicitly sets a benchmark. This stance suggests that G7 nations may increasingly evaluate and regulate digital assets based on their energy profiles, potentially favoring those with more sustainable designs. This principle could thus serve as a precursor to broader G7 policies aimed at promoting energy efficiency across the entire digital asset spectrum.

The following sections will explore the history and growth of cryptocurrencies, their integration into the financial systems of the G7 countries, their energy and environmental footprint, regulatory responses, and the potential future trajectory shaped by the advent of CBDCs. Despite the rapid growth of cryptocurrencies, the early years of this emerging technology were also characterized by controversy and skepticism. Bitcoin and other cryptocurrencies were often associated with criminal activity and were used to facilitate transactions on the dark web for purchasing illicit goods and services (Europol, 2021). As a result, governments and financial regulators around the world were initially slow to adopt or even recognize cryptocurrencies as legitimate assets. Additionally, the lack of regulation and oversight in the early days of cryptocurrencies gave rise to concerns about fraud, market manipulation, and the potential for investors to lose their funds. However, as the industry has matured and become more mainstream, many of these concerns have been addressed through increased regulation, improved security measures, and the development of new technologies aimed at enhancing the transparency and legitimacy of cryptocurrency transactions.

2. METHODOLOGY

For the purposes of the study, the method of statistical analysis was used to determine and interpretate statistical data related to cryptocurrencies, including market trends, price fluctuations, trading volumes, and other key indicators that provide insights into the behavior of cryptocurrencies. By using case studies method, the author was able to examine the impact of cryptocurrencies on specific industries or regions of G7 countries. For example, a case study method has been used to explore the impact of cryptocurrency adoption on the financial sector in Japan, or the use of cryptocurrency in the real estate industry in Canada. The author gathered data and information from various sources such as government reports, industry publications, and interviews with relevant stakeholders to analyze the impact of cryptocurrencies in a specific context. This method provided in-depth insights into the impact of cryptocurrencies on a specific sector or region, allowing for a detailed analysis of the opportunities and risks associated with their use.

This study employed a multi-faceted methodological approach to analyze the impact of cryptocurrencies on the economic security of the G7 countries. Thus, statistical analysis was used to capture the broad scope of cryptocurrency usage and its implications, we relied on statistical data. This included an analysis of market trends, price fluctuations, and trading volumes, which were essential for understanding the economic impact of cryptocurrencies. The data for this analysis were sourced from credible institutions and reports, such as Chainalysis (2023), providing insights into the behavior and evolution of cryptocurrencies in the global market.

Case studies helped to delve deeper into specific instances, we adopted the case study method. This involved examining the impact of cryptocurrencies on particular industries or regions within G7 countries. For example, we explored how cryptocurrency adoption has influenced the financial sector in Japan, drawing on government reports and industry publications. This method enabled a detailed analysis of cryptocurrencies in specific contexts, highlighting both opportunities and risks. Legal analysis was an integral part of our research. This entailed scrutinizing the legal status of cryptocurrencies in G7 countries and their implications for various stakeholders, including investors, businesses, and governments. By comparing the legal frameworks of different countries, we could assess the regulatory responses to cryptocurrencies and their effect on market dynamics. This analysis was informed by a variety of sources, including legal journals and government documents.

We used a comparative method to juxtapose various aspects of cryptocurrency regulation and adoption across the G7 countries. This method was particularly useful in analyzing the development of Central Bank Digital Currencies (CBDCs) and understanding the diverse approaches taken by G7 nations. By comparing these approaches, the study highlighted the factors influencing the adoption and regulation of cryptocurrencies, including cultural attitudes, political and economic stability, and existing regulatory frameworks. This study incorporates an extensive review of academic literature, reports from research institutions and international organizations (e.g., Cambridge Centre for Alternative Finance, Digiconomist, European Central Bank), industry publications, and official government documents and statements from G7 countries and the European Union. This methodological extension is crucial because analyzing energy consumption and environmental impacts requires specialized datasets and source materials distinct from those typically used for purely financial or legal analyses. This involves analyzing data on energy consumption, carbon footprint, e-waste, and reviewing existing and proposed energy-related policies and regulations concerning cryptocurrency mining. Sources provide quantitative data and qualitative analyses on energy use and environmental impact (Karim et al., 2022; Digiconomist, 2025), while others offer insights into policy responses (Carrier, 2022; Howard et al., 2024). Explicitly incorporating this review strengthens the methodological rigor for the newly added sections, enhancing the paper's credibility in addressing critical energy and environmental aspects.

The combination of these methods provides a comprehensive understanding of the complex landscape of cryptocurrencies and their impact on the economic security of the G7 countries. The findings from this multi-methodological approach form the basis for the discussions and conclusions presented in the subsequent sections of the paper.

3. RESULTS

3.1. Implementation of Cryptocurrencies in the Financial Systems of the G7 Countries

The implementation of cryptocurrencies within the financial systems of the G7 countries presents a diverse and complex landscape. This section provides an analysis of how these countries have integrated digital currencies into their economic frameworks, highlighting the variability in adoption rates and approaches.

In the United States, the integration of cryptocurrencies into the financial system has been significant. The country has seen a growing number of individuals and businesses adopting digital currencies for various purposes, from investment to payment processing. As a leading center for cryptocurrency exchanges and blockchain technology, the U.S. demonstrates a strong trend towards the normalization of digital currencies in financial transactions. Japan stands out as one of the most cryptocurrency-friendly countries. The government's regulatory framework has encouraged the growth of the industry, particularly after officially recognizing Bitcoin as a legal payment method in 2017. Japan's case highlights the positive impact of regulatory clarity on the adoption and growth of cryptocurrencies. In Canada, cryptocurrencies have also seen considerable adoption, especially in the real estate and financial sectors. European countries, while having varied approaches, demonstrate an increasing interest in incorporating cryptocurrencies into their financial systems. The European Central Bank's exploration of a digital euro exemplifies this trend.

Cryptocurrencies also operate using a decentralized public ledger known as a blockchain, which is designed to record and validate all transactions in a transparent and immutable manner. The blockchain technology enables secure, transparent, and tamper-proof recording of transactions, making it a highly trusted method of tracking and verifying digital asset ownership and transfer. This innovation has revolutionized the way financial transactions are conducted, making them faster, more secure, and less expensive than traditional financial systems. Nonetheless, cryptocurrencies have several drawbacks when compared to traditional currency. Cryptocurrencies are characterized by their decentralized nature, which means that they are not subject to control by any central authority, such as a government or central bank. Most of the academics of this field believe that an autonomous digital currency that is not connected to any government or other intermediary such as a bank is appealing because of the anonymity and liberty that it affords (Bunjaku et al., 2017).

While this attribute offers advantages such as increased security and transparency, it can also lead to potential drawbacks, such as a lack of stability or the possibility of manipulation of the money supply by a single entity. Anonymity is often cited as a disadvantage of cryptocurrencies, as transactions are not always

tied to a real-world identity. While this can provide privacy benefits, it can also facilitate illegal activity such as money laundering and terrorism financing. Additionally, the lack of transparency can make it difficult to investigate and prosecute these types of crimes.

3.2. Cryptocurrency: Perspective or Not?

Cryptocurrencies have also been characterized by high volatility, with their prices experiencing significant fluctuations within short periods of time. This high volatility has made cryptocurrencies a risky investment option and a less stable store of value than traditional money. The value of cryptocurrencies can be influenced by a variety of factors, including market demand, government regulations, and investor sentiment, which can cause sudden and dramatic price movements. This makes it challenging for investors and businesses to accurately predict the future value of cryptocurrencies, which can impact their adoption and acceptance in the wider financial system.

For example, in 2021, the cryptocurrency market underwent a considerable decline following a prolonged period of exceptional growth. Starting in May, the market began to plummet, with the largest cryptocurrency, Bitcoin, losing nearly half of its value in a few weeks (from a high of over $63,000 in mid-April to around $30,000 in late May). Other significant cryptocurrencies similarly experienced steep drops, with some losing over 80% of their value. The downturn was ascribed to various factors, including amplified regulatory scrutiny, concerns about the environmental impact of mining activities, and a general market correction following a swift growth period.

The question of whether cryptocurrencies represent a sustainable and viable aspect of the financial future is a subject of considerable debate. Cryptocurrencies are characterized by their high volatility, which can present significant investment risks. The dramatic price fluctuations, exemplified by the 2021 market downturn where Bitcoin and other major cryptocurrencies experienced substantial declines, highlight the speculative nature of these assets. However, this volatility also creates opportunities for high returns, attracting a considerable number of investors and traders.

Despite the risks, the adoption of cryptocurrencies is growing, with their utility expanding beyond mere speculative instruments. Bitcoin, as the most recognized cryptocurrency, has seen increased use in mainstream financial transactions. Furthermore, the proliferation of altcoins, like Ethereum, Binance Coin, and others, demonstrates the expanding scope of cryptocurrency applications, particularly in the realms of Decentralized Finance (DeFi) and non-fungible tokens (NFTs). The regulatory landscape for cryptocurrencies remains complex and varied across different jurisdictions. While some countries have embraced these digital assets with favorable regulations, others have imposed strict controls or outright bans. This uneven regulatory environment creates challenges for global cryptocurrency adoption and stability. However, it also presents opportunities for regulatory innovation and the development of more robust financial systems.

Considering the technological advancements and increasing global acceptance, cryptocurrencies could potentially play a significant role in the future financial landscape. The ongoing development of CBDCs by central banks, including those in the G7 countries, indicates a recognition of the potential benefits of digital currencies. However, the success of cryptocurrencies in the long term will depend on their ability to address key challenges, including regulatory compliance, market stability, and reduction in illicit uses. In summary, while cryptocurrencies offer promising prospects in terms of innovation and financial inclusion, their future in the global financial system is not without challenges. The balance between their potential benefits and inherent risks will likely shape their role in the evolving financial landscape (G7 Finance Ministers, 2021).

In their joint statement, the G7 officials also said that any CBDCs must support, and "do no harm" to, the ability of central banks to fulfil their mandates for monetary and financial stability. It is of utmost importance to emphasize the implementation of rigorous standards pertaining to privacy, accountability, and transparency to ensure the protection of users' data, as well as to establish trust and confidence among users. It is necessary to provide clear and transparent information on how data will be secured and used to avoid any potential breach of privacy. Therefore, measures should be taken to ensure that privacy is maintained at all times, and accountability for the protection of users' data is made a top priority in the development and implementation of any digital currency or payment system. Any CBDCs ecosystem must be secure and resilient to cyber, fraud and other operational risks, must address illicit finance concerns and be energy efficient. CBDCs must operate in an open, transparent and competitive environment that promotes choice, inclusivity and diversity in payment options.

3.3. Global Energy Consumption of Cryptocurrency Mining

This section details the energy consumption patterns of cryptocurrencies, particularly those utilizing Proof-of-Work mechanisms like Bitcoin, and their extensive environmental ramifications. It also explores technological shifts towards greater energy efficiency and the role of renewable energy. The Proof-of-Work (PoW) consensus mechanism, foundational to Bitcoin and other early cryptocurrencies, necessitates enormous electricity consumption (Karim et al., 2022; Bradley, 2025). This is a direct consequence of the computationally intensive process where miners compete to solve complex mathematical problems to validate transactions and mint new coins (Bradley, 2025; Jouri, 2025). The Bitcoin network's global annualized energy consumption has been estimated to be comparable to that of entire nations; for instance, figures suggest consumption levels similar to Poland (approximately 175.87 TWh) (Digiconomist, 2025; Bradley, 2025). Other comparisons indicate Bitcoin consumes more energy than countries such as the Czech Republic, the Netherlands, and Ukraine, and around half the consumption of G7 members Italy and the United Kingdom (Karim et al., 2022). To put this into perspective, the energy consumed for a single Bitcoin transaction (estimated at 1369.28 kWh) could power an average U.S. household for approximately 46.93 days (Digiconomist, 2025).

The primary driver for this substantial energy use is intrinsically linked to the economic incentives of PoW mining. The price

of Bitcoin, in particular, significantly influences the network's environmental impact; as its value increases, mining becomes more profitable, thereby incentivizing more participants to deploy energy-intensive hardware (Karim et al., 2022; Digiconomist, 2025). Miners, as rational economic actors, are willing to absorb high energy costs as long as the potential reward from mining (the value of the cryptocurrency) exceeds these operational expenditures (Karim et al., 2022). Furthermore, the design of the PoW algorithm, often incorporating a "difficulty adjustment" mechanism that increases the computational challenge as more mining power joins the network, inherently pushes for greater energy consumption to maintain competitiveness (Kumar & Balamurugan, 2024).

The geographical distribution of mining operations has also seen significant shifts, impacting the energy mix utilized. Historically, China was a dominant hub for cryptocurrency mining, benefiting from inexpensive energy sources, including coal-fired power and abundant seasonal hydropower (Velický, 2023). However, the Chinese government's ban on cryptocurrency mining in June 2021 triggered a mass exodus of mining operations to other countries, notably the United States, Kazakhstan, and Russia (Wendl et al., 2023; Digiconomist, 2025). This migration had immediate consequences for the carbon intensity of mining. For example, miners lost access to significant hydropower resources in China and relocated to regions like Kazakhstan, which heavily relies on coal for power generation, thereby increasing the share of fossil fuels in the global mining energy mix, at least initially (Digiconomist, 2025). This highlights the vulnerability of the cryptocurrency's environmental footprint to national policies and the geographic concentration of mining. As G7 nations, particularly the United States, absorbed a considerable portion of this relocated mining capacity (Wendl et al., 2023), their domestic energy mixes and regulatory policies have become increasingly critical in determining the global environmental impact of these digital assets. This also underscores a potential challenge: stringent energy regulations in G7 countries could lead to "carbon leakage," where mining operations shift to jurisdictions with less stringent environmental standards and more carbon-intensive energy sources.

3.4. Environmental Consequences

The immense energy consumption of PoW cryptocurrency mining translates into a range of significant environmental consequences, extending beyond just electricity usage. A primary concern is the substantial carbon footprint, particularly when mining operations rely on electricity generated from fossil fuels (Velický, 2023; Kumar and Balamurugan, 2024; Digiconomist, 2025). Estimates for Bitcoin's annual carbon dioxide emissions vary, with some sources suggesting figures around 98.10 million metric tons ($MtCO_2$), comparable to the emissions of Qatar (Digiconomist, 2025), while others, such as the Cambridge Centre for Alternative Finance (CCAF) in 2025, estimated it at 39.8 $MtCO_2$, akin to Slovakia's annual emissions (Wendl et al., 2023). The shift in mining from China, which had access to seasonal hydropower, to regions like Kazakhstan with coal-dominant energy, reportedly led to an increase in the average carbon intensity of electricity consumed by the Bitcoin network. In 2025, it was estimated that approximately half of the electricity used for Bitcoin mining was generated from fossil fuels (Velický, 2023).

Electronic waste (e-waste) is another significant environmental burden. The specialized computer hardware used for mining, known as Application-Specific Integrated Circuits (ASICs), has no alternative use beyond cryptocurrency mining and a relatively short operational lifespan due to the constantly increasing mining difficulty and technological obsolescence (Velický, 2023). A 2021 study estimated an average lifespan for mining devices at just 1.3 years, leading to an annual e-waste generation of over 30,000 metric tons, comparable to the small IT equipment waste produced by the Netherlands. This study linked each Bitcoin transaction to approximately 272 g of e-waste (Wendl et al., 2023). However, these figures are subject to debate; a 2024 systematic review suggested a longer hardware lifespan of 4-5 years, and CCAF data from 2024 estimated a significantly lower annual e-waste figure of 2300 metric tons, attributing this to a high rate of hardware recycling, resale, or repurposing (Velický, 2023). These differing estimates highlight the complexity in quantifying e-waste and the evolving dynamics of the mining hardware market.

Beyond greenhouse gas emissions, cryptocurrency mining can contribute to air pollution harmful to human health. The combustion of fossil fuels to power mining operations can release fine particulate matter (PM2.5) and other pollutants. The study by Brownstein (2025) investigated 34 large Bitcoin mines in the United States, finding they consumed 33% more electricity than the city of Los Angeles, with the vast majority sourced from fossil fuels. The study estimated that this activity exposed approximately 1.9 million Americans to higher levels of PM2.5. Notably, the research highlighted the transboundary nature of this pollution, where a power plant in one state supplying a mine in another could impact air quality in a third state, underscoring the need for federal-level regulatory consideration (Brownstein, 2025). However, this study has faced criticism from some energy and digital asset experts who argue its methodology, particularly the use of marginal emissions accounting and selective data, may have exaggerated the air pollution impact (Hunt, 2025). The Digital Assets Research Institute (DARI) also published a formal rebuttal echoing these concerns. This academic debate underscores the challenges in accurately attributing specific environmental harms to a decentralized global activity and the critical need for transparent, rigorously peer-reviewed research.

The environmental footprint also includes significant water consumption. The Bitcoin network's annual freshwater consumption has been estimated at 2,772 gigaliters (GL), a volume comparable to the total water use of Switzerland. A single Bitcoin transaction's water footprint has been likened to the amount of water in a backyard swimming pool (Digiconomist, 2025). Furthermore, there are concerns regarding methane emissions. Some Bitcoin mining operations are powered by electricity generated from the combustion of associated petroleum gas (APG), a methane-rich byproduct of crude oil drilling that is often flared or vented into the atmosphere. While combusting methane to produce CO_2 and energy is less damaging to the climate than releasing methane directly (as methane is a more potent greenhouse gas

in the short term), this practice still results in emissions and can economically enable continued or expanded oil drilling operations, potentially delaying the broader transition away from fossil fuels (Wendl et al., 2023).

These multi-dimensional environmental impacts, spanning carbon emissions, e-waste, air and water pollution, and indirect effects on fossil fuel infrastructure, necessitate a comprehensive assessment by policymakers. Focusing solely on carbon emissions provides an incomplete picture of the externalities, all of which can incur significant societal costs, from public health burdens to waste management challenges and resource scarcity. G7 policy responses, therefore, need to be multifaceted to address this spectrum of environmental concerns effectively.

3.5. The Shift towards Energy Efficiency: Proof-of-Stake and Renewables

In response to the significant energy and environmental concerns associated with PoW, the cryptocurrency industry and researchers have explored and implemented more sustainable alternatives. Proof-of-Stake (PoS) has emerged as a leading alternative consensus mechanism that is dramatically more energy-efficient than PoW (Jouri, 2025; Kalnoki, 2025). In PoS systems, network validation is not achieved through competitive, energy-intensive computation. Instead, validators are chosen to create new blocks and confirm transactions based on the number of coins they hold and are willing to "stake" as collateral (Jouri, 2025).

This fundamental difference in mechanism design leads to a drastic reduction in energy use. It is estimated that PoW networks like Bitcoin consume over 99% more energy than PoS networks such as Tezos, Polkadot, or Solana (Cole, 2024). The most prominent example of this transition is Ethereum's "Merge" in September 2022, when the second-largest cryptocurrency shifted from PoW to PoS. This upgrade reportedly reduced Ethereum's energy consumption by an estimated 99.95% (EY Switzerland, 2022; OSL, 2025b). Before the Merge, Ethereum's energy consumption was comparable to that of a medium-sized country; post-Merge, it became comparable to that of around 2100 American homes (Cole, 2024). According to OSL (2025b), the carbon footprint of a single Ethereum transaction plummeted from approximately 109.71 kg of CO_2 (PoW) to about 0.01 kg of CO_2 (PoS). This technological shift represents a paradigm change, decoupling blockchain security from massive energy expenditure and offering a viable pathway for aligning blockchain technology with environmental sustainability goals. PoS networks can also offer improvements in transaction throughput and scalability compared to many PoW chains (Jouri, 2025). For instance, while Bitcoin processes roughly five transactions per second at a high energy cost per transaction (around 830 kWh), some PoS networks can handle significantly more transactions at a fraction of the energy cost. Networks like IOTA and Hedera report even lower energy per transaction figures (Cole, 2024).

The integration of renewable energy sources into cryptocurrency mining operations is another avenue being pursued to mitigate the environmental impact, particularly of remaining PoW networks (Brian, 2025). Proponents argue that using solar, wind, and hydroelectric power can significantly reduce the carbon footprint of mining (OSL, 2025a). Benefits cited include lower operational costs due to reduced electricity expenses, an improved public image for the mining industry, enhanced energy independence for mining facilities, potential access to government incentives for green energy use, and greater resilience against the volatility of fossil fuel prices. Innovations such as more efficient solar panels and advanced battery storage solutions are making renewable energy more feasible for the continuous power demands of mining (Table 1).

Innovations such as more efficient solar panels and advanced battery storage solutions are making renewable energy more feasible for the continuous power demands of mining (OSL, 2025a). Industry groups like the Bitcoin Mining Council have reported an increasing share of sustainable energy in the global mining mix, claiming 58.9% as of early 2025, up from 36.8% in 2020 (Brian, 2025). Initiatives like the Crypto Climate Accord aim to decarbonize the entire crypto industry, targeting net-zero emissions by 2030 (Gschossmann et al., 2022). Examples of renewable energy use in mining include the following:

Table 1: Comparative energy and environmental metrics of major cryptocurrencies/mechanisms

Feature	Bitcoin (Proof-of-work)	Ethereum (Proof-of-stake, post-merge)*	VISA (Traditional payment)**
Annual Energy Consumption	~175.87 TWh (Bradley, 2025))	Drastically reduced by~99.95% versus PoW; now comparable to~2,100 US homes	~0.74 TWh (740,000 GJ for all operations in 2019)
Energy per Transaction	~1369.28 kWh	~0.01 kg CO_2 equivalent, implying very low energy; some PoS networks<0.001 kWh	~0.0002 kWh (derived from annual consumption and 138.3 billion transactions in 2019)
Est. Carbon Footprint	~98.10 $MtCO_2$/yr	Reduced by~99.95% versus PoW	Significantly lower per transaction than PoW Bitcoin
Primary Energy Sources	Mixed; ~50% fossil fuels; 58.9% sustainable	Grid-dependent, but mechanism itself is low energy	Grid-dependent
E-waste per Transaction	~272g (2021 study; lower estimates exist	Negligible due to no specialized mining hardware needed for validation	Minimal from transaction processing itself
Water Footprint (Annual)	~2,772 GL	Not specifically detailed, but vastly lower due to energy reduction	Not specifically detailed for comparison

*The Ethereum PoS figures reflect the dramatic efficiency gains post-Merge. **VISA data from 2019 is used as a baseline for a traditional, high-volume payment system
Source: compiled by the author based on EY Switzerland (2022), Wendl et al. (2023), Cole (2024), Brian (2025), OSL (2025a), Digiconomist (2025)

- Companies like Soluna Holdings, which develops green data centers co-located with wind farms in Texas (Gerke, 2025)
- Operations in Paraguay utilizing surplus hydropower (Brian, 2025)
- Projects that capture flared natural gas (methane from oil drilling) to power mining rigs, thereby reducing direct methane emissions compared to flaring (Brian, 2025)
- Deutsche Telekom's pilot project in Germany using surplus renewable energy for Bitcoin mining (Vardai, 2024)
- Japan's promotion of "green mining" initiatives utilizing surplus solar energy (Ekshian, 2024).

However, the narrative around "green mining" is not without its complexities and skepticism. Critics point out that much of the mining industry still relies on existing power grids, which often have a significant fossil fuel component. Bradley (2025) found that the mining industry does not inherently help decarbonize the grid but largely draws from it. There is an asymmetry problem: the high and often constant power demands of large-scale mining operations may not always align with the intermittent supply of some renewables, leading to continued reliance on fossil fuels for baseload or backup power. A crucial concern is the "crowding out" effect: if PoW crypto-assets increasingly consume renewable energy, they may divert these limited green resources from other essential uses or sectors that are also trying to decarbonize, potentially hindering broader green transition targets (Gschossmann et al., 2022). Globally, renewable energy still constitutes a minority share of electricity generation, making the allocation of these resources a critical issue. Therefore, while renewable energy integration offers potential, G7 policymakers must critically evaluate claims of "green mining." Policies should aim to ensure genuine "additionality" (i.e., that mining leads to new renewable capacity rather than just consuming existing supply) and prioritize energy for essential services or broader decarbonization efforts, especially when energy resources are constrained.

3.6. Regulation and Policy Responses in G7 Countries

The regulatory landscape for cryptocurrencies within the G7 is multifaceted, addressing financial stability, investor protection, illicit activities, and increasingly, the energy and environmental implications of these digital assets. While general cryptocurrency regulations, such as those implemented by the Securities and Exchange Commission (SEC) and Commodity Futures Trading Commission (CFTC) in the United States, the Canadian Securities Administrators (CSA) and FINTRAC in Canada, the Financial Services Agency (FSA) in Japan, and various EU bodies like the European Banking Authority (EBA) and European Securities and Markets Authority (ESMA), have been evolving, specific attention to the energy dimension is a more recent but growing focus. The development of Central Bank Digital Currencies (CBDCs) across G7 nations—with Japan piloting a CBDC, the ECB investigating a digital euro, the Banque de France testing wholesale CBDCs, the Bank of England establishing a CBDC Taskforce, Canada conducting research, and the US Federal Reserve exploring possibilities via Project Hamilton and a Presidential Executive Order —is also being shaped by energy considerations.

A significant indicator of the G7's stance is the principle articulated by its Finance Ministers and Central Bank Governors that any CBDC infrastructure must be designed for energy efficiency to support the transition to a net zero economy (McKee et al., 2021). This sets a precedent and signals broader concern regarding the energy demands of digital finance. The European Commission's 2022 Action Plan for Digitalizing the Energy System explicitly acknowledged the substantial global electricity consumption by crypto-assets, particularly those using PoW mechanisms. The Commission called for international cooperation to develop energy-efficiency labels for blockchains and urged EU Member States to implement measures to reduce the electricity consumption of crypto-asset miners. These measures included ending tax breaks and other fiscal benefits for miners and preparing to halt crypto-asset mining activities if load-shedding on electricity systems becomes necessary, especially in light of energy crises. A comprehensive report on the environmental and climate impact of new technologies in the crypto-asset market, including policy options, is anticipated from the Commission by 2025 (Carrier, 2022). This reflects a policy evolution where initial designs for state-led CBDCs incorporate energy efficiency from the outset, while policies for existing private cryptocurrencies are often more reactive, driven by emerging energy security concerns or environmental pressures (Table 2).

Thus, the United States has the high energy consumption associated with cryptocurrency mining, which poses notable legal and regulatory challenges. Concerns have been raised about its contribution to climate change impacts and the strain it places on national and regional power grids. Mining operations often gravitate towards areas with inexpensive electricity, which may not always be sourced from renewable energy; for instance, even in the Pacific Northwest with its abundant hydroelectric power, it was reported that less than half of the mining operations utilized renewable sources. This increased energy demand has, in some localities, led to significant increases in electricity bills for residents, with some experiencing hikes of over 30% (Bradley, 2025). Several impediments hinder a swift transition to renewable energy for U.S. mining facilities. These include an asymmetry between the consistent high power demands of mining and the often intermittent supply of renewables, restrictive state and local policies that can obstruct the development of new renewable energy projects, and supply chain bottlenecks for renewable technologies (Bradley, 2025).

In response, various solutions have been proposed, primarily from academic and advocacy spheres. These include making renewable energy tax credits conditional, denying them to mining operations that unduly burden the power grid or fail to meet predefined energy efficiency standards. Other proposals involve the increased use of local or state moratoria on new mining operations and the establishment of customer assurance mechanisms to shield consumers from energy price surges linked to mining activities (Brownstein, 2025). A more fundamental shift suggested is to reconsider how electricity is regulated, potentially not treating it as an ordinary commodity for such energy-intensive applications (Bradley, 2025).

Health and pollution concerns have also entered the discourse. The study by Brownstein (2025) pointed to increased PM2.5 air

Table 2: Overview of G7 national/regional policies on cryptocurrency mining energy consumption and environmental impact

Jurisdiction	Key policy stance on crypto mining energy	Specific measures/initiatives	Key bodies involved	Relevant legislation/ directives
United States	Fragmented; concerns over grid strain, pollution; some proposals for regulation/ incentives for renewables.	State/local moratoria proposed; conditional tax credits debated; EPA action suggested for pollution. White House EO on digital assets (implies energy review).	EPA (potential), State/ Local Govts, Federal Reserve, Treasury.	No specific federal law yet; state-level actions vary.
Canada (esp. British Columbia)	Restrictive/Precautionary at provincial level.	BC: Moratorium on new grid connections (until Dec 2025); new powers to regulate/ prohibit supply, set rates. Other provinces (MB, NB, QC) also regulating.	Provincial Govts (e.g., BC LGIC), BC Hydro, CSA, FINTRAC.	Utilities Commission Act (Legislative Assembly of British Columbia, 1996).
United Kingdom	Focus on financial regulation, taxation, and combating illegal energy theft for mining. Less specific policy on legal mining energy use.	Intent to implement CARF by 2027; plans for compulsory crypto regulation. Crackdown on electricity theft.	HM Treasury, FCA, HMRC, Police.	Property (Digital Assets etc) Bill (House of Lords, 2025).
France	Potentially strategic; exploring use of low-carbon nuclear energy for "Made in France" Bitcoin.	Proposal for pilot project with EDF; tailored regulatory framework for nuclear-powered mining suggested by industry association. High tax rate on mining.	Ministry of Economy and Finance, AMF, (potentially EDF).	MiCA (EU level); National tax laws (World, 2025; Adan, 2025).
Germany	Proactive industry/policy interest in integrating mining with renewable energy grid management.	Legislation promoting use of surplus renewable energy; industry projects (Terahash, Deutsche Telekom) using renewables/heat recovery.	Federal Govt (potential), Industry (Deutsche Telekom, Terahash), EBEA.	National laws on renewable energy and grid management (Vardai, 2024; Saptakee, 2024).
Italy	Regulatory focus on financial aspects/AML. Energy concerns likely addressed via EU framework.	Subject to EU directives (e.g., MiCA, Commission's Action Plan). No specific national energy policy for mining identified.	Ministry of Economy and Finance, CONSOB, Banca d'Italia (within ECB/ EU framework).	National implementation of EU directives (MiCA) (Carrier, 2022; Gschossmann et al., 2022).
Japan	Proactive encouragement of sustainable/green mining.	Initiatives to use surplus solar energy for mining; focus on responsible innovation. Strong VASP regulation. Active CBDC pilot.	FSA, Ministry of Economy, Trade and Industry (METI) (likely).	Payment Services Act, other financial regulations (Ekshian, 2024; Fung, 2025).
European Union (Overarching)	Growing concern; call for measures to lower consumption, end tax breaks, potential shutdown in crisis. Energy efficiency for CBDCs.	Action Plan for Digitalising Energy System; MiCA (disclosures on environmental impact); report on environmental impact due 2025.	European Commission, ECB, EBA, ESMA.	MiCA Regulation, EU Energy Directives (potential application) (McKee et al., 2021; Carrier, 2022).

Source: compiled by the author

pollution exposure for millions of Americans due to emissions from power plants supplying Bitcoin mines, suggesting a potential need for federal regulation by bodies like the Environmental Protection Agency (EPA) due to the interstate nature of such pollution. President Biden's Executive Order on digital assets, which calls for exploring the risks and benefits of a U.S. CBDC and establishing a comprehensive framework for responsible digital asset development, is expected to implicitly encompass energy and environmental considerations given the scale of mining in the U.S. The U.S. thus faces a complex interplay between federal and state regulatory authorities. While many potential regulatory tools (zoning, moratoria) lie at the state or local level, the transboundary nature of environmental impacts like air pollution may necessitate federal oversight. This creates a tension that could lead to a fragmented regulatory landscape or a push for more coordinated national policy.

As for Canada, several provinces have taken proactive steps to manage the impact of cryptocurrency mining on their energy systems. In British Columbia (BC), the provincial government implemented a temporary suspension (moratorium) on new electricity connections for cryptocurrency mining projects, initially for 18 months starting December 2022, and later extended to 36 months, now set to expire in December 2025 (Howard et al., 2024). The rationale behind this was the concern that unchecked growth in mining could impede BC's progress towards its electrification goals under the CleanBC plan and make it more challenging to maintain low electricity rates for other consumers (Government of British Columbia, 2024).

A report from BC Hydro highlighted the perceived challenges posed by crypto-mining to the province's clean energy transition (Howard et al., 2024). This suspension was legally challenged by a prospective mining company, but the BC Supreme Court upheld the government's directive, ruling that differentiation based on unique electricity consumption characteristics and economic or cost-of-service reasons does not constitute undue discrimination (Howard et al., 2024).

Furthermore, Bill 24 amended BC's Utilities Commission Act, granting the Lieutenant Governor in Council (LGIC) extensive powers to regulate the provision of electricity service for cryptocurrency mining. These powers include the ability to prohibit electricity supply for mining (indefinitely or for a specified period), set specific rates, limit the amount of energy or capacity supplied, and establish conditions for receiving service (Howard et al., 2024). The overarching policy goal is to strike a balance between the public interest and the commercial interests of both BC Hydro (the public utility) and cryptocurrency mining operations. The provincial government has characterized mining as an energy-intensive industry that creates "very few jobs or economic opportunities" for British Columbians (Howard et al., 2024). Other Canadian provinces, including Manitoba, New Brunswick, and Quebec, have also implemented measures to regulate power supply and electricity rates for crypto-mining operations, with some also resorting to moratoria (Government of British Columbia, 2024). This provincial-level leadership demonstrates a precautionary approach to regulation, driven by concerns over energy capacity management and local economic benefits. This could lead to a varied regulatory environment across Canada, influencing miners' operational decisions.

In the UK, cryptocurrency mining is legal for both individuals and businesses, with profits subject to appropriate taxation, such as Income Tax or Capital Gains Tax. If mining is conducted as a business activity, it is taxed as trading profits. The regulatory framework for cryptocurrencies in the UK is currently somewhat fragmented, though evolving. The government has expressed its intent to implement the OECD's Crypto-Asset Reporting Framework (CARF) by 2027 (Steer, 2019). In April 2025, the Finance Minister announced plans to bring crypto-assets under compulsory regulation, aiming to enhance consumer protection and market stability (Rozen, 2025).

A significant concern in the UK has been the rise of electricity theft to power illegal cryptocurrency mining operations. Law enforcement agencies have uncovered illicit "Bitcoin factories" that were operating by unlawfully diverting electricity from the grid (Steer, 2019). While the environmental implications of Bitcoin mining globally are acknowledged, specific UK government policies directly targeting the energy consumption of legal mining operations are not prominently detailed in available information, beyond adherence to the broader G7 principle of energy efficiency for CBDCs (McKee et al., 2021). The primary focus appears to be on combating illicit activities and establishing a comprehensive financial regulatory and taxation framework for the crypto sector. This suggests that direct intervention in the energy use of legitimate mining operations may be less developed compared to actions seen in some Canadian provinces or proposed at the EU level, unless energy security becomes a more acute issue or international obligations necessitate more specific measures.

France is positioning itself as a crypto-friendly nation within Europe, supported by a robust technology sector and the implementation of a clear regulatory framework, including the EU's Markets in Crypto-Assets (MiCA) Regulation in 2025 (World, 2025). Cryptocurrency mining activities in France are subject to taxation, potentially up to 45% under the BNC (non-commercial profits) regime (World, 2025). Interestingly, there is a strategic perspective emerging in France that views Bitcoin mining as a potential opportunity, particularly in leveraging the country's significant low-carbon nuclear energy capacity, which provides approximately 70% of its electricity (Adan, 2025). Adan, a French association for digital assets, has proposed that "Made in France" Bitcoin, mined using this decarbonized energy, could offer several benefits. These include monetizing surplus nuclear energy (estimated at $100-$150 million per GW per year), assisting in the amortization of investments made by EDF (the national electricity utility), stabilizing the electricity grid by absorbing excess power, supporting the integration of intermittent renewable energy sources, and even repurposing the waste heat generated by mining for applications like district heating or industrial use. From a competitiveness standpoint, localizing low-carbon mining activity could strengthen the French Web3 ecosystem, attract investment, reduce capital outflows, and bolster digital sovereignty. Adan has called for a pilot project in collaboration with EDF and the development of a regulatory framework tailored to make Bitcoin mining an asset for France's energy transition and innovation objectives (Adan, 2025). This approach contrasts with more restrictive measures seen elsewhere, focusing instead on strategic integration and optimization based on national energy strengths.

Germany is also showing signs of a proactive approach, with some industry perspectives positioning it as a leader in sustainable Bitcoin mining. This involves leveraging German engineering expertise to develop solutions that combine renewable energy sources with heat recovery systems from mining operations. Approximately 60% of Germany's electricity is generated from renewable sources (Saptakee, 2024). There are indications that Germany is introducing legislation aimed at promoting the use of surplus renewable energy for cryptocurrency mining, rather than allowing such energy to be curtailed or wasted. This aligns with the modular and flexible nature of mining operations, which can be deployed where excess energy is available. Several industry projects exemplify this trend. For example, Terahash is developing a project that integrates solar power, battery storage, and Bitcoin mining at an industrial park. This setup is designed not only to stabilize the grid but also to lower energy costs for businesses in the park and provide recovered heat for community facilities like schools and event halls (Saptakee, 2024). Similarly, Deutsche Telekom, Europe's largest telecommunications provider, has initiated a project dubbed "Digital Monetary Photosynthesis." This involves mining Bitcoin using surplus renewable energy that would otherwise go unused, in collaboration with Bankhaus Metzler. The project aims to test the regulatory effect of Bitcoin

miners on the energy grid, converting surplus energy into digital value (Vardai, 2024). The European Bitcoin Energy Association (EBEA), active in the region, advocates for Bitcoin mining as a potential solution to Europe's energy challenges, emphasizing the flexibility of miners to adjust their energy consumption rapidly, thereby helping to stabilize grids and support renewable energy production (Vardai, 2024). This approach suggests a focus on integrating mining into the energy system as a flexible load to support Germany's significant renewable energy capacity.

Italy's regulatory efforts concerning cryptocurrencies have primarily concentrated on financial aspects, including defining various cryptocurrency functions, Distributed Ledger Technologies (DLTs), and smart contracts, as well as implementing Anti-Money Laundering (AML) measures and investor protection safeguards through decrees and the adoption of EU directives like MiFID II. Cryptocurrencies are generally classified as financial instruments or as a form of currency that is not legal tender. Taxation policies are also in place, with capital gains from cryptocurrencies taxed at 26% (a rate set to increase to 33% in 2026). Income from mining activities for individuals is likely treated as general income upon sale of the mined crypto, while business-scale mining could be subject to progressive individual business income tax rates (23-43%) or corporate tax (24%) (Wimmer, 2025). However, specific national policies or regulations directly addressing the energy consumption of cryptocurrency mining in Italy are not evident from the available information (Bradley, 2025).

While the Italian Ministry of Environment and Energy Security is engaged in promoting general sustainability initiatives, and Italy, during its G20 Presidency, emphasized a broader green transformation, direct linkages to crypto mining energy use are not specified (Wimmer, 2025). As a member of the European Union, Italy will be influenced by and required to implement EU-wide regulations and recommendations, such as those from the European Commission regarding the energy use of crypto-assets (Carrier, 2022) and the MiCA regulation. The European Central Bank (ECB), of which Banca d'Italia is a key member, has also expressed concerns that crypto-assets with significant carbon footprints contribute to climate transition risks for the financial system and can negate greenhouse gas emission savings achieved in other areas (Gschossmann et al., 2022). Therefore, Italy's approach to crypto mining energy will likely be significantly shaped by these broader EU frameworks rather than bespoke national policies on this specific issue.

Japan has adopted a generally progressive and proactive stance towards cryptocurrencies and their regulation. A notable aspect of Japan's approach is the active advancement of eco-friendly cryptocurrency mining practices. This includes initiatives to utilize surplus solar energy for mining operations, aligning with the country's broader sustainability goals and its commitment to environmental responsibility. The rationale behind this is multifaceted: to reduce energy waste, support the domestic crypto mining sector, minimize the environmental impact of blockchain technology, and attract green investment, thereby positioning Japan as a leader in sustainable blockchain operations (Ekshian, 2024). The Financial Services Agency (FSA) oversees the regulatory framework, which emphasizes consumer protection and market integrity. Licensed Virtual Asset Service Providers (VASPs) in Japan are subject to stringent requirements, including robust Know Your Customer (KYC) and Anti-Money Laundering (AML) protocols, proof of reserves audits, and the segregation of client assets (Fung, 2025). Japan is also actively exploring a retail CBDC, with pilot programs underway, driven partly by a desire to enhance the resilience of its payment infrastructure, a concern highlighted by past events like the 2011 earthquake and tsunami. While promoting "green mining," there is no indication from the provided information of outright bans or severe restrictions on the energy use of mining operations in Japan. Instead, the focus appears to be on fostering sustainable integration of mining within the energy system and the broader digital economy (Ekshian, 2024). This approach of proactive governmental support for sustainable practices within the crypto mining industry, coupled with a strong regulatory framework, offers a model that contrasts with more restrictive measures seen in some other jurisdictions.

4. DISCUSSION

Cryptocurrencies have been marketed as a means of promoting financial inclusion and innovation, but they have also been misused by criminal organizations for illegal activities, including but not limited to money laundering, terrorist financing, drug trafficking, and ransomware attacks. The decentralized nature and pseudonymity of certain cryptocurrencies have made them appealing to criminals seeking to evade law enforcement and detection. Nonetheless, it should be emphasized that not all uses of cryptocurrencies are illicit, and numerous legitimate businesses and individuals employ cryptocurrencies for legal purposes (Balz, 2021).

The significant energy consumption and resultant environmental degradation from unsustainable cryptocurrency mining practices represent another critical facet of their "dark side." This aspect extends beyond ecological risks, creating substantial reputational challenges for the cryptocurrency industry and potentially undermining its social license to operate. If unaddressed, these environmental concerns could provoke stricter regulations or even outright bans in some jurisdictions. The intense competition for energy resources, particularly in regions already experiencing energy stress or those committed to ambitious green energy transitions, can exacerbate existing societal tensions and compromise energy security for essential services and other industries (Gschossmann et al., 2022; Kumar and Balamurugan, 2024; Bradley, 2025). Specifically, the reliance of many PoW mining operations on fossil fuels directly contravenes global efforts to combat climate change, a paramount concern for G7 nations committed to international climate agreements.

While distinct, the challenges of illicit finance and negative environmental impact are interconnected contributors to the "dark side" of cryptocurrencies, both attracting significant regulatory scrutiny. Activities detrimental to society, whether financial crimes or environmental damage, invariably provoke governmental responses aimed at mitigating these harms. There can be an overlap where the anonymity sought by illicit actors aligns with mining

operations seeking cheap, often unregulated, energy sources, potentially in jurisdictions with weak environmental oversight. The overall societal cost attributable to cryptocurrencies thus encompasses not only the direct financial losses from crime and fraud but also the extensive externalities stemming from environmental damage. This implies that regulatory frameworks must adopt a holistic perspective. Addressing financial crime while neglecting significant environmental harms, or vice versa, offers only a partial solution to managing the multifaceted risks associated with cryptocurrencies. Public support for cryptocurrencies within G7 nations could wane considerably if they are perceived as being both financially risky and environmentally damaging. Criminals, particularly those operating in the realm of cybercrime, have capitalized on the advantages afforded by cryptocurrencies and have begun utilizing them for such activities:

- Illicit Activities and Financial Crimes: The pseudonymous nature of cryptocurrencies has made them a favored tool for various illegal transactions, including money laundering, terrorist financing, and black market dealings. Cases such as the use of Bitcoin in dark web marketplaces underscore the urgent need for effective regulatory frameworks to combat these abuses. As highlighted by reports from Europol and the U.S. Department of Justice, the scale of cryptocurrency-related crimes is significant and growing, posing serious challenges to law enforcement agencies worldwide.
- Ransomware and Cybersecurity Threats: The rise of cryptocurrencies has coincided with an increase in ransomware attacks, where attackers demand payment in Bitcoin or other digital currencies. These incidents not only result in financial losses but also raise critical concerns about cybersecurity and the vulnerabilities of digital infrastructures. The complexities of tracing and addressing these crimes in a decentralized and borderless digital landscape are profound.
- Fraudulent Schemes and Consumer Protection: The decentralized and unregulated nature of cryptocurrencies also paves the way for various forms of financial fraud, including Ponzi schemes and fraudulent Initial Coin Offerings (ICOs). High-profile cases, such as the collapse of BitConnect, serve as stark reminders of the risks to consumers and the need for greater transparency and investor protection in the cryptocurrency market.
- Terrorism financing. Cryptocurrencies have been utilized for terrorism financing by terrorist organizations, as they find digital currencies to be a preferred choice to fund their activities due to their decentralized nature and anonymity. The use of cryptocurrencies makes it challenging for law enforcement agencies to track and prevent terrorist financing activities. Terrorist groups such as ISIS, Al Qaeda, and Hamas have been associated with the use of cryptocurrencies. In response, financial institutions and governments have taken steps to strengthen their anti-terrorism financing measures, including stricter regulations and monitoring of cryptocurrency transactions.
- Scams and phishing attacks. Criminals can use various tactics such as fake ICOs, phishing emails, or messages to trick individuals into revealing their private keys or accessing their wallets. Once the criminals have access to the wallet, they can steal the cryptocurrency stored in it. These types of scams have become increasingly common in the cryptocurrency world, and it is important for individuals to be cautious and vigilant when receiving unsolicited messages or offers related to cryptocurrencies.

Cybercrime is attractive to criminals due to several key characteristics, including the speed of action, accessibility, limitlessness, uncertain jurisdiction of states, and difficulty for legal investigation. These factors make it easier for criminals to carry out illicit activities and evade law enforcement. There have been a few cases of cryptocurrency being used for terrorism financing in the United States of America. In 2019, the US Department of Justice (DOJ) made an announcement regarding the dismantlement of an online platform known as "SadaqaCoins" which was being used by ISIS to finance its operations. The platform relied on cryptocurrency to raise funds for the group's activities. The US Department of Justice (DOJ) announced in August 2020 that it had seized more than $1 million in cryptocurrency that had been raised by Al-Qaeda and its affiliate groups. The funds were reportedly raised through several methods, including social media and a fake charity that claimed to be providing COVID-19 relief. The cryptocurrency was said to have been used to finance a range of activities, including terrorist attacks.

In 2019, the Israeli Defense Forces (IDF) made an announcement stating that they had discovered a fundraising campaign conducted by Hamas, which involved the use of cryptocurrency. According to the IDF, Hamas was soliciting donations for its military wing, the al-Qassam Brigades, through the use of Bitcoin (BTC). Upon analyzing the fundraising activities of various terrorist organizations using cryptocurrencies, it can be observed that Hamas has raised the largest amount of funds so far. This can be attributed to the organization's active solicitation of donations, primarily in the form of Bitcoin (BTC), through its website and affiliated Telegram channels. It has been observed that Hamas tends to intensify its cryptocurrency fundraising activities during periods of heightened geopolitical conflict (Wilder, 2021). This is reflected in the increased frequency of solicitations for donations and the amounts of funds raised during such periods. This suggests that Hamas strategically leverages the use of cryptocurrencies as a means to finance its military operations during times of conflict. Cryptocurrency hackers stole $3.8 billion in 2022 — up from $3.3 billion in 2021. October had the most crypto hacks in a single month with $775.7 million stolen in 32 separate attacks (DeVon, 2023). Decentralized finance protocols, also referred to as DeFi protocols, were responsible for roughly 82% of the total cryptocurrency stolen by hackers in 2022, which amounted to $3.1 billion.

Decentralized finance protocols, also known as DeFi protocols, are blockchain-based financial platforms that enable users to access financial services such as lending, borrowing, and trading without the need for intermediaries such as banks. By removing the need for traditional financial intermediaries, DeFi protocols are designed to provide more transparency, efficiency, and accessibility to financial services. However, the decentralized nature of DeFi protocols also presents some risks. As these platforms are built on open-source code and are largely unregulated, they can be

vulnerable to security risks such as hacks, scams, and other fraudulent activities.

There also have been several high-profile cases of fraud with cryptocurrencies in the United States. In 2018, the Securities and Exchange Commission (SEC) filed charges against BitConnect, a cryptocurrency platform, for allegedly operating a Ponzi scheme. The company was accused of raising $2 billion from investors by making fraudulent promises of high returns on investment. The Securities and Exchange Commission (SEC) claimed that BitConnect was, in fact, a fraudulent scheme, and the case was one of the largest cryptocurrency frauds ever prosecuted.

Previously, in December 2017, the SEC charged PlexCoin and its founder Dominic Lacroix with fraud, alleging that they had raised $15 million through an initial coin offering (ICO) by making false and misleading statements to investors about the potential returns on investment. The SEC claimed that the promised returns of 1354% in less than a month were impossible to achieve and that the company was a fraud. As a result, the SEC obtained an emergency asset freeze to prevent the company and its founder from continuing to raise funds from investors.

BitGrail was an Italian cryptocurrency exchange that was hacked in 2018, resulting in the loss of over $170 million worth of Nano cryptocurrency. The exchange's founder, Francesco Firano, was accused of fraud and mismanagement and is currently facing legal action.

Another case of fraud with cryptocurrencies in Europe was Crypto Capital. It was a payment processing company that was used by several cryptocurrency exchanges, including Bitfinex. In 2019, Crypto Capital's founders were arrested on charges of money laundering and fraud, and it was later revealed that the company had embezzled over $850 million from its clients. In recent years, there have been several cases of fraud involving cryptocurrencies in Japan. One notable case is the Mt. Gox scandal, where the Tokyo-based cryptocurrency exchange filed for bankruptcy in 2014 after losing around 850,000 bitcoins worth over $450 million at the time. The company later claimed that the bitcoins were stolen due to a security breach. In 2019, the former CEO of Mt. Gox, Mark Karpeles, was found guilty of falsifying data and embezzlement by a Japanese court (Boar and Wehrli, 2021).

Another case involves the Japanese cryptocurrency exchange Coincheck, which suffered a massive hack in 2018 that resulted in the loss of over $500 million worth of digital currencies. The hack was one of the largest in history of country and led to increased scrutiny of the country's cryptocurrency industry. Following the incidents, the Japanese Financial Services Agency (FSA) introduced stricter regulations on cryptocurrency exchanges to prevent such incidents from happening in the future, as the incidents led to a significant loss of confidence in the security and reliability of cryptocurrencies.

There are several measures that can be taken to combat fraud and illicit activities related to cryptocurrencies. For example, Know Your Customer (KYC), is a process that financial institutions and other organizations implement to verify their clients' identity and evaluate the risk of illegal activities such as money laundering, terrorist financing, and fraud. The process entails gathering personal information and authenticating it with official documents such as passports, driving licenses, and utility bills. Regulatory authorities mandate Know Your Customer (KYC) requirements to curb criminal activities by ensuring that financial institutions have a clear understanding of their clients, their income sources, and the objective of their transactions.

Know Your Customer (KYC) regulations have been established in many countries worldwide, including the United States, Canada, the United Kingdom, Australia, Japan, South Korea, and most European Union member states. However, the specific requirements and regulations for Know Your Customer (KYC) may differ between countries and even between financial institutions within the same country. Additionally, some financial institutions may implement more rigorous Know Your Customer (KYC) requirements than what is mandated by regulatory authorities.

Another set of regulations for institutions to establish customer due diligence processes, identify and report suspicious activities, and maintain adequate records of financial transactions is Anti-Money Laundering (AML). These regulations are a set of laws and guidelines aimed at preventing the use of financial systems for the purpose of laundering money obtained through illegal activities, such as drug trafficking, fraud, and corruption. Financial institutions are also required to train their employees to recognize potential money laundering activities and report them to the appropriate authorities.

Counter-Terrorism Financing (CTF) is a set of measures aimed at preventing terrorist organizations from raising, moving, and using funds for their activities. Counter-Terrorism Financing (CTF) involves various regulatory, legal, and law enforcement actions, such as financial sanctions, asset freezing, and criminal investigations. Counter-Terrorism Financing (CTF) regulations and policies are typically developed and implemented by national governments and international organizations, such as the United Nations Security Council and the Financial Action Task Force (FATF). Counter-Terrorism Financing (CTF) measures are in place in many countries around the world, including the United States, Canada, the United Kingdom, Australia, Japan and most countries in the European Union. Just like before, the specific CTF requirements and regulations vary between countries and regions, and may also depend on the nature and scope of the terrorist threat.

Whitelisting of cryptocurrency is a process used by cryptocurrency exchanges and other platforms to ensure that only legitimate transactions are processed. It involves creating a list of approved cryptocurrency addresses, also known as "whitelisted" addresses, and blocking transactions that involve addresses not on the list. The goal of whitelisting is to prevent illegal activities such as money laundering, terrorist financing, and fraud by ensuring that only verified and legitimate transactions are processed. Whitelisting can be done manually or through automated systems that use artificial intelligence and machine learning algorithms to detect suspicious activities. It is commonly used by cryptocurrency exchanges in

countries where regulatory authorities require strict compliance with Anti-Money Laundering (AML) and Counter-Terrorism Financing (CTF) regulations.

Educating users about the risks of fraud and how to protect themselves is an important step in preventing fraudulent activities in the cryptocurrency space. This can include providing information on common scams and fraud schemes, as well as steps that users can take to protect their accounts and assets. Some measures that can be taken to educate users include providing educational resources on websites and social media channels, hosting webinars or workshops, and collaborating with industry organizations and regulators to develop best practices and guidelines. Additionally, platforms can implement user-friendly security measures such as two-factor authentication and multi-signature wallets to help prevent unauthorized access to user accounts. By providing users with the tools and knowledge they need to protect themselves, the cryptocurrency industry can work towards a safer and more secure ecosystem for all participants.

Navigating the regulation of cryptocurrencies presents a complex challenge for governments and financial authorities. Balancing the need for innovation with consumer protection and financial stability is a key concern. Various countries within the G7 and beyond have adopted differing regulatory stances, from strict regulations and bans to more open, innovation-friendly approaches. The evolving regulatory landscape, while necessary, also creates a patchwork of standards and rules that can hinder the global coordination needed to effectively address the dark side of cryptocurrencies.

In sum, while cryptocurrencies offer innovative possibilities for financial systems, their dark side presents significant challenges that necessitate careful consideration and proactive measures. Understanding and addressing these challenges is essential for the responsible development and integration of cryptocurrencies into the global financial landscape.

5. CONCLUSIONS

The growing popularity of cryptocurrencies and blockchain technology has led to a significant increase in the market for digital assets over the past decade. As more individuals and institutions recognize the potential benefits of cryptocurrencies, the market is projected to continue expanding at an accelerated rate. This growth is being driven by a number of factors, including increased adoption of cryptocurrencies by mainstream financial institutions, the development of new and innovative use cases for blockchain technology, and the growing demand for Decentralized Finance (DeFi) applications. As a result, the cryptocurrency market is expected to become increasingly prominent in the global financial landscape in the years to come.

Overall, while the number of cryptocurrency transactions is still relatively small compared to traditional financial transactions, the growing adoption of cryptocurrencies and blockchain technology suggests that the volume of transactions is likely to continue to grow in the coming years. The emergence of these digital currencies, along with Bitcoin, represented a significant departure from traditional financial systems that rely on centralized institutions for transaction processing and the creation of new money. The introduction of new digital currencies demonstrated the potential for blockchain technology to create a decentralized financial system, and fueled further innovation and experimentation in the field of cryptocurrency.

The research indicates that Proof-of-Work cryptocurrencies, exemplified by Bitcoin, exhibit exceptionally high energy consumption, comparable to that of entire nations, and contribute significantly to global carbon emissions, electronic waste, and other environmental pollutants. This energy demand can strain national power grids, potentially impact electricity prices, and complicate the achievement of climate mitigation targets, all of which have direct bearings on economic security. While technological advancements like Proof-of-Stake offer dramatic reductions in energy use, and efforts to power mining with renewable energy are underway, challenges related to the scale of demand, the true "greenness" of these operations, and potential resource competition persist.

The G7 countries have demonstrated a varied and evolving policy response to these energy challenges. Approaches range from moratoria and considerations of operational shutdowns during energy crises in some regions, to strategic efforts to integrate mining with national energy strengths, such as utilizing surplus low-carbon nuclear or renewable energy in others. This divergence highlights the complexity of the issue and the risk of uncoordinated actions leading to outcomes like carbon leakage, where environmental burdens are merely shifted to jurisdictions with weaker regulations. The G7's collective stance on ensuring the energy efficiency of future Central Bank Digital Currencies, however, signals a clear direction and sets a benchmark for the broader digital asset ecosystem.

To navigate this complex interplay of innovation, energy security, environmental sustainability, and economic stability, the following policy recommendations are proposed for G7 nations:

1. Promote International Coordination and Standards: G7 nations should spearhead international efforts to establish common minimum standards or best practices for the energy consumption and environmental impact of cryptocurrency mining. This collaborative approach, building on initiatives like the EU's call for international cooperation (Carrier, 2022), is essential to prevent carbon leakage and ensure a globally level playing field.
2. Incentivize Energy-Efficient Technologies: G7 governments should actively encourage, and where appropriate, consider mandating the transition towards less energy-intensive consensus mechanisms such as Proof-of-Stake. Policy tools could include support for research and development, offering preferential regulatory treatment for digital assets based on energy-efficient technologies, or requiring clear disclosures on the energy use associated with different cryptocurrencies.
3. Develop Clear Guidelines for "Green Mining": Transparent and robust criteria are needed to define what constitutes genuinely sustainable cryptocurrency mining. These guidelines should

address the "additionality" of renewable energy (i.e., ensuring mining leads to new renewable capacity), verify the use of genuinely curtailed or stranded energy sources, and assess the overall impact on grid stability and energy allocation. Such measures are crucial to prevent "greenwashing" and ensure that renewable energy claims are credible.

4. Integrate Crypto-Energy into National Energy Planning: G7 countries must explicitly incorporate the potential energy demand from cryptocurrency mining into their national energy transition strategies and electricity grid planning. This foresight is necessary to avoid undue strain on existing infrastructure, ensure energy security for all users, and make informed decisions about whether finite energy resources are optimally allocated to mining versus other societal or decarbonization priorities.
5. Implement Carbon Pricing or Environmental Levies: Consideration should be given to applying carbon pricing mechanisms or specific environmental levies to energy-intensive PoW mining operations. This would help to internalize the environmental externalities associated with their energy consumption, unless such operations can demonstrably prove carbon neutrality through verifiable and additional means.
6. Enhance Transparency and Disclosure Requirements: Mandating clear, standardized, and regular disclosures from cryptocurrency issuers, exchanges, and mining operations regarding their energy consumption, the sources of their energy, and their overall environmental impact is crucial. This aligns with emerging requirements, such as those in the EU's MiCA regulation concerning disclosures of principal adverse environmental impacts, and would empower investors, consumers, and policymakers to make more informed decisions.
7. Support Independent Research and Data Collection: G7 nations should fund and support independent, peer-reviewed research to improve understanding of the evolving energy footprint of various cryptocurrencies, assess the effectiveness of different mitigation strategies, and analyze the broader socio-economic impacts. Addressing controversies and data gaps, such as those highlighted by the Harvard study and its critiques, requires more robust, transparent, and openly accessible data.
8. Apply the Precautionary Principle Where Necessary: In situations characterized by high uncertainty regarding the environmental or energy grid impacts of cryptocurrency mining, particularly concerning large-scale PoW operations, G7 nations should be prepared to apply the precautionary principle. This could involve measures such as temporary moratoria on new operations, as seen in British Columbia, Canada, or restrictions on mining activities during periods of energy crisis, as suggested by the European Commission.
9. Ensure CBDC Energy Efficiency Leadership: G7 authorities must continue to uphold and rigorously implement their stated principle that any national CBDC must be highly energy efficient. By doing so, they can set a powerful example and standard for the entire digital asset ecosystem.
10. Foster Public and Investor Awareness: Educational initiatives should be undertaken to inform the public, investors, and businesses about the varying energy implications of different cryptocurrencies and blockchain technologies. This increased awareness can drive demand for more sustainable digital assets and practices.

The overarching challenge for the G7 countries lies in harnessing the innovative potential of digital currencies while ensuring that their development and adoption align with urgent national and global imperatives for energy security and climate change mitigation. A failure to comprehensively address the energy and environmental footprint of cryptocurrencies could not only undermine their long-term viability and social acceptance but also jeopardize the broader goals of achieving sustainable economic development in an increasingly digital world. Policy responses must be adaptive, nuanced, and evidence-based, capable of evolving alongside this rapidly changing technological landscape, with the ultimate aim of steering innovation towards genuine sustainability.

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