Future Technology
Open Access Journal
ISSN 2832-0379

November 2022| Volume 01 | Issue 03 | Pages 06-13

Journal homepage: https://fupubco.com/futech

https://doi.org/10.55670/fpll.futech.1.3.3

Future Publishing LLC

Article

Crypto has an emissions challenge: Here's what leaders can do about it

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ARTICLE INFO

Article history:
Received 05 July 2022
Received in revised form
12 August 2022
Accepted 19 August 2022

Keywords:
Crypto mining; Crypto policy;
Energy policy; Sustainable crypto

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DOI: 10.55670/fpll.futech.1.3.3

ABSTRACT

Reaching a market capitalization of more than $3 trillion last year and today remaining well over the $1 trillion mark, investor interest in cryptocurrency continues to soar. Yet with bitcoin alone estimated to use up to 120.9 terawatt-hours of electricity annually — more than that used by Portugal in a year – so too is interested in crypto's carbon footprint. The question for governments is how best to help decouple crypto from carbon. This paper argues for a tiered package of incentives and regulations to maximize the use of clean energy and promote energy efficiency in crypto-mining operations. Specifically, policymakers must: (1) support efficiency innovation by incentivizing miners to switch to less energy-intensive designs while addressing issues related to software and hardware upgrades, including better e-waste management, and (2) incentivize clean-energy use while tackling the challenges arising from the intermittency of renewables, grid strain and other the negative side effects of crypto-mining, and the challenges around auditing. While carbon offsets are increasingly popular within the crypto sector, policymakers should be wary as offsets do not address the root causes of carbon pollution. Offsets should only be used as a last resort. Outright bans on crypto mining have unintended consequences. On the other hand, a laissez-faire approach would clearly exacerbate the climate crisis. As crypto attracts more interest, a pragmatic way forward is to balance its risks and opportunities by adopting the right mix of regulations and incentives. In so doing, governments can ensure crypto mining does not undermine international climate goals.

1. Introduction

1.1 Crypto's achilles heel

Shortly after Tesla announced it would begin accepting payments in bitcoin, the company's co-founder and social-media influencer Elon Musk tweeted a U-turn, citing cryptocurrency's large carbon footprint as the reason for the reversal [1]. Despite this, crypto has continued to attract interest faster than most other investments, even though crypto-mining is highly energy intensive due to the number and types of computations associated with it. Governments recognize that unabated growth of the crypto industry could undermine progress in mitigating climate change. About 75 percent of bitcoin mining uses fossil-fuel energy [2] which generates the equivalent in emissions of the Philippines [3]. Thus, digital assets like bitcoin are likely to be a major global source of CO_2 if the electricity production is not decarbonized. Figure 1 illustrates how bitcoin's electricity usage compares with selected countries [4]. Clearly, policymakers must address the carbon impact of crypto. Yet an outright ban on mining operations could also multiply emissions, as has been seen in China. After the practice was banned there, miners that had been relying on cheap hydropower relocated to neighboring countries where fossil fuels are cheap and abundant (like Kazakhstan) [5]. Alternatively, mining operations have gone underground, avoiding regulatory oversight altogether [6].

1.2 Case study: Kazakhstan/Iran/Kosovo – The opportunists?

In May 2021, China's crackdown on bitcoin mining culminated in a full ban of all cryptocurrency-related activities. Miners flocked to countries with cheap energy and favorable tax laws on cryptocurrencies, including Kazakhstan, Iran, and Kosovo. By the autumn, Kazakhstan was responsible for 18 percent of the global hashrate (the total computational power being used by a PoW cryptocurrency to process transactions). But only months later, the cryptocurrency business faced a new hurdle in Kazakhstan: the government throttled the power supply of the miners following civil unrest and blackouts [7]. Demand for electric power was at an all-time high, leading to emergency outages and rationing. The country's Ministry of Energy blamed the crypto industry for the crisis. In October 2021, the Kazakhstan government announced it would cut off the miners' power supply, and in January 2022, it started to tax the energy use of registered miners.

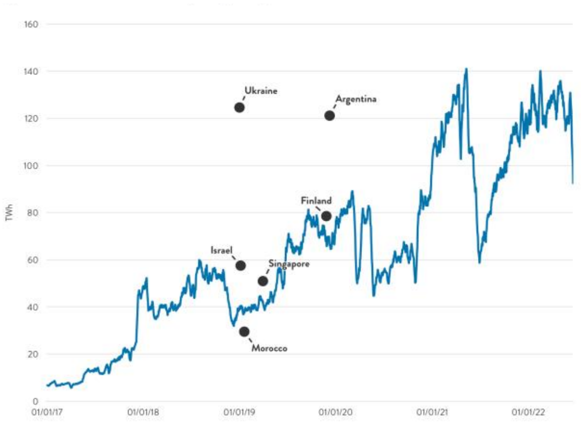

Figure 1. How bitcoin's electricity usage compares with selected countries [4]

Kosovo, which had one of Europe's cheapest electricity rates, also moved to ban cryptocurrency mining after blackouts in January 2022. Similarly, Iran has enforced month-long bans on crypto-mining to ease the strain on the energy grid. In less than a year, miners moved from China to countries with cheap electricity, only to be forced to move again [8]. Many are now moving to the US. BitFuFu, for example, a mining company backed by Chinese mining giant Bitmain, moved to Kazakhstan after China's ban but then simply abandoned its 80,000 mining rigs at the end of 2021 after weeks of power rationings for plans to start over in the US [9]. Starting over is complex, with lead time to build mining infrastructure in the US spanning six to nine months and a global shipping-container shortage. Miners were quick to move to countries with low energy prices, but the governments were not prepared to meet the energy demands or monitor the consumption of these new facilities. From a regulatory standpoint, legalizing blockchain is not enough: it is just the first step. Governments should build a robust regulatory framework around the industry by, for example, imposing energy-efficiency limits on miners and pushing for energy-efficient blockchains. The question for governments is how to best manage the growing industry to maximize its potential benefits but minimize its emissions. The US, for example, recently launched an inquiry into the energy and climate impact of cryptocurrencies following President Biden's executive order [10]. More than 80 countries are exploring how best to regulate or promote cryptocurrency [11].

2. A three-dimensional challenge

Those in favor of crypto argue that cryptocurrencies are valuable not only as a means of exchange but also as a store of value. They point to crypto's role in fundraising efforts for environmental and social causes, including aiding victims of humanitarian disasters such as Ukrainians caught up in Russia's invasion of their country. They add that when compared to gold, crypto is democratic in access, more secure, and offers better liquidity as potential advantages. Beyond crypto's value as a financial tool or asset, supporters argue the industry's emissions are less significant relative to others like lower than those of the global banking industry, the US military, and or the world's global fleet of collection of air-conditioning, and heating units.

2.1 Case Study: the United States – The mixed bag

The US has become the second-biggest mining destination on the planet, accounting for nearly 17 percent of all the world's bitcoin miners in 2021 [12]. An increase in mining of 151 percent since September 2020 was driven by cheap energy and the exodus of miners from China. Around 50,000 formerly Chinese miner rigs have moved to the US, meaning North America now accounts for almost 40 percent of the global hashrate. Miners are choosing to move to the US because of China's ban on mining and energy supply issues, as well as subsequent restrictions or bans in countries like Kazakhstan, Iran, and Kosovo. Across the US, the crypto industry has mobilized lobbyists to persuade individual states to pass favorable rules. In New York, concern over the environmental impact of energy-intensive mining resulted in a flood of lobbying to combat potential crypto-regulatory measures [13]. However, a bill instituting a moratorium on new fossil-fuel-powered PoW crypto mines was passed by the state legislature in early June 2022 [14]. By contrast, other states like Georgia, Illinois, and Kentucky have instituted tax incentives for mining companies. It is unclear how mines can boost the local economy as the state is not fostering a tech cluster or an innovation hub. Further, mines do not create a significant number of jobs. Legislators must scrutinize industry claims before offering tax breaks or other incentives to miners. Generally, incentives are unwarranted.

Around the US, crypto-favorable laws are being passed. Nevada is banning local governments from taxing smart contracts or blockchain technology, while Colorado is becoming the first state to accept crypto as payment for taxes. Miami's mayor accepted donations in CityCoins, a private-sector crypto experiment in civic engagement [15]. Hawaii, though, remains one of the hardest states to trade cryptocurrency, with a fledging cryptocurrency pilot program ending this year. Texas became the second US state after Wyoming to recognize virtual currencies as a category of financial assets subject to the state's commercial laws, paving the way for crypto businesses to operate in the state [16]. Texas also has very low energy prices due to its deregulated power grids. But the state has not been spared energy-supply issues. Texas paid Bitcoin miners to stay offline during the February 2021 power outage in order to ease the strain on the grid. Furthermore, the surge in electricity demand has led to Texas requiring large new mining rigs to seek permission to connect to the grid so that the extra consumption can be planned for [17]. The full effect of a sudden influx of miners from China and elsewhere remains to be seen (although, notably, many of China's miners have just moved their operations "underground", connecting to off-grid energy and hiding from regulators). Mining has strained US grids and increased pollution. States taking a more proactive approach towards miner licensing, taxation, regulation, and support are likely to perform better in the long run.

2.2. The way forward

However, getting embroiled in debates about crypto's value or whether the industry's emissions are justified is of limited use to governments trying to navigate the way forwards today. The pressing challenge for policymakers is to guide the industry's development to maximize the opportunities and minimize its carbon impact. Specifically, they need to: (1) enable the adoption of low-energy protocols; (2) support other energy efficiencies; (3) raise the bar on clean energy; and (4) take a realistic approach to offsets.

3. Enabling low-energy protocols

3.1 The opportunity

Technological innovations could potentially reduce the energy consumption of crypto-networks. The greatest determinant of the energy consumption of a cryptocurrency is whether it uses a blockchain and, if so, which consensus mechanism secures it. Figure 2 shows the significant difference between the energy consumption of different crypto and consensus mechanisms [18].

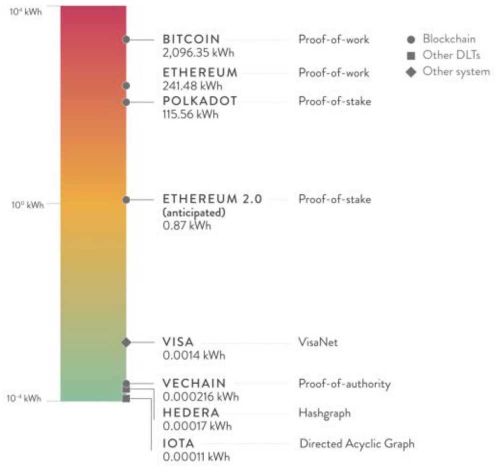

Figure 2. Energy consumption of different crypto and consensus mechanisms [18]

Dozens of consensus mechanisms are potentially more energy efficient than proof-of-work (PoW) and may be applied in a variety of contexts [19]. Proof-of-stake (PoS) is one of the well-known consensus mechanisms offering high energy efficiency. With PoW, used by bitcoin, a network member solves an arbitrary mathematical puzzle- the "work"- in order to validate a transaction. In the case of PoS, participants referred to as "validators" lock up set amounts of cryptocurrency or crypto tokens – their "stake" – and in exchange, they get a chance to validate new transactions and earn a reward. Ethereum estimates that moving to PoS will reduce its energy consumption by 99.95 percent [20]. It plans to complete this transition in the summer of 2022. Although bitcoin is the largest cryptocurrency by market share, most of the top 25 cryptocurrencies use more energy-efficient protocols than PoW — and new tokens generally avoid PoW. Optical proof-of-work (oPoW) could eliminate energy as the primary cost of mining by using light as the basis of computing [21]. Blockchain is the most widely used distributed ledger technology for cryptocurrency. However, there are other technologies that promise to be less energy intensive than blockchain and may be appropriate for different crypto-applications. Directed Acyclic Graph (DAG) may be more suitable than bitcoin for mass transactions, while public hashgraphs may be more scalable, versatile, and energy efficient.

3.2 The challenge

Convincing crypto-miners to undertake radical efficiency improvements, however, can be challenging. Switching a widely established, permissionless crypto-network to an energy-efficient alternative is more difficult to implement than doing so with a newer network or one that is private. For bitcoin, it is near impossible: its energy-intensive PoW mechanism is a feature, not a bug. It is what drives investor confidence in the network's security since it is cost-prohibitive for a nefarious entity to gain computing power greater than that of all honest users.

Changing bitcoin's consensus mechanism requires gaining majority buy-in from the hundreds of thousands of miners around the world. However, bitcoin might fall out of favor because of PoW's inherent issues with scalability. The energy-intensive nature of each transaction means bitcoin is ultimately unlikely to be useful as a payment mechanism. Developing an entirely new, low-energy crypto network that is scalable, secure, and decentralized (the blockchain trilemma) is equally challenging. Many energy-efficient protocols today are still in the early stages of development but are yet to be properly tested.

3.3 Making progress

Policymakers must begin to think about creating incentive structures to make new, more efficient alternatives flourish. The blockchain network Ethereum recently announced it would move from PoW to a PoS consensus mechanism; minimizing the risks involved in such ambitious projects should be a focus for policymakers. For example, decentralized finance (DeFi) insurance company Nexus is seeing a huge uptick in customers in anticipation of the launch of Ethereum 2.0 but is operating within an unregulated area of insurance law [22]. A strong governance framework around DeFi insurance (among other factors) would help ensure the industry can transition to PoS while maintaining customer confidence [23].

4. Supporting other energy efficiencies

4.1 The opportunity

Aside from consensus mechanisms and underlying ledger technology, innovations relating to the miners' operating models can also provide efficiency gains. Transaction batching and second-layer transactions can make mining more efficient by decreasing the overall number of transactions [24]. Other technologies can increase the efficiencies of conventional PoW mining where it is still used. Harnessing waste heat from mining equipment is one opportunity. For example, an Antminer S9 bitcoin mining unit generates as much heat as a room heater; waste heat from crypto-mining can be used to heat commercial and residential buildings [25]. Other miners are turning to immersion cooling, which allows for much better energy efficiency. While some types of coolants are relatively innocuous, those based on fluorocarbon have significant climate-change impacts as they are ozone-depleting.

4.2 The challenge

Efficiency gains require new software and hardware. With hardware upgrades come to the challenge of ewaste. As hardware gets more energy efficient and powerful, it renders prior models obsolete in a process that can happen as quickly as every 1.5 years. Most bitcoin is mined on application-specific integrated circuit (ASIC) machines that cannot be repurposed for other uses. Consequently, by one estimate, bitcoin mining produced 30,700 metric tonnes of e-waste in 2021- the equivalent of all the small IT ewaste produced by the Netherlands [26].

4.3 Making progress

Policymakers should consider maintaining a functional ecosystem for a circular economy for addressing ewaste from crypto-mining, as well as supporting more demonstrations and proofs-of-concept for promising innovations in the field.

5. Raising the bar on clean energy use

Crypto mines must run off clean energy, or their operations will exacerbate the climate crisis. Proponents argue that crypto mines can operate as a bulk buyer of clean power, helping to balance the grid and fund new renewable capacity as well as associated transmission upgrades. Miners also have an opportunity to use "stranded" energy, such as gas, a by-product of oil drilling that would otherwise be flared (notably, stranded energy is not renewable but puts energy that would otherwise be wasted to productive use) [27]. Figure 3 depicts which energy sources powered bitcoin between the end of 2019 and July 2021 [28].

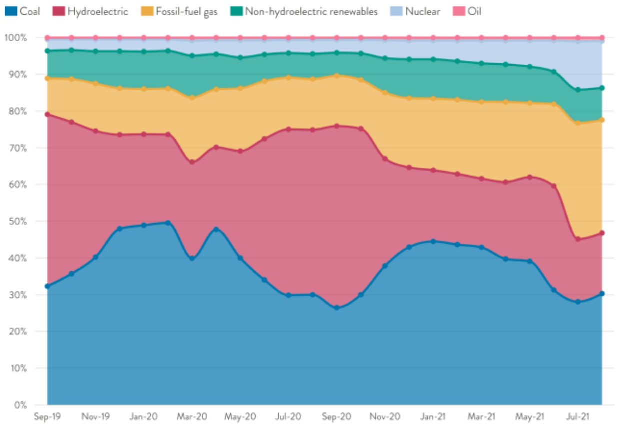

Figure 3. How bitcoin is powered by energy source [28]

5.1 The challenge

Mandating the use of clean energy for mining is challenging given the distributed, often international nature of crypto networks. And because bitcoin mining is so lucrative, it has incentivized extension of the lifespan of polluting fossil-fuel power plants to run mining hardware around the clock [29]. For example, in May 2022, a crypto-miner in Indiana signed a five-year contract with a coal plant even though the plant was supposed to retire the next year [30]. Even when renewables are cheap and plentiful, intermittency and seasonality spur miners towards supplementing their consumption with fossil power. For example, the hydropower that pre-ban bitcoin miners in the Chinese province of Sichuan relied on varies dramatically throughout the year. While miners took advantage of cheap hydropower, they also increased baseload demand on the grid throughout the year – which was met with coal [31].

Mandating a switch to clean energy could also create further risks detrimental to the environment, public health, and grid infrastructure. Unless carefully regulated, crypto mines can divert renewable energy from other sectors, overwhelm aging grid infrastructure, and increase electricity costs for other consumers, including families and small businesses [32, 33]. Further, the volatility of the crypto market puts utilities at risk – if utilities increase capacity to satisfy crypto-mining demands, but the crypto mines shut down, then utilities (and, by extension, taxpayers) could be left with stranded assets. There are also issues with using stranded energy. While promising, the use of flare gas is only an interim solution because oil drilling must be phased out to meet our climate goals. It is also difficult to scale. Energy derived from coal waste, left over from coal-fired power plants or from old car tires, can emit toxic air and water pollution that harms local communities as well as greenhouse gasses [34, 35].

5.2 Making progress

Addressing the energy challenge requires ensuring access to a steady supply of low-cost renewables, minimizing the unintended negative consequences and improving transparency and auditability. The crypto industry is taking steps to address barriers to the deployment of renewable energy, including widening participation in regenerative finance (ReFi). Trading platforms provide a means to invest directly in renewable-energy projects in return for digital renewable-energy certificates (RECs). Sustainable Bitcoin Standard, for example, creates a financial incentive for bitcoin miners to use REC-verified clean energy and, in turn, creates a path for investors to add "proof of sustainable mining" to their bitcoin holdings. Industry groups, such as the Crypto Climate Accord, are pledging to mine crypto exclusively with renewable energy and leveraging blockchain to verify miners' green claims [36]. The policy must increasingly support such initiatives while ensuring their transparency and integrity, for example, by requiring mining operations to disclose the fuel sources they use. Policymakers must also remove barriers to clean energy procurement and facilitate investment in renewables and associated infrastructure. In addition, regulators must raise the bar on the licensing requirement for mining facilities, getting more stringent with energy, air, and water quality standards. Mining facilities participating in international crypto-networks can be particularly challenging to audit and must be managed through mandatory disclosures.

6. Taking a realistic approach to offsets

Offsets allow emitters to mitigate emissions from a carbon-accounting standpoint. Crypto enthusiasts are driving up demand for carbon offsets in a new wave of ReFi. Toucan aggregates carbon offsets from various established registries like Verra (off-chain registries) and converts them into carbon tokens on one blockchain super-registry to increase transparency, verifiability, and asset liquidity [37]. KlimaDAO took the concept a step further, attempting to sweep all offsets from off-chain registries into one pool to create artificially scarce offsets that would drive up the price of offsets [38]. Similarly, new cryptocurrencies like bitcoin zero and solarcoin are emerging with a unique value proposition – owning them means owning a unit of the underlying currency and a unit of carbon offset. But offsets are notoriously problematic [39]. First, they eliminate the need to cut emissions. It is generally easier for an emissions-heavy industry to buy offsets than to fundamentally change its business model. Offsets also do not address localized pollution - a fossil-fuel plant can keep polluting a nearby community in New York if it buys offsets purporting to reforest a part of Brazil [40]. Offset schemes suffer from a range of issues [41]. They include:

- Limited transparency: pricing is opaque; sometimes offsets are double-counted (in other words, sold twice).
- Flawed accounting. For example, impossible-to-verify counterfactual baselines against which to measure future emissions reductions.
- Human rights issues: some forest-conservation projects have resulted in the violent ejection of indigenous residents.
- Lack of a standard framework: this is required in order to distinguish between high-quality offsets and lower-quality ones. For example, between permanent carbon

removal achieved through high-risk investment in direct air capture (DAC), and a less consequential scheme which prevents tree-felling in a remote rural location in Malawi.
- Lack of regulation in the global voluntary offsets market: as a result, the market is replete with competing for private registries, compounding the above issues. There have been cases of manipulations and greenwashing as credits change hands between intermediaries.

Policymakers should ensure offsets are only used as a matter of last resort. As experts on carbon offsetting argue, an entity should only buy offsets if it is also making a good-faith effort to reduce absolute emissions. Where offsets are used, they should reflect a whole-systems perspective on emissions by including those associated not only with an individual crypto transaction but also from the blockchain network and the history of the mined unit. Retiring credits after an initial purchase must also become the norm to limit the risks of opacity, double-counting, and manipulation associated with resales. Finally, emphasis should be placed on RECs rather than carbon offsets to help create a market for renewable energy. Innovation policy can help bolster investment in complementary technologies, including remote sensing, artificial intelligence, and blockchain, for more accurate, transparent, and timely reporting of offset-project performance. Policymakers should push for the development of stronger standards and best practices in the compliance market and support the same in the voluntary market.

7. Forging a path forward

Tackling crypto's emissions requires taking a holistic view of challenges across the three dimensions of clean energy use, improved efficiency, and high-quality offsets. Across all three areas, policymakers must be ready to assess risks and opportunities; engage relevant stakeholders, including miners, utilities, project developers, and local communities; regulate through appropriate instruments; and incentivize innovation and best practices in the crypto community. Environmental agencies, energy agencies, utility regulators, central banks, and state and national legislators will all be needed to play their part in implementing the recommendations below.

8. Recommendations for policymakers

8.1 Assess

- Licensing bodies should evaluate the potential costs and benefits of mining operations, taking local factors, including clean-energy capacity, into account before granting a facility a permit.
- Develop a tiered licensing framework to reflect how well miners are performing based on clean-energy use, local environmental impact technology, operational efficiency, and the quality of offsets. The framework can help determine which facilities can operate and the level of government support available to miners.

8.2 Engage

- Engage industry groups to develop and disseminate efficiency standards and best practices on energy procurement while addressing the pitfalls in carbon offsetting. Hardware and capital requirements have resulted in consolidation among miners, enabling policymakers to engage the industry collectively.
- Engage other stakeholders, including environmental justice and other community groups living near mining facilities, taxpayer groups, and non-profits dealing with climate change, to ensure policies adequately protect public health and the environment.
- Encourage institutional investors to purchase only cryptocurrencies that use solely clean energy, as well as the least amount of energy possible.
- Partner with ecosystem members, including utilities and relevant government agencies, to ensure the services they provide to miners reflect the licensing framework. This will maximize pressure on miners doing the least to decarbonize their operations.

8.3 Regulate

- Impose energy-efficiency limits on miners. Energy regulators should impose minimum energy efficiency limits based on kWh per square foot to ensure the methodology being used to mine cryptocurrency is the best available technology and uses the least amount of energy possible. These standards should increase in stringency over time. Incentivize renewable energy usage with financial regulatory tools to require greater transparency regarding carbon pollution from digital assets.
- Protect communities and small businesses by requiring that high-density energy users pay higher rates.
- Pre-empt grid strain by requiring that crypto mines submit load-requirement estimates and interconnection studies to utility regulators prior to obtaining permission to connect to the grid. Miners should also be required to cover costs for interconnections, transmission upgrades, and specialized infrastructure.
- Prevent environmental degradation through stringent reviews of air pollution, noise pollution, and effluent discharge, as well as creating buffer zones to protect communities.
- Guard against volatility by working with utility firms and power providers to ensure miners provide security deposits or use short-term market purchases with pass-through cost arrangements when procuring energy.
- Mitigate harm from e-waste. Environmental agencies should establish rules and regulations to mitigate harm from large quantities of e-waste disposal.
- Preclude public investment in carbon-polluting products by mandating sovereign-wealth funds and other public vehicles only to buy crypto products that use clean energy as well as the least amount of energy possible.
- Prevent climate backsliding. Do not allow fossil-fuel plants to be recommissioned for cryptomining (or any other use).
- International coordination is key to addressing the impacts of crypto-mining, which inherently lends itself to transnational operations. National legislators should work with their counterparts to standardize efficiency limits and other measures.

8.4 Incentivize

- Model best practices by ensuring government agencies working on digital assets, such as central banks developing digital currencies, prioritize the most energy-efficient technologies possible.
- Invest in support systems for technology and business-model innovation, including industry-academic partnerships to maximize knowledge transfer.
- Facilitate tech demonstrations for promising solutions, including low-energy consensus mechanisms like oPoW, and non-mining solutions, for example, secondary layers and pre-mined tokens.

- Incentivize investment in complementary technologies including those that can improve system performance and transparency – remote sensing, the Internet of Things, and artificial intelligence.

9. Conclusion

There are now more than 18,000 cryptocurrencies with 300 million users worldwide, a number that is still growing. Although attitudes towards crypto vary, the industry's potential impact on climate is a very real issue that must be addressed. Some governments are more accommodating of crypto in general – and PoW in particular – than others. Whatever approach governments take, however, crypto is here to stay and could continue to be a source of environmental concern. Furthermore, it is not enough to crack down on the industry in one country. As history has shown, that only encourages offshoring to other countries where the impact can be more severe. Now is the time for policymakers to take bold steps in forging a future where sustainable mining thrives. Making the bold move requires focusing less on the ceaseless debates about whether cryptocurrencies are inherently valuable or whether emissions can be justified. Rather it requires taking concrete steps to identify the best way to limit the spread of energy-intensive mining operations in regions with a limited supply of clean energy while supporting efficiency innovations. Crypto is still in its early days. Now is the time to shape its future.

Acknowledgment

Thank you to all those who helped inform this paper, including:

Michael Brune, Change the Code, Not the Climate
Mandy DeRoche, Earthjustice
Jessica Hernandez, Environmental Working Group
Eli Keene, Key Capture Energy
Bradford Van Voorhees, Sustainable Bitcoin Standard
Ashley Lannquist, International Monetary Fund

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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