THE LINUX FOUNDATION | Research

Web3 and Sustainability

How We Can Reduce the Climate Impact of Blockchains, How Blockchains Can Help Reduce Our Own

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Foreword

Intel and Linux Foundation Research hosted the Sustainable Blockchains Roundtable on July 29, 2022. Since then there have been many developments influencing the sustainability aspects of this technology. The two big ones related to sustainability: the Ethereum merge and an increase in regulation with respect to mining proof-of-work cryptocurrency. With Ethereum moving to proof of stake we have seen the first large-scale transition away from the energy waste designed into proof of work (See Figure 3 on page 15). This has shown that blockchain ecosystems don't necessarily need to be tied to energy use to be useful. Regulations, driven by energy cost increases in 2022 and concern about the impact of proof-of-work on energy and sustainability, have started to increase[1]. This is accelerating the debate into legislatures (local and national) about what is the appropriate impact of this technology on our energy grids, and what are the downstream sustainability impacts.

The key message is that technology, in all its forms, can have both positive and negative impacts and that consequential understanding of the adoption of this technology to the problem of global warming is an important factor which needs to be more at the forefront in our decision making.

At Intel our commitment to addressing climate change has a broad base and is focused on multiple dimensions. We've pledged to be net-zero in our global operations by 2040, to increase the energy efficiency of our products, and to lower the carbon footprint of PC platforms using our chips.[2] Intel's Carbon Reduction and Green Software team led this roundtable and works to also extend the reductions to our Scope 3 downstream emissions, helping our customers achieve lower emissions when using our products. This roundtable grew out of that effort, to create a better understanding of the implications of investments in high-energy workloads such as proof-of-work, gaming, and AI to build products which minimize the environmental impact while maximizing the value to our customers.

The roundtable was created and led by Tamara Knesse (Director of Developer Engagement), and Zane Griffin Talley Cooper (Graduate Technical Intern). It is their vision, hard work, and impact which made this report possible.

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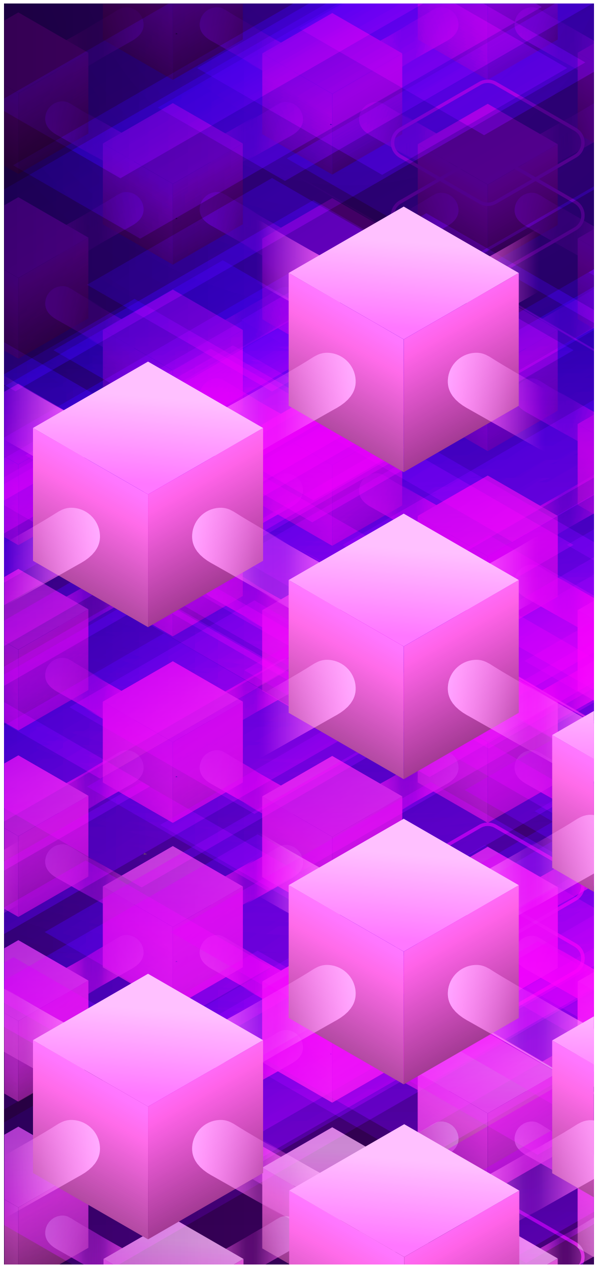

1 https://www.marketplace.org/2023/01/13/crypto-mining-hits-a-very-rough-patch/

2 https://www.intel.com/content/www/us/en/newsroom/news/net-zero-greenhouse-gas-emissions-operations.html#gs.pa1wq8

Introduction

In organizing this event and drafting the following report, which draws on roundtable discussions, we wanted to build community, drive ecosystem-wide change, and create business and organizational value. We can't solve the climate crisis with one technology designed by one company—it requires a holistic, cross-industry effort, with input from communities, academic researchers, and climate advocates. We also hope that this report serves as a guidepost for those in the tech industry who may have little familiarity with Web3, to gain a more nuanced understanding of the diversity of communities, projects, and approaches to sustainability across this emerging developer ecosystem.

Intel's stalwart commitment to open source is a key piece of this endeavor, as we build relationships and technologies with fellow travelers to enact positive social change.[3] We hope that the public report produced from this event will help build knowledge about sustainability and blockchains for the broader community.

In addition to many representatives from across Intel Business Units and Intel Labs – including Arjun Kapoor, Director of Strategy for Intel® Blockscale™, and Claire Vishik, an Intel fellow for hardware, security, and cryptography[4]—we gathered an interdisciplinary cohort of academics and researchers thinking about the cultural, ecological, and political stakes of blockchains from a variety of perspectives:

- Proof-of-work (PoW) infrastructure builders and providers thinking differently about compute/energy relationships
- Carbon market and energy trading companies that are leveraging Web3 technologies
- Greenhouse gas standards organizations that are facilitating carbon measurement and credit verification both on and off the blockchain.[5]

Our participants hailed from numerous different geographies, including Australia, Canada, Iceland, Switzerland, the United Kingdom, and the United States. In addition to including a range of perspectives, both in terms of ideology and geography, we also paid attention to gender and racial diversity, which we felt were important, given the blockchain space's general problems with diversity.[6]

We included a range of communities across the Web3 landscape, including Bitcoin, Ethereum, decentralized autonomous organizations (DAOs), and more, which made for a more diverse and interesting event.[7] Participants engaged in small breakout sessions and larger group discussions around the meaning of sustainability, and varied approaches to both using blockchain technology to aid in sustainability efforts and making blockchains themselves more climate friendly.

While attendees largely stayed away from remarks about the crypto crash, the moment certainly colored our conversations. Many participants expressed concern over the sometimes dubious nature of carbon credits and other greenwashing claims, which

3 Pat Gelsinger, "An Open Letter to an Open Ecosystem," LinkedIn, LinkedIn Corp., 25 Oct. 2021. https://www.linkedin.com/pulse/open-letter-ecosystem-pat-gelsinger.

4 Claire Vishik, Intel fellow, LinkedIn, LinkedIn Corp., n.d. https://www.linkedin.com/in/cvishik.Teixeira

5 "Proof-of-work," Wikipedia, Wikimedia Foundation Inc., last updated 13 Oct. 2022. https://en.wikipedia.org/wiki/Proof_ of_work.

6 Frizzo-Barker, Julie A., Women in Blockchain: Discourse and Practice," Co-Construction of Gender and Emerging Technologies, AoIR Selected Papers of Internet Research, 5 Oct. 2020. https://doi.org/10.5210/spir.v2020i0.11215.

7 "Decentralized Autonomous Organization," Wikipedia, Wikimedia Foundation Inc., last updated 19 Oct. 2022. https://en.wikipedia.org/wiki/Decentralized_ autonomous_ organization.

seem dangerously close to the scams and security breaches plaguing crypto in general.

To ensure privacy and candor at the event, we followed Chatham House Rules, meaning that participants were free to use information from the discussion, but not attribute any particular comment.

The freedom of anonymity led to rich discussions and crucial insights into the staggering challenges and bountiful opportunities currently facing the Web3 space. Calls for standardization and regulation were strong. Additionally, accurately calculating the emissions associated with proof of work is difficult, though many have tried.8 But the public perception of non-fungible tokens (NFTs) and other energy-intensive use cases have led to some companies banning NFTs or efforts to ban crypto transactions altogether.[9] The success of Web3's unique approaches to sustainability and carbon reduction depends on strong infrastructures for on-the-ground verification and reporting.

At the roundtable, most participants did not mention the Merge, Ethereum's transition from proof of work to proof of stake, that finally coalesced on September 15, 2022.[10] This long-awaited change purported to slash the network's energy use by roughly 99 percent.

However, there are key differences between what is said and what is done, and as a community we need to explore those differences further. We also need further research to deepen our knowledge and understanding of these gaps.

With the Merge, the net reduction in energy use across what we once called the Ethereum network is much harder to determine. Not all graphics processing units (GPUs) previously mining Ethereum just disappeared. The hardware and other infrastructures already built for proof of work are still there and cannot be flipped like a switch. Diverse communities of actors are making all sorts of decisions about what to do with all this hardware. Perhaps some will mine another profitable coin. Maybe some will repurpose their GPU infrastructures for other workloads. There's even a small but vocal contingent of Ethereum miners who have created a hard fork to continue mining Ethereum with a PoW consensus protocol.[11]
The upshot: Ethereum's claim to have reduced its energy consumption by 99 percent is complicated, as the PoW infrastructures built over the last decade will not simply disappear. Some will, sure. But others will become something different. What will they become? What can they become? These are key questions for Intel and other industry leaders.

Although some of our participants attended Merge parties as they waited for the Merge to happen at the stroke of midnight, the Merge and its subsequent fallout are good examples of the gap between discourse and practice that we set out to address in this event with the Web3 community.[12]

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8 Bitcoin Energy Consumption Index, Digiconomist.net, as of 21 Oct. 2022. https://digiconomist.net/bitcoin-energy-consumption.

9 Tan, Eli, "Minecraft Bans NFTs, Sending One In-Game Builder's Token Spiraling," CoinDesk, Digital Currency Group, 20 July 2022. https://www.coindesk.com/business/2022/07/20/minecraft-bans-nfts-sending-one-in-game-builders-token-spiraling/; and Sigalos, MacKenzie, 35"New York Just Passed a Bill Cracking Down on Bitcoin Mining: Here's Everything That's in It," CNBC CryptoWorld, CNBC LLC, NBCUniversal, 3 June 2022. https://www.cnbc.com/2022/06/03/heres-whats-in-new-yorks-new-bitcoin-mining-ban-.html.

10 Buterin, Vitalik (@VitalikButerin), "And we finalized! Happy merge all," Twitter, 15 Sept. 2022, 2:59 AM. https://twitter.com/VitalikButerin/status/1570306185391378434; and "Proof of Stake," Wikipedia, Wikimedia Foundation Inc., last edited 16 Sept. 2022. https://en.wikipedia.org/wiki/Proof_of_stake.

11 Aguilar, Diana, "Ethereum Post-Merge Hard Forks Are Here. Now What?" Cointelegraph, 22 Sept. 2022. https://cointelegraph.com/news/ethereum-post-merge-hard-forks-are-here-now-what.

12 weblin.io (@weblin), "Ethereum Merge Party," Twitter, 15 Sept. 2022. https://twitter.com/i/broadcasts/1OwGWwjkdpRGQ.

For a team of green software researchers trying to anticipate emergent user needs, we viewed the roundtable as an opportunity to have a frank and open conversation about the relationship between climate change and blockchains. When it comes to using blockchains to further decarbonization efforts, or mitigating the harms of energy-intensive PoW systems, everyone has a different working definition of sustainability and a different set of methods for approaching it.

Right before the roundtable, Land Life, a Dutch carbon offsetting firm, accidentally started a massive wildfire in Spain, undoing its own tree-planting efforts.[13] Sometimes technological interventions have unforeseen effects. While blockchain is a small component of Land Life's operation, press coverage like this can make the public wary of green blockchain claims, especially around carbon credits and offsets.[14] Journalists have published stories debunking, or at least complicating, the claims of carbon offset companies: the Thomson Reuters Foundation found that one pioneer in this new market, Brazilian green climate tech firm Moss, which purportedly had the support of Indigenous groups in the Amazon and intended to protect the rainforest, bought carbon credits that it said privately were of "low quality"—a judgment it later reversed in response to the investigation—and mixed them with others to back its digital token, selling them on for far more than it paid.[15] Carbon offsets are valuable as corporations attempt to reach their Net Zero goals, but more needs to be done to verify that carbon credits are reliable.[16]

What is clear from such setbacks is that the sustainable blockchains space is in need of standards, transparency, and accountability, especially when it comes to claims about carbon offsets and other efforts that are intended to benefit Indigenous communities and other marginalized communities in the Global South.

Because the Security and Exchange Commission implemented new environmental, social, and governance (ESG) disclosure requirements for publicly traded companies, ESG regulation is making carbon measurement and reporting more important than ever and is shaping practices on the ground as well as long-term strategy and compliance measures. As the bulk of the world's PoW infrastructure has migrated to North America after China's outlawing of cryptocurrency mining in 2021, PoW miners are under more pressure than ever to measure and report their emissions accurately.[17] There are also increasing efforts to communicate better how PoW's high energy use could aid in grid modernization and/or incentivize more renewable energy construction.[18]

Beyond PoW, a vast ecosystem of projects is attempting to reimagine approaches to how sustainability and ESG are imagined

13 Ongweso Jr., Edward and Lorenzo Franceschi-Bicchierai, "Corporate Carbon Offset Company Accidentally Starts Devastating Wildfire," Motherboard, Vice Media Group, 21 July 2022. https://www.vice.com/en/article/v7vdyx/corporate-carbonoffset-company-accidentally-starts-devastating-wildfire.

14 "Explore Our Projects," LandLifeCompany, Land Life Co., as of 3 Nov. 2022. https://landlifecompany.com/projects.

15 Asher-Schapiro, Avi and Fabio Teixeira, "Fears of 'Subprime' Carbon Assets Stall Crypto Rainforest Mission," Context, Thomson Reuters Foundation, 13 Sept. 2022. https://www.context.news/net-zero/long-read/fears-of-subprime-carbon-assets-stall-crypto-rainforest-mission.

16 Teixeira, Marcelo, "As the Amazon Burns, Brazilian Firms Tap Investors in New York for Help," Reuters, Thomson Reuters Corp., 20 Sept. 2022. https://www.reuters.com/business/sustainable-business/amazon-burns-brazilian-firms-tap-investors-new-york-help-2022-09-20/; and "Net Zero Coalition," Climate Action, United Nations, n.d. https://www.un.org/en/climatechange/net-zerocoalition.

17 Malik, Naureen S., "Texas Crypto Miners Face Inquiry from Warren Over Power Use," Bloomberg News, Bloomberg LP, 12 Oct. 2022. https://www.bloomberg.com/news/articles/2022-10-12/texas-crypto-miners-face-inquiry-from-warren-over-power-use.

18 Phillips, Nicola, "The White House Crypto Assets Report Supports Soluna's Business Model," Nicola Phillips Blog, Medium, 12 Sept. 2022. https://medium.com/clean-integration/the-white-house-crypto-assets-report-supports-solunasbusiness-model-4002ba9b6915; and ARK Invest, "Bitcoin is Key to an Abundant, Clean Energy Future," Bitcoin Clean Energy Initiative Memorandum, Square Inc., April 2021. https://assets.ctfassets.net/2d5q1td6cyxq/5mRjc9X5LTXFFihIlTt7QK/e7bcba47217b60423a01a357e036105e/BCEI_White_Paper.pdf.

in the first place (broadly called regenerative finance, or ReFi), including experimenting with the tokenizing of carbon credits.[19] Some of these approaches have become quite controversial, and it is unclear at this juncture how all of it will land.[20] But, as the attendees of our roundtable emphasized, standardization and regulation will help build and shape this space beyond the sometimes chaotic Web3 in which we currently find ourselves.

What will a more standardized and regulated Web3 look like? Intel and other industry leaders have a rare opportunity now to answer this question. Open source solutions are necessarily a part of the answer. A blockchain is, in effect, little more than a distributed ledger protocol that generates consensus through various types of participation and input from actors across its associated network. As a technology, blockchain is not inherently decentralized, but it can encourage certain structures of decentralization. It is not inherently open source, but, as an infrastructure, it can productively encourage open source solutions. And, of course, many climate-related blockchain projects are explicitly open source, including Filecoin Green, Energy Web, KlimaDAO, and Gitcoin.

There are signals that open source sustainable blockchains will be of increasing financial and social interest. Around the same time as our event, Filecoin, a completely open source project, hosted a sustainable blockchains summit in Paris for a two-day summit of expert talks, workshops, and deep dives featuring top thought leaders in sustainability.[21] Open source blockchains help ensure greater transparency while making it easier for various companies and agencies to collaborate.

We hope that this report and other findings from this roundtable can shed some light on the relationship between decarbonization and broader social justice efforts. In Web3 spaces, climate justice is often a “nice to have” rather than an essential part of the conversation, in part because tools for climate justice are as much social, cultural, and political as they are technological. It’s sticky, trying to think through these lenses. Most often, we fall short. Climate justice also requires thinking through multiple scales at the same time. The issues that we are grappling with in Web3 are analogous to problems across the entire tech industry and beyond. As an ecosystem still in its early days, we are thinking hard about climate impacts and carbon accounting from the very start. We also hope that this event can seed new ideas and directions, because we can only move forward, toward a greener future, collectively.

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Zane Griffin Talley Cooper

19 Owocki, Kevin, “How Crypto is Regenerating the World,” Bankless Newsletter, 18 May 2022. https://newsletter.banklesshq.com/p/how-crypto-is-regenerating-the-world; and Fogel, Phil, Ben Noel, and Sebastian Frankel, “Regenerative Finance is the Future of Web3,” FlowCarbon, Flow Carbon Inc., 21 July 2022. https://www.flowcarbon.com/knowcarbon/regenerative-finance-is-the-future-of-web3.

20 Calma, Justine, “Crypto Can’t Fix Carbon Offsets, But Crypto Fans Are Trying Anyway,” The Verge, Vox Media LLC, 18 Aug. 2022. https://www.theverge.com/2022/8/18/23310254/carbon-offsetcredits-crypto-tokens-adam-neumann-wework.

21 Filecoin, “Highlight Video Filecoin Meetup Paris 2022,” YouTube.com, 26 July 2022. https://www.youtube.com/watch?v=qjBXj2bHixk.

Executive summary

The energy needed to run the blockchain network is also the **primary security mechanism for protecting the digital assets stored on it.**

As the effects of climate change worsen, digital assets that use more electricity will look less attractive to investors.

We need better field data and peer-reviewed research on the energy used in mining cryptocurrencies.

The read-write-own Web3 is about asserting rights of **personhood, privacy, and property of open and trustworthy data ecosystems.**

Web3 gives us a new way of organizing and incentivizing the work of society where individuals own and control their assets.

The success of any sustainability project **depends on the context in which we embed the project.**

Project success relies on removing silos, taking an interdisciplinary approach, and developing policy in parallel.

The difficulty of tracking greenhouse gas emissions **makes carbon offsets unreliable in verifying progress.**

A neutral dashboard running on a public blockchain **could help the industry align incentives and confirm claims about recycling practices.**

Technology that transfers the heat of mining devices to district energy systems **holds promise in heating homes and buildings.**

Public policies could help reduce e-waste by incentivizing circular-economy initiatives, direct carbon capture, and renewables.

Regulatory clarity, standards for measuring and reporting, and independent reviews of energy calculations **would help to increase investment.**

Framing the conversation

In July 2022 Intel and the Linux Foundation convened a multistakeholder roundtable on blockchain and sustainability under Chatham House Rule.[1] The goals of the event sponsors were several, including

- "Thinking critically about the meaning and the practices of sustainability across Web3's diverse communities and the social, cultural, political, and technological relationships at multiple scales."
- "Surfacing and seeding new ideas, new directions, and new value across sectors as well, because we can move toward a greener and more just future, only collectively."
- Exploring ways to measure and manage the environmental effects of innovation better and organize ourselves better to minimize the climate impact of our societies.

Among those representing the blockchain space were technologists, academic researchers, and climate advocates gathered via videoconference to have frank and open conversations about climate change and Web3 technologies. What has become clearer is twofold:

- Big data as a global resource, mobile and social media as data gathering and reporting tools, and Internet communications and computing capabilities, including analytics and decision sciences, are instrumental to answering the how.[2]
- As the saying goes, the future is already here and unequally distributed, but its benefits and externalities are unequally distributed as well, with the "poorest and most marginalized people (bearing) the brunt of the burden" long before the future actually reaches them.[3]

What is unclear—and what this research brief hopes to help clarify—is whether blockchain as a foundational layer of Web3 is part of the problem, part of the solution, or both.

Sustainability in actionable terms

Participants discussed the gist of sustainability. "It's a term I often bristle at," said one person. "It's incredibly vague. And so I always ask, 'What are we trying to sustain for whom and for how long? What is the history? What are the power dynamics?'" Another called it "the opposite of a liquidation in a financial sense," not throwing good money after bad but probing deeply to understand what we invested in and why. That sounds simple, but without leadership continuity or institutional memory, the reasons for supporting a sustainability project may not be obvious to the executives inheriting it.

Several borrowed or built on the United Nations' enduring definition of *sustainable development*—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[4] The United Nations has also suggested that we can manage the effects of our "technology and social organization on environmental resources … to make way for a new era of economic growth."[5]

Others expanded the meaning to include technology's "viability over the long term—whether people use it, whether a community has formed around it—not just its environmental impact." Going further in terms of shared open source software like the Linux kernel or the Bitcoin protocols, the discussants broke sustainability into three measures:

- *Sustainable development* means that a project retains and funds core developers (core devs) for the long term, cultivates new core devs, and rotates talent over time;

- *Sustainable participation* means that a project continually communicates with its community, welcomes input in critical decisions, and brings the community along; and
- *Sustainable operation* so that use of the technology at any scale and in any context does no harm and maybe even helps the environment.

But these are not just about the numbers—the number of people, of interactions, and whether a project holds firm, forks, or fails—though those are important. Fully appreciating what roundtable participants had to say requires us to step back and look at Web3 and how we got here.

Growth of participation in Web3

People have been using the Bitcoin blockchain as a store of value, a source of income, and a stimulus for innovation since 2009. As of this writing, there were 977 thousand active addresses and over 800 code contributors and handful of active core devs, relevant to our measure of sustainable participation.[6] Like Web 1, the read-only Internet, it is distributed and open source for all practical purposes; unlike Web 2, the read-write Internet, nobody controls it, though governments have attempted to restrict access to it by controlling telecommunications service providers. Like gold as a store of value, Bitcoin is programmed for scarcity, and its price has comparatively low correlation with conventional asset classes like stocks and bonds, making Bitcoin a tempting hedge against inflation.[7]

For income, anyone can download the Bitcoin software and volunteer their hardware and electricity to run it. The software itself does the rest: it verifies transactions, assembles blocks of transactions, solves a computationally difficult problem, shows the proof-of-work—all to win the right to create the next block and receive a quantity of Bitcoin. The parties that do that are called *miners*. They each maintain a copy of the chain of blocks, or blockchain. Given a miner's proof-of-work, they reach consensus on the winning solution and race to solve the next problem.

The Ethereum blockchain brought significant improvements when launched in 2015. Led by Vitalik Buterin, its creators advanced the design space in two significant ways.[8]

- First, where the Bitcoin blockchain served a special purpose as a *distributed ledger*—issuing a fixed number of Bitcoins and transferring them securely peer to peer without some central authority—Ethereum served as a *virtual computational machine* for running all sorts of computations and applications in a decentralized manner (dapps).
- Second, its creators planned to migrate it from the proof-of-work consensus mechanism to a proof-of-stake model in a process they called "the Merge," which took place in September 2022.[9] As of this writing, it was tracking around 463 thousand active addresses, with over 900 contributors and a handful of quite active devs over time.[10]

People have been building on these blockchains, adapting their software principles into new protocols, platforms, and dapps, and combining them with artificial intelligence, things like sensors, three-dimensional graphics, and augmented reality hardware, all continually connected via Wi-Fi, 5G, satellite, or broadband so that people anywhere in the world can create culture together in real and virtual environments.[11]

Web3, the read-write-own Web, is intrinsically about this open culture—the coordination, confirmation, and recognition of effort, the peer-to-peer exchange and tracking of value, and the assertion of rights of personhood, privacy, and property in ecosystems forming around open and trustworthy data. One roundtable participant observed, "The significant interest in blockchain in various geographies, most notably in Europe, includes its usefulness in the area of privacy. It seems that the technology and related architecture are good."

The challenges at a glance

By and large, roundtable participants underscored that "the imperative is to address blockchain's climate impact," as interest in owning digital assets grows. An online survey conducted by OnePoll in March 2022 revealed that 53 percent of adult Americans believe crypto is the "future of finance," but a third of them want to see more products with low carbon footprints.[12] Some members of the roundtable expressed similar trepidation. Said one person, "We strongly support digital assets. But as effects of climate change grow worse, digital assets that use more electricity will look less and less attractive to investors."

In a spot poll, roundtable participants weighed in on the perceived sustainability challenges facing Web3 technologies (FIGURE 1). Foremost was the energy consumed by blockchains using proof-of-work consensus mechanisms; second was the lack of awareness and understanding of the purpose of that energy and the capabilities of Web3 innovation; third were social and political concerns, particularly the context of these discussions; and fourth was the need for technological and financial accounting standards and regulations. We explore each topic in turn.

FIGURE 1

WHAT IS THE BIGGEST SUSTAINABILITY CHALLENGE FACING WEB3?

Roundtable poll results (N=25)

Energy consumption of proof-of-work

The proof-of-work consensus mechanism pioneered for the Bitcoin blockchain and cloned or adapted by other blockchain developers has been a key driver of this concern, with 175 such chains (like Dogecoin and earlier forks of Ethereum and Bitcoin) listed on *CoinMarketCap*.[13] As Bitcoin's price rises, more parties want to mine. The more miners, the more difficult the puzzle; the more difficult the puzzle, the more energy required to solve it.

"We need to examine the system as it is and see what the entrenched powers or incentive structures already are, to determine how we might improve those incentive structures going forward," a roundtable member suggested. "External incentive structures develop that are very important when we're examining proof-of-work."

Perverse incentives or the cost of trust?

The original vision of the Bitcoin blockchain was "one central processing unit (CPU), one vote" or one chance to come up with the winning solution first, said one participant. Some have likened the process to a lottery held every ten minutes, where the Bitcoin protocols arbitrarily choose a winner. Like a lottery, people found that if they used their graphics processing units (GPUs) or field programmable gate arrays (FPGAs), bought more and better devices, or simply pooled their resources, then they'd increase their odds of winning.[14]

Another participant called this a cycle of "perverse incentives—the more mining hardware, the more likely to make money in a PoW system." Hardware manufacturers developed application-specific integrated circuit (ASIC) mining devices "able to do one million times more than regular machines," the participant said. Some of the latest models of ASIC Bitcoin miners can perform 110 and 148 terahashes a second (TH/s) using 3,250 to 3,850 watts an hour, at a cost between $3,000 and $6,000.[15] In addition to mining pools, corporate mining firms like GRIID, Hive, and Argo formed to warehouse these ASICs for industrial operation. "That led to centralization" of mining and making money, observed the participant. In this bear crypto market, mining operations may consolidate further.[16]

Several roundtable participants pointed to the difficulty of agreeing on the total energy used because of the different methods of estimation. For example, one of the sites referenced during the roundtable, the Cambridge Centre for Alternative Finance (CCAF), is said to take a bottom-up approach, starting with "simplistic weighting of profitable hardware," manufacturer specifications of publicly available devices, and electricity price estimates for its calculations.[17] By CCAF's annualized calculations, the global Bitcoin network uses 93.33 terawatt-hours (tWh) of energy, as of this writing.[18] In contrast, the Digiconimist takes a top-down approach, estimating total mining revenues and the price miners pay per kWh of electricity, then converting those costs to energy consumption.[19] The resulting annualized figure, 131.43 tWh, assumes that mining operations consume 60 percent of mining income.[20]

"Such assumption-based calculations are prone to error," according to Jonathan Koomey, an expert in the energy of computing. "Economic parameters (like Bitcoin prices) are volatile and are at best imperfectly correlated with electricity use." [21] Koomey analyzed the methodologies behind six of the oft-cited estimates of Bitcoin's total electricity use and found that none of them dealt thoroughly with uncertainty and the geographic variations of mining. He recalled the "erroneous reports about information technology's electricity use" in the year 2000: all "these claims turned out to be incorrect, but it took years of peer-reviewed research to prove it." He concluded that we need "far more actual measured data" as well as "infrastructure overhead electricity use," neither of which is readily available yet.

TABLE 1

KOOMEY'S BEST PRACTICES FOR ACCURATE COMPUTING ENERGY ANALYSIS

Do's
Build from the bottom up
Report estimates to the day
Collect measured data for components and systems in the field
Address locational variations properly for the sites of mining operations
Assess uncertainties explicitly and completely
Provide complete, accurate, and transparent documentation
Don'ts
Guess and give rough estimates about underlying data
Extrapolate into the future

SOURCE: JONATHAN KOOMEY, "ESTIMATING BITCOIN ELECTRICITY USE: A BEGINNER'S GUIDE," COIN CENTER, MAY 2019.

One roundtable participant explained the qualms with Bitcoin's carbon footprint: "We're very concerned about digital assets like Bitcoin that are *wasteful by design*. The incentives baked into the code call for using more and more electricity, the more popular they become, not less and less." This person gave an example: "Our cars are using less and less energy, and they are using electricity more efficiently. We need all our assets to do that." For sure, the hardware used to mine cryptocurrencies has become more efficient over time (FIGURE 2).

But, roundtable participants argued, incentives should encourage the creation of assets, digital or physical, that use less energy more efficiently, if they use energy at all. For example, the Environmental Protection Agency's ENERGY STAR program for electronics, office equipment, and other products with digital components saved American consumers "more than 520 billion kilowatt-hours of electricity and ... $42 billion in energy costs" in 2020 alone.[22] In the absence of industry-wide agreement on and commitment to targets and standards, governments may have a role: such regulations as the US National Highway Traffic Safety Administration's fuel economy standards and the Environmental Protection Agency's emissions controls have helped to drive those auto energy improvements.[23]

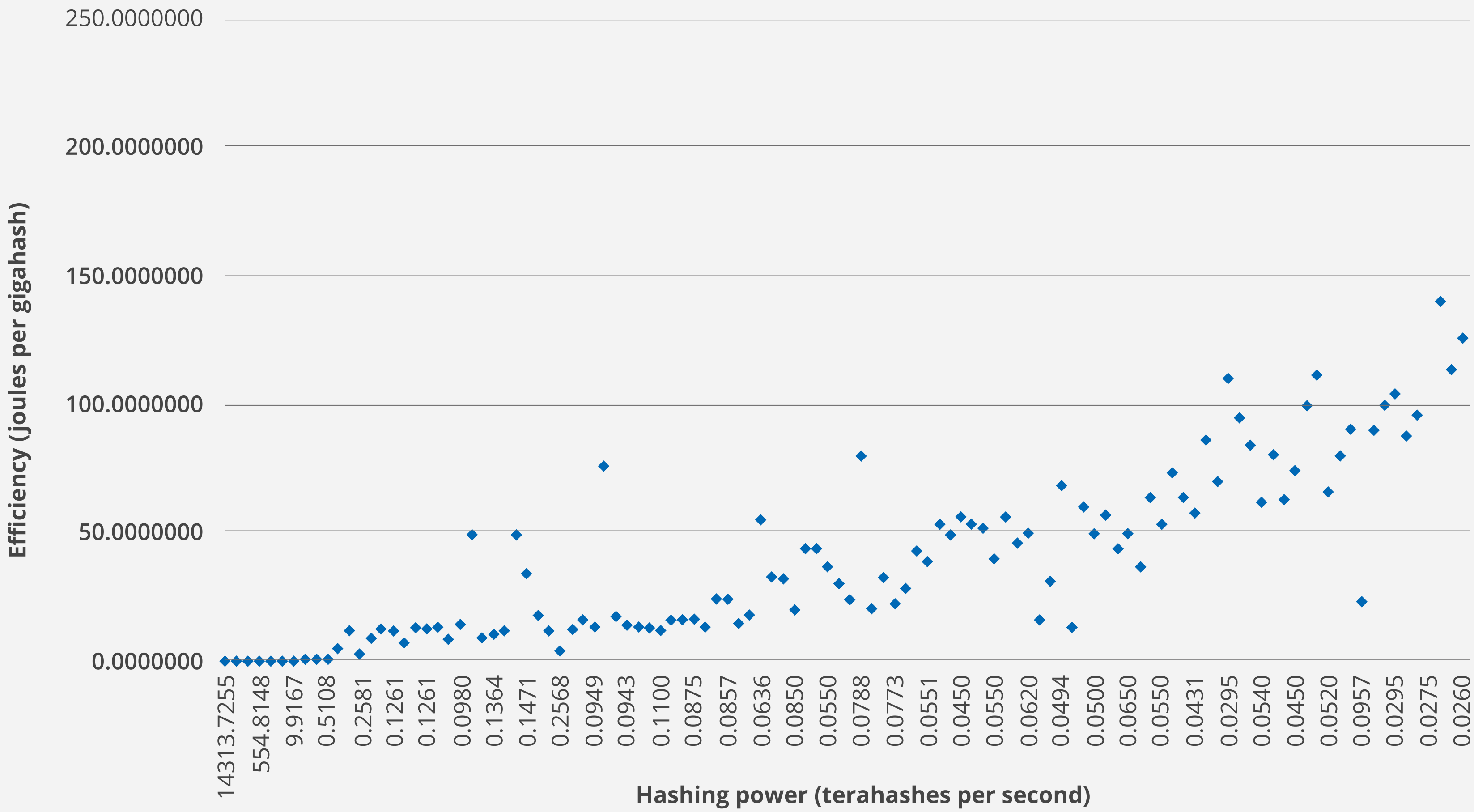
Still, the level of energy is a proxy for the level of security of the Bitcoin blockchain. As the energy costs rise, the cost of hacking the Bitcoin network may outweigh the financial benefits of doing so. Some roundtable participants saw this energy consumption as a feature, not a bug. Said one person, "For the first time, we have a technological platform that solves the trust problem in a ubiquitous and safe way, where no central actor can reverse" what users are trying to achieve together. For holders of Bitcoin in regions of the world with untrustworthy institutions, the level of energy consumption gives them confidence that their holdings are less vulnerable to arbitrary seizure or devaluation. As an Argentine Bitcoin entrepreneur told Jill Carlson, co-founder of the Open Money Initiative, "You cannot hold the peso. That is like holding an ice cream cone in this heat. It's melting. You need to do something." [24]

A roundtable participant explained: "The design creates a direct relationship between the computing power needed to protect the network and the assets stored on it. Energy is the primary security mechanism for the asset." The primary methods of security for fiat currencies are special printing to deter counterfeiting, armored vehicles for transportation, and bank branches with vaults and local distribution. Of several studies comparing the energy of the Bitcoin network with that of the global payment system, the one by consulting firm Valuechain isolated these three components.[25] It estimated that the energy consumed each year in printing and minting (17.61 tWh), cash in transit (166 tWh), and bank branches (175.3 tWh) was 358.91 tWh, more than double the highest Bitcoin estimation.[26] However, these studies also made the kind of top-down assumptions that tend to overestimate electricity usage.

FIGURE 2

INCREASING EFFICIENCY OF HARDWARE USED FOR BITCOIN MINING

Each blue diamond represents a different device, with the oldest machines plotting in the lower left quadrant and the newer ones in the upper right quadrant.



SOURCE OF DATA: CAMBRIDGE BITCOIN ELECTRICITY CONSUMPTION INDEX MINING EQUIPMENT LIST, AS OF 22 SEPT. 2022.

More computationally efficient and scalable blockchains

"Blockchain technologies often rely on a high degree of redundancy," said one roundtable participant. In the Bitcoin blockchain, every miner is racing to solve the same problem. "If enough participants can build the same answer, then it is probably the right answer. But redundancy is inevitably connected with the greater expense of cycles and therefore energy." This person said that "concerns about the environmental impact are driving blockchain technologists to use computations in ways that improve efficiencies and scalability."

Others pointed to sharding as a case in point, where users "split the work to many different machines, get to the network packet level, and have every single machine doing some specific work that is deterministic," but it all happens off-chain. Another was the Lightning Network, a Layer 2 protocol that two parties can use to process a series of transactions between them using an off-chain payment channel, then broadcast the last state of the channel to the Bitcoin blockchain.[27]

Foremost was proof of stake, where the security comes not from burning energy but from staking tokens and losing them if not acting in the best interest of the blockchain. Vitalik Buterin explained: with proof-of-work, "cost of attack and cost of defense are at a 1:1 ratio, so there is no defender's advantage. Proof of stake breaks this symmetry by relying not on rewards for security, but rather penalties" for breaking trust.[28] Ethereum completed its historic shift to proof of stake on 15 September 2022, and the estimated energy use plummeted (FIGURE 3).

The Merge lowered the energy needed to mint and trade digital assets such as non-fungible tokens (NFTs) on Ethereum. That's a real positive for holders and advocates of this very popular asset class. Other blockchains that support NFTs also use alternative consensus mechanisms: Cardano uses proof of stake, and Solana uses modified Byzantine fault tolerance with proof of history, designed to confirm the passage of time between two events in a cryptographic manner.[29]

One participant mentioned the programmatic proof-of-work (ProgPoW) algorithm as an improvement over ethash (the hashing algorithm Ethereum used instead of SHA-256).[30] It was designed to limit further "the amount of ASIC computers that'd be mining ether and transition to more GPUs that users could repurpose in the future to solve other proofs used for privacy technology."

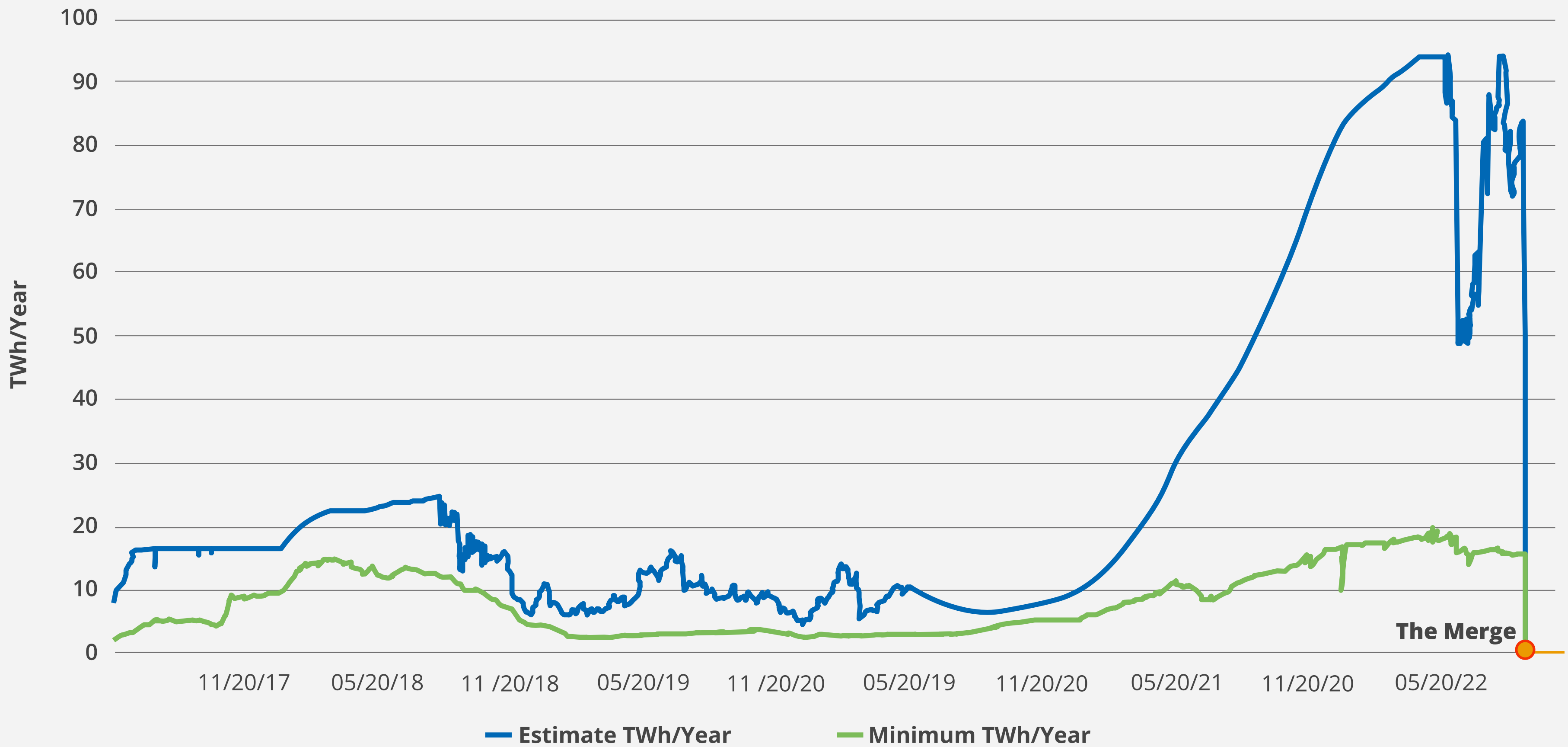
Roundtable participants also mentioned Cardano's research on proof of useful work (PoUW).[31] Its goal is to solve problems that are as computationally difficult as the Bitcoin blockchain's to maintain the blockchain's security, but yield results with real-world relevance such as event scheduling and logistics planning.[32] However, choosing those problems may require some domain-specific knowledge, and verifying results may be a challenge unless the problems are predominately mathematical, because those tend to have "a large repertoire of probabilistic verification methods." [33]

A couple of roundtable participants were uncomfortable with such an approach: "We're talking about which workloads deserve energy, the value of workloads. … I think we're in dangerous, dangerous territory when we're talking about worthiness of workloads." China's social credit scoring system came to mind, through which the government surveils and assigns positive and negative values to citizens' conduct, ranging from volunteering and donating blood (positives) to misbehaving on the subway and protesting politically in person or online (negatives).[34]

A participant suggested that they "focus not on what gets to use electricity. Focus on meeting demand in sustainable ways. … Focus on the value of load in terms of demand side management. Use that selectively as a tool for bringing more renewables online and addressing intermittency issues."

FIGURE 3

ETHEREUM'S ENERGY CONSUMPTION BEFORE AND AFTER THE MERGE



SOURCE OF DATA: ETHEREUM-ENERGY-CONSUMPTION, AS OF 3 NOV. 2022.

Roundtable participants expressed concern over Ethereum's security, now that energy is no longer the chief means of protecting the assets managed on it. According to Chainalysis, thieves nicked $1.9 billion worth of cryptocurrency through July 2022 this year, largely from blockchains not using proof-of-work—and largely from decentralized finance (DeFi) services running atop and between these chains.[35] Chainalysis urged "the industry to shore up security (of decentralized applications and smart contract code) and educate consumers on how to find safe projects to invest in." It also urged law enforcement to "continue developing (its) ability to seize stolen cryptocurrency to the point that hacks are no longer worthwhile." [36]

Hardware production and disposal

Nearly everyone has heard of Gordon Moore's law, that the processing power of a chip doubles every 18 months or so. Lesser known is Jon Koomey's law, that the energy efficiency of computers doubles in roughly that same period (FIGURE 2).[37] Combined, these advances have given each CPU, GPU, and ASIC "Bitcoin mining device … an estimated 18-month life cycle" before it becomes unprofitable at mining and is discarded, resold, or repurposed, said a roundtable member. (Short of quantum computing, however, these performance gains are bumping up against the physics of packing twice as many transistors onto a chip and manufacturing it at scale.[38]) "We're leaving out the hardware engineering side" of environmental concerns about Web3 technologies, said another participant. "As an industry, we're still not reckoning with the amount of waste in producing the hardware that run these systems."

One study of Bitcoin mining's e-waste addressed both those issues, pegging the average profitable lifespan of a miner at only 1.29 years and venturing an annualized estimate of 30.7 metric kilotons (kt) of e-waste associated with discarded equipment.[39] Members of the Bitcoin mining community sent a letter refuting these findings to the Environmental Protection Agency. They explained that, in practice, machines depreciate in value over three to five years, at which point their owners may decide to resell or recycle them.[40] Indeed, amid COVID-related disruptions to the semiconductor supply chain, the secondary market for equipment has grown, with Compass Mining and FoundryX among the mining pools aggregating and reselling old rigs.[41] In anticipation of the Merge, several of the other big mining operations developed plans to pivot their GPUs from PoW mining to deliver "artificial intelligence, machine learning, and visual effects rendering services." [42]

What's more, the letter to the EPA stressed that the aluminum heat sinks and casing of "Bitcoin ASICs are almost entirely recyclable, and contain no toxic or hard-to-recycle components, unlike conventional sources of e-waste like cell phones," with circuit boards containing arsenic and lead as well as gold, copper, and platinum and rechargeable batteries containing cobalt and lithium.[43] Using blockchains to track these electronics could help manage e-waste. For example, when telco giant Telefónica learned that the use of digital technology in Spanish households had surged in 2021, resulting "in an increase in device consumption and wasted electronic equipment," it decided to leverage its managed blockchain, Trust OS, for tracking reusable and recyclable products.[44] It incorporated TrustID using the Hyperledger Fabric framework, to identify each device, and Exxita's "Be Circular" AI platform Aitana to predict the repairability of devices and recoverability of precious metals.[45] Telefónica expects this initiative to extend the lifespan of products and increase the proper handling of toxic materials.

The Circular Drive Initiative is a similar effort to repurpose the hardware used for data storage.[46] It leverages the Chia blockchain network, which features the ecologically friendly proof-of-space-time (PoST) consensus mechanism, to optimize the supply chain for storage hardware reuse.[47] It intends to address the data security risks of such reuse by deploying the IEEE standard for

TABLE 2

CONSENSUS MECHANISMS: A COMPARISON OF DESIGN TRADE-OFFS

NAME	GOALS	ADVANTAGES	DISADVANTAGES	TYPE	EXAMPLES
Proof-of-work (PoW)	Provide a computationally difficult barrier to publishing blocks. Enable transactions between untrusted participants.	Difficult to flood network with bad blocks (denial of service attack). Open to anyone with hardware to solve the puzzle.	Computationally intensive by design: high power consumption, hardware arms race. Potential for 51% attack by obtaining enough computational power.	Permissionless cryptocurrencies	Bitcoin, forks of Bitcoin and Ethereum, many others
Proof of stake (PoS)	Enable a less computationally intensive barrier to publishing blocks. Enable transactions between untrusted participants.	Less computationally intensive than PoW. Open to anyone who wishes to stake cryptocurrencies. Stakeholders control the system.	Stakeholders control the system. Nothing prevents formation of a centralized pool of stakeholders. Potential for 51% attack by obtaining enough financial power.	Permissionless cryptocurrencies	Ethereum, Cardano Ouroboros
Proof of useful work (PoUW)	Provide a computationally difficult barrier to publishing blocks. Enable transactions between untrusted participants.	Difficult to flood network with bad blocks (denial of service attack). Open to anyone with hardware to solve the puzzle. Can be zero-knowledge.	Computationally intensive by design but not a waste of energy. Potential for 51% attack by obtaining enough computational power.	Permissionless cryptocurrencies	Cardano Ofelimos, Primecoin
Proof of history (PoH) on PoS	Enable a less computationally intensive barrier to publishing blocks. Enable transactions between untrusted participants.	Processes transactions extremely fast. Creates a historical record for proving an event occurred at a specific time.	Validator hardware must meet strict specifications; limits decentralization. Estimated to process about 40 petabytes of data per year; individuals may not have storage capacity.	Permissionless cryptocurrencies	Solana

SOURCES: VAN DER LINDEN, KEVIN, "WHAT IS PROOF OF HISTORY?" *ANYCOIN DIRECT*, PHOENIX PAYMENTS BV, 5 JULY 2022. ; FELIX HOFFMAN, "CHALLENGES OF PROOF-OF-USEFUL-WORK," CORNELL UNIV., 9 SEPT. 2022. DYLAN YAGA, PETER MELL, NIK ROBY, AND KAREN SCARFONE, "BLOCKCHAIN TECHNOLOGY OVERVIEW," NISTIR 8202, 3 OCT. 2018.

sanitizing storage.[48] Members hope to scale it up into a viable circular economy business, potentially targeting sectors that would benefit from more affordable equipment.

Another team of researchers in engineering and computer science created an Ethereum-based Internet of Things-enabled system for tracking and tracing electronic devices across their product life cycle using a set of smart contracts.[49] To minimize fraud, they developed reputation-centric criteria for participation, issued certificates of responsible disposal, and integrated with the Interplanetary File System to store images, proofs of destruction, licenses, and other evidence in a decentralized, immutable, and privacy-preserving manner. Their testing demonstrated the security and economic viability of such a system. Using an open source blockchain as a sort of neutral, third-party dashboard for e-waste would help the industry as well as consumers and regulators to confirm corporate claims about "safe, ethical, and green recycling practices" and "align behaviors across recyclers toward a circular economy." [50]

Adoption of sustainable energy and new approaches

The terawatt estimations above of the Bitcoin blockchain's consumption (93.33 tWh–131.43 tWh) do not tell us anything about the carbon intensity of the energy used; renewables instead of fossil fuels can make a difference.[51] Based on a 2021 survey, CCAF estimated that renewable energy, chiefly hydroelectric during the wet season, powered 39 percent of PoW mining devices.[52] The Bitcoin Mining Council conducted its own survey and determined that 59.5 percent of miners were using "sustainable electricity." [53] As one roundtable participant noted, "Quantitative measures like this are complicated and contested by different groups. This is why I argue for more qualitative on-site research across regions."

Many of the corporate miners have already located their data centers in places like Canada, Iceland, and Sweden where they can tap relatively low-cost and abundant renewable energy.[54] If miners significantly increased their use of renewables that didn't fluctuate with the seasons, then they could help mitigate Bitcoin's carbon impact. For example, the start-up Bitzero Blockchain announced plans to develop 200 megawatts worth of data centers in North Dakota over the next three years.[55] It chose North Dakota because of the state's clear "sales-and-use tax break on new computing equipment." [56] Moreover, North Dakota's geology and its laws lend themselves to underground storage of carbon dioxide and natural gas.[57] Bitzero intends to situate one of data centers by a huge greenhouse that the Mandan, Hidatsa, and Arikara Nation is building near the Missouri river.[58] If all goes well, the Garrison Dam will hydropower the data center, Bitzero will capture and transfer its heat to the Three Affiliated Tribes' greenhouse, and tribal members will achieve food sovereignty with fresh and healthy options.

In a similar experiment in northern Sweden, the municipality of Boden began building a greenhouse to be warmed by waste heat from Genesis Mining and HIVE Blockchain data centers powered by the Lule river.[59] Boden, which "imports about 95 percent of its vegetables," also wants to cultivate its own fresh vegetables year-round through this reuse of energy.[60]

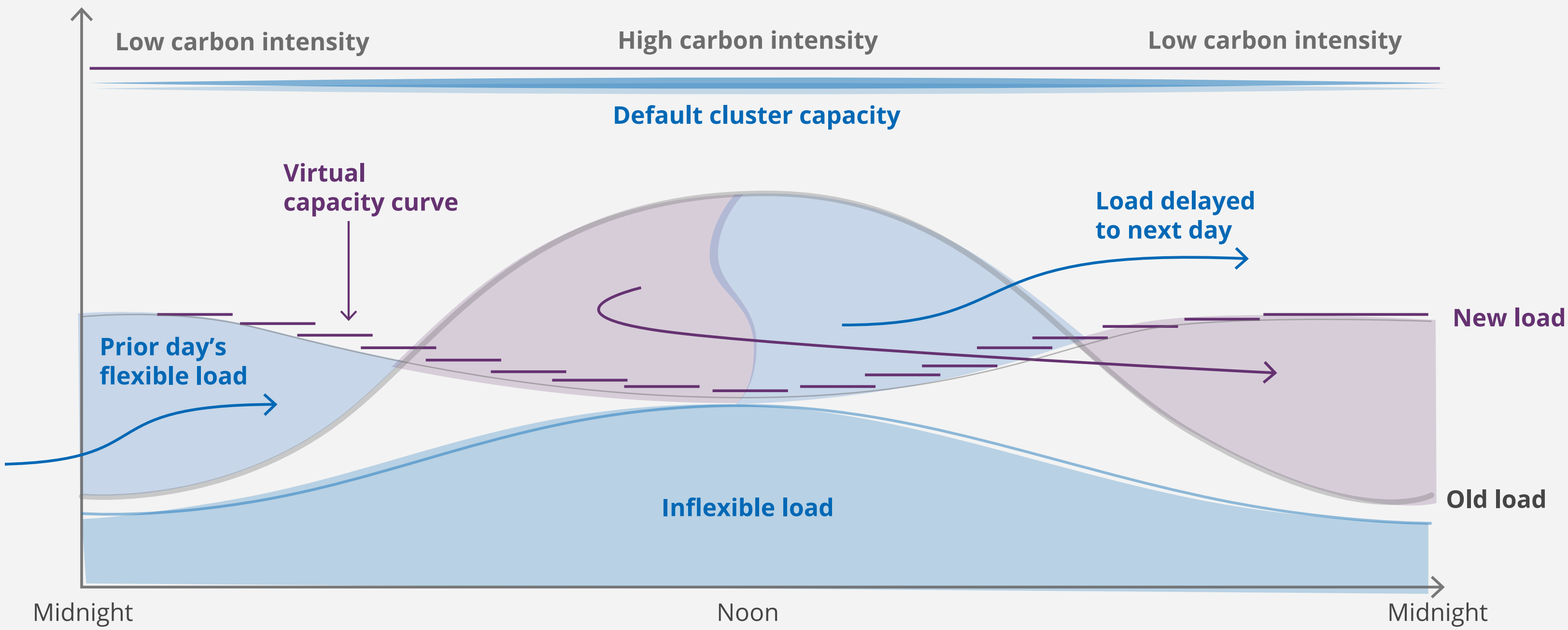
Bitzero's heat recycling project is among the start-up's portfolio of initiatives to achieve what it calls "zero carbon displacement," meaning that its use of 100 percent renewables will not force its neighbors on the same grid to revert to fossil fuels.[61] That calls for hourly accounting of energy consumption to support its claims, since solar and wind generate excess power during the day but little at night. That's what innovators at Google found: "Networked collections of warehouse scale computers ... emit more carbon than needed if operated without regard to the variations in carbon intensity" by time of day, location, and types of energy generation.[62] They've come up with what they call a carbon-aware computing solution that "actively minimizes electricity-based carbon footprint and power infrastructure costs by delaying temporally flexible workloads."[63] They used carbon intensity forecasts to train their prediction models of demand, and they used risk-aware optimization to create what they called *virtual capacity curves* (FIGURE 4), which proved effective in managing the workloads of their data centers to minimize carbon emissions. Large PoW mining facilities might explore such use of artificial intelligence to manage energy loads.

Effective storage is another critical piece of these solutions. For example, the Eurasia-based Bitcoin mining operator SAITech has developed heat capture technology to recover the heat that its mining devices generate. It claims that it can reuse nearly 90 percent of this heat. Its chief executive officer Arthur Lee told *Cointelegraph*, "We will become a better battery for (clean energy sources) to solve the energy-saving and energy storage problem." [64]

Bitzero plans to build "an assembly and distribution hub for graphene battery technology" for storing excess energy. According to the European Space Agency (ESA) and others, "graphene is the single greatest discovery of 21st century materials science": when manufacturers add an ultra-thin layer of the material to conventional Lithium ion cells, the resulting batteries have greater capacity and longer lives.[65] What's more, the manufacturing process can use water and natural cellulose instead of toxic solvents and binders.[66]

FIGURE 4

GOOGLE'S CARBON-AWARE COMPUTING SOLUTION FOR DATACENTERS



ANA RADOVANOVIC ET AL., EFFECT OF USING VCC MECHANISM FOR LOAD SHAPING IN A CLUSTER, 2021. ADAPTED UNDER CC BY 4.0 LICENSE.

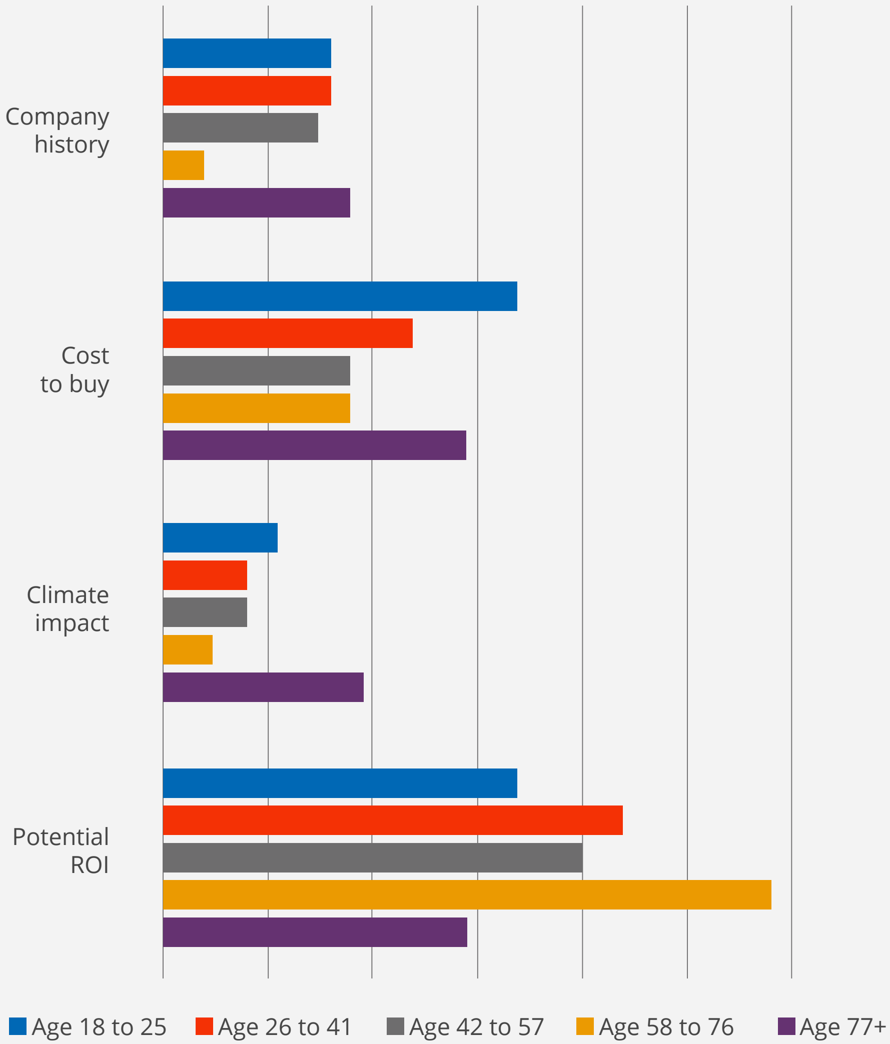
Another approach is to use flared gas for Bitcoin mining. That's gas that an oil company would just burn off otherwise, because capturing and transmitting it would not be cost-effective, whereas using it on the spot to power Bitcoin mining operations minimizes the waste. Enerplus, Equinor, Exxon, and ConocoPhillips have all jumped into the game, getting their field equipment from shops like Crusoe Energy Systems and EZ Blockchain, with mobile technology to mitigate flared, stranded, and landfill gas.[67] "What does this mean for royalty owners?" asked lawyer John McFarland on behalf of land and mineral owners. "Maybe they'll get some royalty on gas sold to the Bitcoin miners, rather than seeing their gas go up in smoke."[68] That's a bonus.

The Canadian tech start-up MintGreen has created what it calls a "digital boiler": it places its Bitcoin miners in a chamber and pumps coolant over those miners to a device known as a heat exchanger, which transfers the heat from one liquid (or gas) to another liquid (or gas) without the two ever touching. (The French start-up WisElement has developed its own boiler solution called Sato as a supplement to "houses equipped with water-based central heating systems. ... as good as any electric boiler with a 99 percent efficiency rate."[69]) MintGreen has partnered with North Vancouver's Lonsdale Energy Corporation, which manages the city's hydronic district energy system, a discrete network of pipes that heat buildings by circulating hot water.[70] Through this method, MintGreen expects to recover 96 percent of the heat wasted in its Bitcoin mining operations.

The UN Environment Programme has called *district energy* "a secret weapon for climate action and human health" because it connects "renewables, waste heat, thermal storage, power grids, thermal grids, and heat pumps, delivering up to 50 percent less primary energy consumption for heating."[71] The US Department of Energy has also recognized the benefits of district energy: "By combining loads for multiple buildings, (these) systems create economies of scale that help reduce energy costs and enable the use of high-efficiency technologies such as combined heat and power."[72] In Web3 parlance, district energy is one of those composable structures that can leverage artificial intelligence in "continuous operational monitoring, advanced load forecasting, and advanced controls," integrate with blockchain-managed microgrids, increase energy grid resilience, and contribute to regional grids in crises.[73] If the digital boiler delivers, and the system's thermal storage can effectively capture excess heat for use in Canada's winter, then it will be an exciting advance.

FIGURE 5

WHAT IS THE MOST IMPORTANT FACTOR WHEN ASSESSING A CRYPTOCURRENCY INVESTMENT?



FORBES ADVISOR COMMISSIONED MARKET RESEARCH COMPANY ONEPOLL TO CONDUCT AN ONLINE SURVEY OF 2,000 US ADULTS IN MAY 2022. THE MARGIN OF ERROR IS +/- 2.2 POINTS WITH 95% CONFIDENCE. SOURCE OF DATA: WAYNE DUGGAN, "SURVEY: 84% OF AMERICANS DON'T BELIEVE THAT BITCOIN INVESTMENTS ARE A THREAT TO THE ENVIRONMENT," *FORBES ADVISOR*, FORBES MEDIA LLC, 31 MAY 2022.

Education and awareness: Carbon offsets

According to an NBC News poll, "one in five Americans has invested in, traded or used cryptocurrency," with 40 percent of Black Americans reporting that they had traded or used crypto. They cited "better transaction speeds, lower costs, privacy, security, and an opportunity to provide underbanked communities with financial services" as reasons for using cryptocurrencies.[74] FIGURE 5 shows what mattered to different age groups as they considered buying Bitcoin and other cryptocurrencies: potential return on investment (ROI) far outweighed crypto's potential impact on climate. Those who published the poll interpreted these results as indicative of respondents' lack of understanding of how crypto works.[75]

The roundtable identified carbon markets as needing greater attention in terms of communications and education. The discussion juxtaposed centralized and decentralized systems for measuring and tracking data: "We live in a society of centralized data, and centralized organizations controlling that data. When any group controls data, there's a natural incentive to use that data for the group's benefit. That's how today's economy is set up. So, it's very hard for everybody else to figure out what's actually going on."

Participants observed that "blockchain people are supporting existing industries and existing frameworks out there, and doing that doesn't leverage the true idea of a decentralized network." Demand from corporate shareholders for environmentally sound investments, combined with the US Securities and Exchange Commission's new requirement to disclose certain climate-related data in corporate registrations and annual reports, has revved up the need for ways to remove carbon from corporate operations.[76] But that can take time.

Carbon offsets and credits can bridge the gap. According to the Green Business Bureau, a *carbon offset* represents a company's successful effort to reduce or remove carbon dioxide or other greenhouse gas (GHG) emissions from one area of operations to offset its emissions elsewhere, whereas a *carbon credit* is a tradable instrument representing its holder's "right to emit a set amount of carbon dioxide or the equivalent amount of a different GHG."[77] One person in the roundtable suggested supporting "avoidance markets. Corporate work has been to avoid emissions, carbon removals. They have yet to play a significant role, but we definitely need to support them."

Implementation challenges

Unfortunately, measuring and tracking GHG emissions is tricky. Said one roundtable participant, "We're very skeptical about the trustworthiness of offsets as a part of the solution." Another agreed: "I don't think that they are ready yet as a trustworthy instrument to verify that carbon implications have been accounted for." For example, one report pointed to the challenges of distinguishing high- and low-quality projects such as the "permanent carbon removal achieved through high-risk investment in direct air capture and a less consequential scheme which prevents tree-felling in a remote rural location in Malawi."[78] Other participants chimed in: "It's really difficult to create carbon credits that genuinely avoid or remove carbon from the atmosphere. We've hired many scientists to think about all the different verticals, in which we might do accounting of carbon emissions and then vet what exists on the market."

The roundtable conversation turned to using "blockchain to improve the structure of the carbon market, which is overcomplicated, inconsistent, and counterintuitive, where newest credits are most valuable, because there are no new environmental benefits when they change hands." A criticism was the opacity of pricing, where offsets are sold twice and therefore counted twice.[79] Someone pointed to "Klima Infinity, a carbon offsetting toolkit that allows people to make sustainability pledges and then retire carbon on chain using RT (retirement token). It has It has an offset retirement aggregator."[80] Another participant suggested looking at "the whole trust infrastructure and how we want to decentralize it." Other ideas included an "API for micro carbon credit" and a "carbon reserve cryptocurrency, a token backed one to one, one carbon credit for every claim token."

Last mile gap

Another key challenge is the "equivalent of the last mile gap where accounting for solutions (like reforestation) is as messy as functional ecosystems." A roundtable participant described it as "a DeFi challenge related to total value locked. Many times, it's legal: there's a gap in legal structure for people to reach from the digital into the physical. Does the legal structure enforce agreements, if parties don't honor them?" This person had considerable experience grappling with this gap: "We've built on the shoulders of giants of carbon registered juries who are already the physical arm in the world, verifying all the information, and then feeding that information into the blockchain by purchasing it for us." In addition, there are verification bodies that conduct validation of projects. The attestation of the mitigation lays out the number of credits that a party can and can't register. To bridge the last-mile gap, the person suggested either finding a physical entity to engage with legal authorities, or identifying regulations or agreements that work between parties.

In a recent report, the World Bank explored the use of multiple technologies to capture data close to the source in a digital monitoring, reporting, and verification (D-MRV) system for carbon markets. In a waste-to-energy pilot in Chile, the project team secured sensor data on a blockchain; and in a wood tracking protocol pilot, the team in Peru ran satellite and drone data through AI algorithms to detect and record changes to the forest.[81] Since they secured the data on a blockchain on site, no one elsewhere could tamper with it, and third-parties elsewhere could access it and verify that it hadn't been altered. The report concluded that distributed ledger technology and immutable cloud storage can help carbon markets to "transition to one-time certification of D-MRV systems with recurring remote verification of project data."[82] The World Bank has mapped out where this D-MRV field work fits in its "End-to-End Digital Ecosystem for Carbon Market," featuring tokenization, a registry of digital carbon assets, exchanges, and a Chia blockchain-based data warehouse with a services layer.[83]

IoT devices with telemetry and other data feeds captured by smart contracts or Layer 2 solutions could automate remote data collection on carbon projects. One researcher suggested that a blockchain-based IoT network could help reduce traffic congestion and the need for public parking, to open up green urban spaces. The data could help policymakers and engineers to optimize the mix of parks, parking, and public transit.[84] Finally, so-called trust fabrics like Alvarium, "a virtual overlay that aids in the delivery of data from devices to applications with measurable trust characteristics," might eventually help to bridge the gap with greater confidence.[85]

Overall, the roundtable was positive about the potential for blockchain innovation here: "In the carbon market, we're creating a more transparent system, one that has easier access, and one that allows information to demand side participants and to suppliers, whether they're carbon project developers or others. ... It's a paradigm shift in how the market can develop in the future."

Social and political

Enough time has passed since the launch of the Bitcoin and Ethereum blockchains that we have data to challenge prior claims and guide policy.

For example, when it comes to banking the unbanked, Dr. Will Cong at Cornell University and colleagues analyzed data from the Ethereum network to determine the extent to which Ethereum was financially inclusive under the PoW consensus mechanism.[86] They found a concentration of asset ownership and mining operations. Instead of transacting peer to peer on Ethereum, individuals were using dapps and DeFi protocols; larger players were using the network itself. The researchers concluded that, "under the current gas fee mechanisms, high transaction-fee rates for small players, significant congestion-induced fluctuation of gas prices, and large return volatility of tokens hinder financial democratization and inclusion."[87]

They analyzed proposals to address these issues (such as EIP-1559) but found "that it still causes high transaction fees for small players because it is a matter of scale rather than mechanism design." On the plus side, "the burning of base fees has a perhaps unanticipated benefit of transferring wealth from large players to small and new agents, which facilitates financial inclusion." Cong and colleagues also showed how "airdrops as redistributive policies can improve financial inclusion."[88] All that to say, we have more data to study the market dynamics of each blockchain, to inform the types of real-world projects we might want to undertake.

On energy policy, some countries such as Kosovo and Iran have banned Bitcoin mining because of the strain it puts on local energy grids.[89] But grids can vary widely across a country in terms of age of the technology, composition of power generated, configuration of transmission, dynamics of distribution and load, and the environment of consumption. To inform policymakers, an engineering team at Cornell conducted a nation-wide study of the feasibility, profitability, and environmental damage of Bitcoin mining in the United States.[90] It found that states like Washington and Vermont—with lower electricity prices and greater penetration of renewables in their grids—could minimize the carbon footprint of data centers used for mining operations. In those two states, crypto mining happened to be the most profitable as well, in contrast with Kentucky and West Virginia, where crypto mining was the least profitable and most harmful.[91] The researchers concluded that, if public policies offered "incentives for direct carbon capture from the air and eco-friendly mining, then cryptocurrency becomes more sustainable."[92]

Regarding e-waste, "policymakers should support circular-economy initiatives … as well as more demonstrations and proofs of concept for promising innovations in the field."[93] One study found that "the primary way to ensure an e-waste recycler will engage in honest practices with minimum supervision is to make it the more profitable option, either by decreasing the costs of recycling or increasing the penalties for fraudulent practices."[94] That means "targeted subsidies, higher penalties for fraud, and manufacturers ensuring their electronics are more easily recyclable." [95]

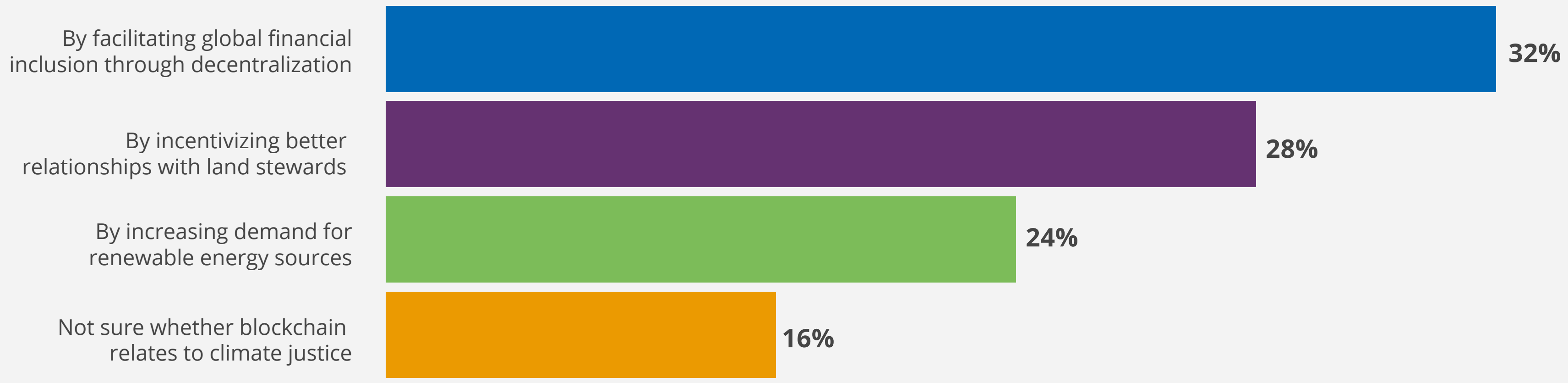
The value of diversity and inclusion

Let's circle back to sustainability as a concept, how members of the roundtable applied it to both physical and digital resources. They did the same with another important concept—climate justice. One person summed it up for the roundtable: "All participants don't share the work or bear the costs equally. Nor do they share the benefits and the harms equally." A case in point is the shipping of 3.3 Mt of e-waste "from high-income to middle-and low-income countries, further trickling down regionally toward the poorest

FIGURE 6

WHAT IS THE BEST WAY BLOCKCHAIN CAN CONTRIBUTE TO CLIMATE JUSTICE?

Roundtable poll results (N=24)



within the region."[96] FIGURE 6 summarizes the roundtable's view of blockchain's role in contributing to climate justice.

Highly relevant and applicable to digital worlds and their impact on the planet are three principles of climate justice that project planners need to keep in mind:[97]

- *Distributive justice*, which refers to "the allocation of burdens and benefits among individuals, nations, and generations," so that acting on our opportunities today doesn't activate someone else's crisis tomorrow, long after we have extracted value and moved on.
- *Procedural justice*, which refers to the people in a community who get to "decide and participate in decision-making," so that strategy development and implementation go hand in hand—no closed-door dealmaking, no handing down of resolutions, no brushing off of concerns.
- *Recognition* of diverse cultures and perspectives, where parties engage with each other equally, robustly, and with respect and fair consideration—all of which help drive innovation, improve the viability of innovative ideas, and increase the self-agency of those so engaged.[98]

In practice, these principles of inclusion, diversity, and engagement generate options that are customized for communities, yet contribute to regional efforts. "Climate justice lies at the heart of our efforts," said another roundtable participant.[99] "The tools for climate justice are just as much social, cultural, and political as they are technological. It requires us to think in multiple scales simultaneously—the scale of the globe, the smaller firm like the start-up, the large corporation, the state, the planet itself, as well as the code, the technology, the community, the infrastructure, and so on."

It prompts such questions as, what is the impact of mining for battery materials on the communities whose lands are permanently damaged, uninhabitable? When funding conservation projects such as reforestation to capture carbon and create carbon offsets, have we engaged not just the governments we plan to fund but also the indigenous residents of the targeted lands?[100]

"Some of these blockchain companies can't legally do anything about it, but not talking about it makes the problem much worse for those people, especially women. We should be able to communicate and find the solution," and not punish the people for how their governments have behaved, said one roundtable participant. That's the promise of Web3.

Roundtable participants also brought in the concept of *regenerative finance* (ReFi), a practical application of *regenerative economics*, where we account for negative externalities of economic activity to the transaction level and compensate those individuals or communities affected. ReFi trading platforms give investors a means of participating in sustainable-energy initiatives in exchange for renewable-energy certificates, which are "market-based instruments that represent the property rights to the environmental, social, and other non-power attributes of renewable electricity generation."[101] For example, the Sustainable Bitcoin Protocol is a decentralized autonomous organization (DAO) seeking to persuade Bitcoin miners to mine Bitcoins using clean energy by rewarding them with "sustainable Bitcoin certificates," which are meant to represent "transferable assets that represent sustainably mined Bitcoin." [102]

The human infrastructure needed

Finally, participants wove in a fourth important concept, human infrastructure as a mechanism for change and implementation: "Solutions require human infrastructure to work." That's no small statement, when we consider its meaning in physical and digital dimensions. The World Bank has characterized human infrastructure as the set of public policies for financing and delivering "health, education, and nutrition," where the state ensures "the efficient, equitable allocation of resources ... in key subsectors that have high economic returns and that help the poor the most." [103]

Those investments are table stakes for participating in the human infrastructure of cyberspace, which expert Fran Berman called "a synergistic collaboration of hundreds of researchers, programmers, software developers, tool builders, and others who understand the difficulties of developing applications and software for a complex, distributed, and dynamic environment."[104] In these environments, people work across a network that "integrates and coordinates resources using standard, open, general-purpose protocols and interfaces to deliver nontrivial qualities of service," rather than within a corporation that centrally controls resources using proprietary tools.[105]

The technology supports the kind of approach and behavior that we need to solve complex problems. For example, one participant pointed out the challenges of silos: "Conversations are very siloed, like people trained in scrap metals are trying to use blockchain to chart where this material was brought from and where it's discarded." The person suggested having "a holistic discussion of the different kinds of engineering required and the different kinds of intelligence and education they need." In hindsight, the benefits of industry consortia around blockchains were less about identifying blockchain solutions and more about understanding the problems everyone else was trying to solve in the organization or supply chain.

Those who thrive in this type of distributed environment "provide the critical human network required to prototype, integrate, harden, and nurture ideas from concept to maturity."[106] They drive the kinds of global initiatives hosted by, for example, the Ethereum Foundation, the Linux Foundation, and the World Wide Web Consortium. "Web3, the distributed environment, takes communities and individuals much closer to owning and controlling their assets," said one participant, pointing out the incentives that align contributors' efforts in a network. It responds to the United Nations' call for organizing the work of society in new ways.[107]

The KlimaDAO as a decentralized autonomous organization is a case in point. It describes itself as a "collective of environmentalists, developers, and entrepreneurs who aim to pool their knowledge and expertise to drive change in the carbon markets, today." The DAO's native asset KLIMA is an ERC-20 token backed by "at least one tonne of tokenized verified carbon offsets" in the DAO treasury.[108] Those who complete projects and collect offsets can tokenize them on Klima via something called the Toucan protocol carbon bridge. If participants drive up the price of carbon assets, then they make carbon-removal projects more financially attractive to companies.[109] That serves to motivate and coordinate climate action in a *decentralized manner* rather than a centralized one.

That's a distinguishing feature of Web3 human infrastructure—it comes with incentive tooling.[110] It's also a profound observation: setting up workflows and motivating people via a network model is different from that of the traditional corporate structure. To a greater extent, market forces and behavioral economics are in play. A roundtable participant summed it up nicely: "If we're not taking an interdisciplinary approach to sustainability, then our solution is always going to be shortsighted. And if it doesn't involve policy, then even our best efforts are going to fall flat."

Shovel-ready use cases

Many of the ideas circulated during the roundtable combined blockchain and the energy grid itself with a goal of decentralizing the generation and management of the latter. Since the roundtable, record-breaking monsoon rains have pummeled Pakistan, and a category five hurricane has swept through the Caribbean and across Florida.[111] Russia persists in its campaign against Ukraine, with energy facilities in the crosshairs. Who knows whether a hacker is on the verge of exploiting a hole in the IT systems security controlling a regional grid or power generation facility? "Consider the negotiations with Saudi Crown Prince Mohammed bin Salman to boost oil production and combat soaring global prices," veteran journalist Michael Casey wrote. "That world leaders must cater to the interests of a sole unelected human being to solve an economic crisis that affects all eight billion of us is the epitome of a centralization problem."[112] Negotiations did not pay off. In early October, the Organization of the Petroleum Exporting Countries Plus decided to cut oil production by two million barrels a day.[113] Conservation of fossil fuels, onboarding of more renewables, and distributing grid resources are imperatives.

Leveraging blockchain in a more distributed and localized grid could increase grid security and resiliency in three ways. First, without a central point of control, a distributed grid reduces the probability of large-scale attack. Second, parties hash and encrypt data before transmitting it. Third, since parties cannot change the data without consensus of all parties, they'd all be able to detect fraud more quickly.[114]

The challenge for governments is finding projects that are ready for funding. "What's encouraging now with the ReFi space is that there's a lot of cross communication from the players who've been in the market for decades on how to do this," said one roundtable participant. "We're setting up working groups on how we can put blockchain technology to work in a very positive way. It's a really unique application of blockchain technology and a real-world use case."

Consider the Energy Web Chain's implementation of its distributed operating system with Austrian Power Grid's "flex hub." APG maintains stability of generation and consumption within the Austrian grid. It already integrated horizontally with other European energy markets but wanted to integrate vertically with small-scale renewables. Energy Web's solution helped to qualify and register energy generating units, manage bids, and settle payments for small-scale distributed energy resources (DERs).[115] Customers could register their DERs directly and accredited third parties could verify the details of any registered unit, such as residential batteries. It requires community engagement.

Another roundtable participant confessed, "I'm always advocating for more boring use cases like traceability. That's what's interesting to me, that's what makes what you all are saying really valuable. Okay, we can move toward something where we can trace an asset across its life cycle." A not-so-boring example is UK-based company Circulor, which has developed a suite of blockchain-enabled tools that document the provenance of the mineral and natural resources used in the automotive and electronics sector. The Circulor system creates an immutable audit trail for suppliers and buyers to track raw materials like cobalt through the supply chain, giving all parties a nearly real-time view of these assets.[116] Hardware manufacturers can extend it to include recycling and putting the recycled materials back into the supply.

Patching up aging energy infrastructure in developed economies and building out new fossil-fuel grids in emerging markets are not prudent. Blockchain supports decentralized models, with dropping costs and technological innovations in renewables. "These advances have driven a steady trend toward decentralization in electricity markets, with larger and more diverse participation than ever before," according to the nonprofit Energy Web Foundation. Consumers are better equipped than ever "to produce, store, and manage electricity on their own terms at prices competitive with conventional utility tariffs."[117] The Brooklyn Microgrid is a good example.[118] Developed by LO3 Energy, it is a blockchain-based microgrid in Brooklyn, New York City, where residents used their own devices to trade photovoltaic-generated energy, directly and securely with their neighbors.[119]

A roundtable participant proposed a model that implants a power plant's economic offtaker—that is, the buyer of its energy—in "a project that uses..." part of the energy for the computing application and puts the rest of the energy into the local economy so that the community can use it in their energy environment."

Like the LO3 Energy project, the success of such a model depends heavily on the social, political, cultural, and infrastructural contexts in which developers embed their projects. Indeed, are there core developers and a talent pipeline? Are there signs of growing participation? Are there plans for operations over time?

Standards and regulation

The conversation around standards and regulation was lively. "So much is happening in the DeFi space, you know, that people are taking actions and then asking for forgiveness later. Experiments are constantly underway." But the lack of regulatory clarity around distributed energy networks and other innovative models was hindering serious investment; regulations tend to favor incumbents. States like North Dakota and Wyoming have been passing laws that give tax breaks to petrol producers so that they can fuel Bitcoin mining and data centers instead of flaring gas, and these have benefitted blockchain entrepreneurs willing to work with the big oil companies.

Also, the lack of generally accepted units of measure and principles for reporting energy consumption leads to obfuscation and misunderstanding, with apples-to-oranges comparisons that don't provide context, such as comparing the Bitcoin network's energy consumption to that of an entire country rather than to a traditional global payment network. Regulators might consider licensing requirements and mandatory disclosures for mining facilities, so that they use some percentage of renewables.[120]

Participants generally agreed that blockchain industry-created calculators didn't provide full context for the calculations, either deliberately or out of ignorance, misconstruing energy consumption (e.g., NFTs) to the public. Even the energy-per-transaction calculation doesn't tell the whole story (e.g., for nesting multiple assets to multiple addresses in single transaction); one person suggested using unspent transaction output as a measure instead.

In terms of hardware energy ratings, someone said, "There are thirty publicly traded Bitcoin miners, and no two miners talk about their energy in the same way; there are no clear frameworks." Everyone was generally in favor of an independent review of energy consumption calculations, with independent auditors and transparent methodologies. These are multi-stakeholder challenges requiring multi-stakeholder problem-solving.

Build on current momentum

The roundtable discussion revealed the significant progress many of the participants had made in their collaborations on industry standards for measuring and reporting. The fruits of one such initiative is Green Proofs for BTC, "a framework for assessing and certifying the carbon impact of Bitcoin mining operations" and an incentive for Bitcoin miners to cut their carbon emissions. The goal is to provide greater clarity around environmentally responsible mining and greater transparency to miners' sustainability claims. Bitcoin miners themselves share details not just on electricity they used but also on their location and the renewables they bought. Said one participant, "The Green Proof set is designed to facilitate and support green commodities markets. So, that does include carbon accounting and the emissions associated with different types of commodities." Another participant added that Green Proofs help to "understand the emissions implications of specific Bitcoin mining facilities, so that we can bring more transparency to buyers, regulators, and the general public about the implications of any organization with which they choose to do business."

The roundtable also discussed the guidance on accounting and reporting energy usage in crypto mining to advance the Crypto Climate Accord.[121] In terms of scope, it distinguishes between direct and indirect emissions from an entity's primary operations as well as its supply chain upstream and downstream. It outlines a process for determining the amount of mining-related emissions and presents consequential and attributional (location based and market based) approaches to emissions accounting. It should greatly inform the efforts of those groups working on technical and accounting standards and practices. Participants kept in mind that incumbents have a vested interest in existing standards. The goal is to test the standards' utility and validity in decentralized contexts and propose alternatives or improvements if necessary.

Develop technical standards

Participation in standards development and adoption for project design, implementation, reporting, and verifications throughout is critical. One participant gave this example: "Due to the lack of good practices in carbon offsetting, we established a technical committee under a standardization party that is a member of ISO (International Organization for Standardization), and set out a standardized and normalized approach to creating a corporate project and doing the offsetting."[122]

Likewise, the blockchain and distributed ledgers committee of the IEEE Standards Association is working on a standard for using blockchain in carbon trading applications that "specifies the technical framework, application processes, and technical requirements for carbon trading applications based on blockchain … and carbon consumption voucher coding"[123]; and a standard for using blockchain in low carbon zones evaluation, which includes "an evaluation model and evaluation index system" and "defines the technical requirements and management requirements."[124]

Another participant described the work of the "Global Steering Group for Impact Investment (GSG) program[125] and the Verified Carbon Standard, a full-fledged offset certification program managed by Verra.[126] Both originated from the Clean Development Mechanism[127] under the Kyoto Protocol.[128] These are requirements for creating a project and lay out some core principles every project must conform to. … You demonstrate the baseline, the project emissions, and lay out the number of credits to be generated."

Roundtable participants also saw a need for and industry-wide commitment to, and agreement on, energy targets and reporting standards with data transparency and openness to independent ratings of mining equipment. Manufacturers could support recycling programs to recover the casing and aluminum, potentially as rebates for the purchase of new devices, especially in those jurisdictions where most miners are based but regulation of e-waste disposal is poor or poorly enforced.[129] Including mining devices in existing public recycling programs could help.

Develop accounting standards

To address trust and consistency issues, innovators need agreed-upon standards for carbon accounting of blockchain technology—methodologies not just for proof-of-work and proof-of-stake type networks for calculating emissions and showing provenance of carbon credits.

A participant located in one of the jurisdictions preferred by Bitcoin miners said, "Here, we are 100 percent renewable energy production. So, all mining here is renewable. How can a miner or entity doing the proof-of-work demonstrate use of renewable energy—perhaps through renewable energy certificate or corporate credit?" This person suggested tapping stranded energy assets or finding stranded energy to utilize for proof-of-work.

The IEEE blockchain and distributed ledgers committee is also working on a standard for blockchain-based green power identification application. The committee noted that the three major green power identifying systems in use today—EKOenergy, Green-e, and International Renewable Energy Certificate—support green power certificate issuance, trading, and traceability but not “internationally accepted and socially common green power consumption identifications, to further promote trade facilitation and to promote global green and low-carbon transformation.”[130] The IEEE standard for using blockchain to evaluate low carbon zones also covers “carbon accounting data sources, data storage, data interaction, data accounting, emission factor database establishment, carbon accounting method selection and prediction.”[131] The hope is that these will help in establishing and verifying the baselines used to gauge future emissions reductions.[132]

The person explained the impact on the bottom line: “As US ownership of digital assets become more institutional, the ESG concerns are tantamount. So, the very companies that want to own the asset are investing in the mining business and creating products by copying the renewable energy industry. If I can prove my ESG footprint and carbon footprint of my operations, then I can convert a variable revenue stream to a fixed revenue stream. That will increase the number of institutional holdings, and all that capital goes into this new renewable computing infrastructure to generate the asset. It’s a virtuous cycle.” It’s also a powerful incentive for national and international accounting bodies to coordinate and develop these standards together on a fast track.

Conclusion

"Today, we have a much clearer line of sight to the era of distributed user-controlled environments, thanks to blockchain," said one of the participants. "Before we can realize full potential of Web3 and broader uses of blockchain beyond finance, we must optimize technology and architecture for new environments and solve for sustainability." Others agreed. The roundtable came up with three areas of action.

1. **Governance of ecosystems.** This starts with engaging in standards development and working toward industry buy-in and commitment. "It's about aligning incentives of different stakeholders within a particular blockchain community toward a goal, which may or may not align with their interests," one person stressed. Many people wanted to get ahead of regulation and develop and voluntarily adopt industry guidance and independent ratings rather than wait for government mandates and compliance.

2. **Cultivation of knowledge.** This starts with identifying initiatives such as regenerative finance that will inform engagement, policy development, and standards development. One person suggested "focusing on the traceability benefits of blockchain to support markets for emerging green commodities, more robust voluntary, carbon offset markets, sustainable aviation, fuel, biofuel, all the replacement fuels and the green commodities that we're going to see more and more of as we try to keep on this 1.5° C trajectory."

3. **Greater advocacy for infrastructure innovation.** This requires a balanced approach. Developing economies have the potential to benefit from Bitcoin blockchain infrastructure, and so projects and initiatives should help them to go green and stay green. Aging economies need an energy infrastructure refresh; blockchain can be part of the solution.

"Self-sovereign identity, machines, batteries, electric vehicles, solar panels, and so forth will all factor into the energy sector in a more meaningful way in coming years," said one person. Another recommended discussing blockchain capabilities such as traceability as an element of every government infrastructure project.

The future "requires an upgrade of the energy, computing and storage hardware, and telecommunications infrastructure—the available electricity, the available computing power, the available connectivity, the available storage, how computing power is linked to less cycle expenditure for certain processes, and so on." We're talking about nothing less than a different design of foundational technologies. Everyone in the blockchain space—users, developers, investors, miners, researchers, educators, policymakers, and regulators—has a role to play in minimizing the technology's climate impact and maximizing its use in sustainability initiatives. Together, we can make meaningful progress.

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