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The Bitcoin Dilemma

Weighing the Economic and Environmental Costs and Benefits

palgrave
macmillan

Part V

Cryptocurrency and the Environment

Someday the world may have abundant sustainable power. The question is whether that day will arrive in time to avoid the cataclysmic problems associated with global warming arising from the burning of fossil fuels. Any unnecessary increase in electricity consumption merely amplifies this dismal prophecy. I explore in this part the link between electricity consumption and greenhouse gas emissions. These chapters conclude that the additional burden on energy consumption arising from bitcoin mining is already making precarious the promises made by nations to curb greenhouse gas emissions and global warming.

This book documents that the expected rise in the price of bitcoin directly translates into greater electricity demand. The energy consumption arising from bitcoin mining significantly burdens the climate and is doing so at an accelerating rate. However, crypto advocates argue the opposite. Their strategy to give the perception of environmental stewardship while simultaneously contributing heavily to environmental degradation is called *Greenwashing* and is described in this part. Most researchers agree that, if the coin is to properly internalize the consequences of mining to preserve the environment, public policies must be developed to deal directly with its environmental externalities.

A number of commentators and researchers express grave concern over the effect of Proof of Work mining on the environment, while others suggest such concerns are either overblown or addressable. Schinckus et al. (2019) register their concern about the carbon footprint and energy consumption of bitcoin mining, and assert that increased bitcoin speculation is challenging

sustainability. They were one of the first to demonstrate the link between trading volume and energy consumption.

Perhaps the most publicized study appeared in Nature–Climate Change. Mora et al. (2018) asserted that, should bitcoin continue its current trend and experience the same sort of growth as other innovations, it could generate sufficient electricity consumption to contribute to a two-degree Celsius growth in the average global temperature as a result of its greenhouse gas emissions. Without the benefit of *The Bitcoin Dilemma, t*he authors assert that migration of mining to less expensive (sustainable) energy can mitigate this, as could improvements in hardware and the protocol. While there may be flaws in their analysis, their concerns remain valid.

Mining Efficiency Improvements

Masanet et al. (2019) attempt to contradict the dismal prophecy of Mora et al. by claiming they insufficiently weighed improvements in miner efficiency and energy carbon dioxide footprints. Similarly, Cocco et al. (2019) also harbor hope that improvements in the bitcoin algorithm can alleviate environmental challenges. They draw parallels between bitcoin and gold mining. While these results sound intuitive, *The Bitcoin Dilemma* demonstrates that neither efficiency improvements nor diversion of sustainable power to Proof of Work mining will reverse the trend they note.

Continuing with the theme of miner efficiency as a (false) cure for the greenhouse gas externality of Proof of Work mining, O'Dwyer and Malone (2014) explore the upper bound of energy usage in the hardware Arms Race. They assert that profitability requires increasingly faster and more energy-efficient hardware, but they also fail to observe that this arms race is self-defeating, as *The Bitcoin Dilemma* describes.

Mir (2020) describes the various factors that impinge on bitcoin energy consumption and emerging ways to optimize energy use. They too assert that the reason why bitcoin does not currently consume yet more energy is that processing efficiency continues to improve. Unfortunately, they do not recognize the economics uncovered by *The Bitcoin Dilemma*. They do, however, correctly conclude that other algorithms may offer relief to the Proof of Work methodology.

Truby (2018) noted the threat to global warming from bitcoin mining and call for public policy to internalize such negative externalities. They observe that "the libertarian promise of a decentralized and secure peer-to-peer payments system have (sic) largely been substituted with the speculative

pursuit of private wealth creation with little social utility." They add that the system has been designed to demand increasing energy consumption without due consideration to the environment. While Truby (2018) fails to appreciate the futility of mining efficiency improvements when there is a bitcoin miner arms race, some public policies are proffered. These include a registration or a profits charge, a maximum greenhouse gas threshold for transactions, properly priced carbon markets, and other mining taxes.

Increasingly, the mining industry is becoming aware of their environmental impact, but eschews regulation through taxation or energy efficiency standards. The fundamental Bitcoin Dilemma remains unacknowledged, as is the inevitable shift of other energy consumers to more expensive and greenhouse gas-generating fossil fuel-based electricity sources. Ultimately, environmental policies require an international approach given the ability to shift mining activity to favorable jurisdictions.

Some researchers have asserted that various other factors may hopefully but mistakenly mitigate *The Bitcoin Dilemma*. They draw this different conclusion based on the common intuition that energy efficiency improvements should normally result in reduced energy consumption. However, these statements do not explicitly model the unique nature of the bitcoin protocol and its automatic difficulty adjustment mechanism that creates the arms race to the bottom, using electricity as the ammunition. For instance, Spross (2017) questions the amount of energy bitcoin requires. He notes "Bitcoin is designed to make the computations easier as the supply of bitcoins grows." *The Bitcoin Dilemma* contradicts Spross' conclusion that bitcoin mining energy consumption declines over time, bitcoin's energy use is driven by the value of each coin. As that price rises, the return on mining bitcoin keeps rises proportionately. Nonetheless, Spross correctly observes that long and sustained declines in bitcoin's price would lower its energy consumption.

The prevailing theme debunked by *The Bitcoin Dilemma* is that there is a technological fix that will mitigate ever-growing energy consumption in bitcoin mining. Most of these optimistic researchers have relied on innovation as the energy consumption salvation. For instance, Cocco et al. (2016) document the transition of bitcoin mining technologies. They track empirically and through modeling the trajectory of bitcoin prices and note the rising necessity for improved hardware to preserve mining profits net of electricity costs. Interestingly, they also observe obsolescence of mining technology in approximately one year on average. Such obsolescence presumably results in miners of greater efficiency with each passing year. Similarly, Bondarev (2020) asserts that more efficient use of electricity resources for mining could be

accomplished by an order of magnitude improvement in electricity provision qualities, improved heat handling, and other technical mechanisms,

A different approach is championed by Badea et al. (2021). They begin their analysis with advocacy for the Austrian Economic School position advocated by Friedrich August von Hayek, in his "Denationalization of Money: The Argument Refined." They argue that competition creates a superior currency. While Hayek's thesis occurred before our understanding of monetary theory in a fractional reserve system necessitates monetary oversight, the authors suggest that the 6442 cryptocurrencies in circulation (some of which live only a few days) create such a marketplace of competition for a superior digital coin.

While not a reprieve for bitcoin, others propose popularization of other cryptocurrencies. Li et al. (2019) measure the carbon footprint of the cryptocurrency Monero based on various mining technologies. They note hashing algorithms significantly affect mining efficiency and the carbon footprint. Likewise, Scheltz (2021) advocates for the differentiation between bitcoin's energy consumption and that of newer cryptocurrencies which employ more energy-efficient authentication methods.

From the environmental perspective, the authors try to salvage bitcoin mining by asserting that the economic impact of cryptocurrency is small compared to other payment systems. Consistent with other commentators, they quote Baur and Oll (2019) that technical solutions can mitigate bitcoin's carbon footprint and suggest that mining can even enhance the availability of sustainable energy, and digital currencies could save one billion trees annually. In a different approach to dilute the damage of Proof of Work mining on the environment, Baur et al. (2019) assert that bitcoin environmental consequences should be addressed not in absolute terms but rather relative to other investments. They argue that bitcoin in a diversified investment portfolio can reduce the overall portfolio carbon footprint.

The mining industry has presented a number of truisms that allow them to claim a modicum of environmental sensitivity. For instance, Walton (2022) reports that miners can earn upwards of 10% of their revenue by voluntarily participating in load-shedding agreements. Yet, he also quotes Prof. Eric Hittinger of the Rochester Institute of Technology, who states "It's complicated…It's never quite clear to me where the line is between exaggeration and fabrication… I think crypto does provide some flexibility to electricity grids. It does introduce additional demand in, maybe, some of the right places. (However) we could usually use that electricity for something that is maybe more socially valuable than mining crypto."

However, at the same time, other miners unapologetically seek cheap power with little regard for greenhouse gas emissions. Milman (2022) reports that mining is inducing a renewal of interest in fossil fuel coal plants. The Hardin coal plant in Montana is part of a wave of "zombie" fossil fuel plants repurposed for bitcoin mining, especially following China's edict to ban mining in 2021 as their way to reduce demand for their coal power plants.

These various authors assert with little proof that the industry can police itself for the greater good and consistent with accelerating environmental concern. More consistent with *The Bitcoin Dilemma* is the work by de Vries (2020), who argues that market short run dynamics and profitability may result in the employment of inefficient mining technologies. He also notes that current estimates, which do not fully incorporate long run electricity consumption trends, may actually underestimate an industry that consumes electricity at a similar scale to the 200 TWh electricity consumption of the world's data centers.

Forum Shopping

To squeeze one geography simply results in a bulge elsewhere in the balloon. A line of research explores the internationalization of bitcoin. For instance, Roberts (2022) notes that the 2022 aggression of Russia upon Ukraine has induced Ukrainian citizens to rely on bitcoin as its nation's ATM machines are depleted. Bitcoin is also employed to transfer funds to combatants, while Russia and its leaders may employ bitcoin to circumvent economic sanctions. "Like many in crypto say, the tech is agnostic." But Ethereum founder Vitalik tweeted, "Ethereum is neutral, but I am not." Roberts concludes this may be the first crypto war, but not the last.

This theme of improving mining efficiency, tapping into diverse power sources, or migrate across locations, remains a prevailing but simplistic theme. Köhler et al. (2019) outline the geographical differences in carbon footprints from bitcoin mining globally. They too assert that mining efficiency can mitigate the footprint if activity is moved to regions with a greater mix of sustainable energy. Meanwhile, Náñez et al. (2021) assert that mining sustainability can be improved by moving activity to regions that source their electricity more sustainably. They state that the China mining ban was designed in part to accomplish such a geographical displacement.

Also, along the geographical mitigation theme, Bitir-Istrate et al. (2021) provide a case study of a mining farm in Bucharest, Romania. Based on

their case study, they recommend a (presumably global) protocol to develop a consistent framework to measure the net effects of mining on sustainability. They further recommend that farms employ at least 50% sustainable energy as a global policy and agree to mandates of various efficiency standards. Recently, Iran mandated a requirement for 100% renewable energy as a precondition for mining.

Others document the international mobility of bitcoin mining. Tabuchi (2022) documented that China's ban of cryptocurrency mining in 2021 resulted in an exodus of miners to Kazakhstan and the United States. This geographical shift increased industry reliance of mining from hydroelectricity to electricity derived from fossil fuels. She quotes researchers from Vrije Universiteit Amsterdam and M.I.T. that show this transition may result in the addition of 65 million megatonnes of additional carbon dioxide emissions annually, according to researcher Alex de Vries. The study relied on data from Foundry USA, a mining pool that tracks mining locations in the US.

Such nations' mining evictions displace rather than replace mining farms. Newbery (2021) observes the U.S. now represents 35% of global bitcoin mining following the China crackdown and relates that Tesla entrepreneur Elon Musk stopped taking payments in bitcoin because of environmental concerns. Newberry reports that some argue bitcoin may stimulate expansion into renewables but that two thirds of mining is from non-renewables. She correctly observed "If overall energy consumption increases in a particular state because of mining, it could push other industries to use more non-renewable energy." That states have already seen the consequences. Benetton et al. (2021) noted New York State ratepayers began to pay significantly more for energy following the arrival of large-scale bitcoin mining. Crypto's profits are ratepayers' losses.

Yet, as Newbery notes, miners continue to search for crypto-friendly regulation and cheap electricity. Such explorations have attracted them to New York for its cheap electricity, Kentucky for abundant coal and tax breaks, and Texas for crypto-friendly laws. She also notes the reopening of fossil fuel plants in Montana and Pennsylvania, and also reports on the Plattsburgh, NY experience and on the Texas blackouts exacerbated by bitcoin mining.

Despite industry claims otherwise, these environmental damages are real and pronounced. In the most detailed analysis of monetary damages, Goodkind et al. (2020) find that, for every $1 of bitcoin mined generates $0.49 in climate and health damages in the U.S. and $0.37 in China. They expect other Proof of Work cryptocurrencies to follow that similar pattern. They

argue that internalizing pollution externalities are necessary to somewhat offset these problems.

Some operators wish to change the narrative. The Crypto Climate Accord (2021) is a group that offers a series of policies to reduce the negative externalities of mining, and asserts that more efficient machines and better network design, load shifting, relocation, employment of more renewables, and offsetting emissions can mitigate the damage of mining. In that same vein of internalizing such pollution externalities, Jackson (2021) discusses how the mining industry must balance "(the need to) transition to renewable energy (versus the needs of) billionaires and industry evangelists" to address the Crypto Climate Accord. He notes Ripple's participation in the Alliance, with their Proof of Stake protocol, and its use of renewable energy and improved energy efficiency. With regard to the CCA, Jackson notes:

> With the noose already tightening around the PoW protocol due to its impact on the environment, many voices supporting green crypto appear to fall into the conflicted category of self-interest and selfishness. Given the incentives and money at stake within the industry, especially as networks compete for more users and adoption, this latest attempt to self-regulate feels a little insincere… If money weren't involved or at stake, the initiative might take on a different look and feel. But given the "winner take all" attitude prevailing in today's crypto climate, the CCA might just be the edge that organizations feel is necessary to put them on a perceived higher moral plane, despite the genuine environmental concerns the industry must address.

I next explore the implications of mining on our broader physical and political environment. Ultimately, this part will conclude by noting that greenhouse gas emissions know no political boundaries.

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Carbon Footprints

The Bitcoin Dilemma is based on an economic model of the bitcoin mining sector that demonstrates the inexorable link between the price of bitcoin and the energy its mining consumes. I further demonstrated empirically in *The Bitcoin Dilemma* from Chapter 8 that, on average, energy consumption has increased by 0.73% for every 1% price increase. This relationship proved to be both pronounced and statistically significant, even though bitcoin went through a halving event in 2020. Indeed, even with the halving in 2020, the bitcoin price actually rose at a quicker rate than the quantity of bitcoin rewarded declined in all but one year. The price of bitcoin is demand-driven and is completely disconnected from the reward offered to miners.

The incredibly high value of bitcoin dictates its energy consumption. The value of newly-mined bitcoins is essentially usurped in a combination of electricity costs and mining profits when one can secure electricity at rates below what residents and businesses pay. Electricity costs, and the heat it generates, are the prices to pay for bitcoin mining. Neither of these would be significant if bitcoin were valued at a price Satoshi observed while active. Nonetheless, both Satoshi and Finney articulated a concern for Proof of Work mining wastefulness, even at the insignificant levels in the early 2010s. Satoshi observed, "Generation is basically free anywhere that has electric heat, since your computer's heat is offsetting your baseboard electric heating. Many small flats have electric heat out of convenience."[1] The energy intensiveness observed now could scarcely be contemplated then.

[1] https://bitcointalk.org/index.php?topic=813.msg9454#msg9454, accessed April 19, 2022.

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https://doi.org/10.1007/978-3-031-09138-4_20

The dramatic increase in energy consumption since the beginning of bitcoin's corporate era, following the development of the Antminer S9 machine, spans the years in which miners increased collective processing power by a factor of ten, and three to five times the mining efficiency per kilowatt-hour of electricity consumption. Yet energy consumption continued to increase with the price of bitcoin. While bitcoin mining machines are somewhat sensitive to the price of bitcoin, and the used market especially so, the payback period for purchases of these miners nonetheless remained at less than one year typically, and sometimes significantly less. The economic environment is ideal for a free entry perfectly competitive miner arms race using electricity as the ammunition.

This bitcoin mining arms race is amplified by the nature of mining innovation. The price of miners acts as an upfront sunk cost that a new miner would have to overcome before net profits become positive. However, if such a payback period is relatively short, or if robust miner rental markets exist, miner prices do not significantly constrain mining growth. Nor are such costs relevant once a miner has already committed to mining. Miners continue to operate when revenues exceed electricity costs. If one were to abandon mining because of a lack of profitability, the salvage value of the miner would depend on whether another operation could profitably place the miner back into service. The main determinant of mining profits is not the fixed costs of machine purchases, but the variable cost of electricity.

Miners routinely appeal to online calculators that calculate the level of gross profits, net of their variable cost of electricity that one can expect at various costs of electricity. The industry well-understands that the determining factor of both profitability and energy consumption is a combination of bitcoin price, for which increases in the price raises energy consumption, and electricity costs, regardless of miner energy efficiency.

Recall gross profits from mining do not arise because of miner scarcity or an ability for the market to reach equilibrium. Instead, profits are simply a rent one receives by having access to electricity at a rate lower than the electricity price sufficient to break even in mining. A miner can be profitably operated at any electricity cost at or below the cutoff energy cost c^*:

$$\text{Cutoff energy cost } c* = bP_0Q_0\mathrm{e}^{(g-f)t}/M* \tag{20.1}$$

Those with energy costs below c^* then divert the electricity costs avoided to pure profit. In other words, profits arise solely because of electricity advantages. Offering a concession of a share of total energy at a lower cost c simply grants these operators a greater profit of $(\mathrm{c}^* - c)$ for each kilowatt-hour they consume. Of course, by diverting power to such operations results in

higher electricity prices shared by the remainder of ratepayers, at least at a rate equal to the profits of miners, assuming the utility can obtain sufficient additional power no higher than the default rate c^*. In essence, other ratepayers pay for mining profits that arise when mining diverts cheap power to their own operations.

If, instead, the utility must purchase additional and more expensive energy at high effective retail prices than the cutoff energy cost c^*, ratepayers pay an even greater additional burden and hence subsidize miners even more. This net cost to other consumers of electricity was estimated by Benetton et al. (2021) for New York State. They determined from 2019 data that increases in electricity rates as a consequence of the bitcoin presence of $165 million for residents and $79 million for commercial users per year. Nationwide, Benetton et al. determined that ratepayers across the country pay an additional one billion dollars annually in electricity costs because of the supply that is diverted to bitcoin mining.

The discussion shows that the dynamics of mining are more nuanced than they may appear to the casual observer. Over the long run we expect the cost of mining, in both miners and electricity, to approximate their revenue. But that conclusion represents the zero-profit free entry condition, and it is defined by the most expensive energy source that can be profitably mined. For instance, the free entry condition for the most common S9 miner required a maximum electricity cost of $0.10 per kwh early in 2022. On the other hand, a state-of-the-art Antminer S19 could profitably mine at $0.30 per kilowatt-hour power cost given their greater energy efficiency by a factor of more than three, when the price of bitcoin is $45,000, net of a mining pool commission of 1%.

Put another way, the Antminer S9 machine can profitably operate in many areas of the United States. The average electricity cost is $0.1042, which would make the world's most common miner unprofitable, but the S9 is typically profitable for any region with slightly lower than average cost or if the operator is able to recycle heat generated from miners. These S9 miners would be expected to migrate to only the lower cost regions.

Let us assume a miner has excess capacity at a mining farm with access to electricity at, for example, $0.06. The operation would ensure that all its highest efficiency miners are operating. Should it also plug in any spare S9 miners? Absolutely, since the supply price is lower than the Antminer S9 breakeven price c^* of $0.10. A mining farm with surplus S9 machines that cannot operate affordably at a price higher than $0.10 ought to sell these surplus machines at whatever market price that can be obtained, unless the operator decides to retain these older devices in the hope that the bitcoin

price will rise. If it does sell these units, they will be purchased by a farm that has a lower power cost than c^*, and hence could run the miners profitably.

The S9 machine is thus what economists call the marginal machine. Miners that can produce the same processing power as the S9 with less energy are then able to pocket as gross profits the energy savings per unit of processing power. If we define the number of miners as the industry capacity for S9 machines, each S19 miner would be equivalent to about three S9 machines, but at an equivalent power cost per hour of only one S9 machine. The S19 miner receives as a profit from the energy avoided of two S9 miners. Greater efficiency does not result in reduced energy consumption. Instead, it results in increased profits, at the expense of other rate payers who cannot then access low-cost electricity because of mining demand.

The Energy Consumption and Carbon Footprint of Bitcoin Mining

Cambridge Center for Alternative Finance constructs a *Cambridge Bitcoin Electricity Consumption Index* that makes a best estimate of total worldwide energy consumption based on its research of the mix of mining machines manufactured and employed in the industry. They estimate that the industry consumes 150 terawatt-hours annually,[2] equivalent to the annual consumption of a top-twenty five electricity consuming nation.

This electricity consumption is equivalent to 41 medium-sized coal power plants, each which produces an average of 3.5 terawatt-hours of electricity each year. Globally, there are about 8,500 coal plants, and they collectively produce 9,440 terawatt-hours of electricity per year, representing 40% of global electricity production. These plants contribute 10.1 gigatonnes of carbon dioxide emissions,[3] which is equivalent to about a third of the emissions from generation of the world's electricity and a fifth of human-made greenhouse gasses.[4]

Coal power plants generate one megatonne of carbon dioxide emissions per terawatt-hour of electricity produced.[5] The carbon dioxide emissions that could be avoided from a reduction of 142.4 terawatt-hours of electricity devoted to bitcoin production in April of, 2022, represents a reduced carbon footprint of 142 million metric tonnes of carbon dioxide annually.

Because each nation hosting significant bitcoin mining also operates coal-fired power plants, the diversion of sustainable energy to bitcoin production

[2] https://ccaf.io/cbeci/index, retrieved April 7, 2022.

[3] https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions, accessed February 13, 2022.

[4] https://en.wikipedia.org/wiki/Coal-fired_power_station, accessed February 13, 2022.

[5] U.S. EPA (2019), "Greenhouse Gas Reporting Program Industrial Profile: Power Plants Sector," https://www.epa.gov/sites/default/files/2020-12/documents/power_plants_2017_industrial_profile_updated_2020.pdf, accessed April 7, 2022.

maintains demand that keeps coal production online well past the point they would have otherwise been decommissioned. Unless a bitcoin farm is totally powered by its own proprietary non-fossil fuel energy source, if it is on the grid, it is preventing nations from closing 41 coal power plants worldwide.

Once the trend in expected bitcoin prices analyzed earlier are combined with reward halving, we see a general upward trend in energy consumption that could reasonably exceed 160 terawatt-hours per year by 2030. The equivalent level of coal-fired power plants that may need to be retained to accommodate overall electricity demand as a consequence of the rise in bitcoin mining equates to fifty three coal-fired plants by 2030.

Figure 20.1 shows that expected industry projections in the price of bitcoin results in a continuous increase in global energy consumption. These calculations are based on two competing measures of mining industry electricity consumption. Diginomics typically yields a larger level of consumption, but most experts rely on the more refined Cambridge Energy Consumption Index (CECI) estimate. The latter more conservative index estimates 117.4 terawatt-hours of mining electricity consumption as of December of 2021. Based on *The Bitcoin Dilemma* model, the bitcoin price extrapolation, the reward divisions, and CECI estimates of electricity consumption, expected electricity demand is predicted to rise to 161 TWh/s by 2030, a further 37% increase in consumption. This greater energy consumption is equivalent to an additional 12 medium-sized coal power plants, based on emissions of one metric tonne of carbon dioxide per megawatt of electricity generated by coal powered generation plants, each generating an average of 3.5 TWh of electricity annually.[6,7,8]

Note also that, while the constant innovations in the industry do not decrease electricity consumption, the obsolescence of older machines also creates electronic waste of 31.57 metric tonnes per year, as documented by Digiconomist.[9]

On the contrary, Proof of Stake mining requires as few as a handful of trusted miners. Recall that blocks of bitcoin were originally mined using ordinary personal computers that could perform the hash function at a rate in the millions rather than the tens of trillions of hashes per second. Were a single trusted PC, or a modern Antminer S9 ASIC to mine blocks, one

[6] Generated from data from https://en.wikipedia.org/wiki/Coal_power_in_the_United_States, accessed March 9, 2022.

[7] https://www3.epa.gov/ttnchie1/conference/ei20/session5/mmittal.pdf, accessed April 7, 2022.

[8] https://www.mcginley.co.uk/news/how-much-of-each-energy-source-does-it-take-to-power-your-home/bp254/#:~:text=A%20standard%20500%20megawatt%20coal,around%204%2C750%20pounds%20of%20coal, accessed April 7, 2022.

[9] https://digiconomist.net/bitcoin-energy-consumption/, retrieved on February 26, 2022.

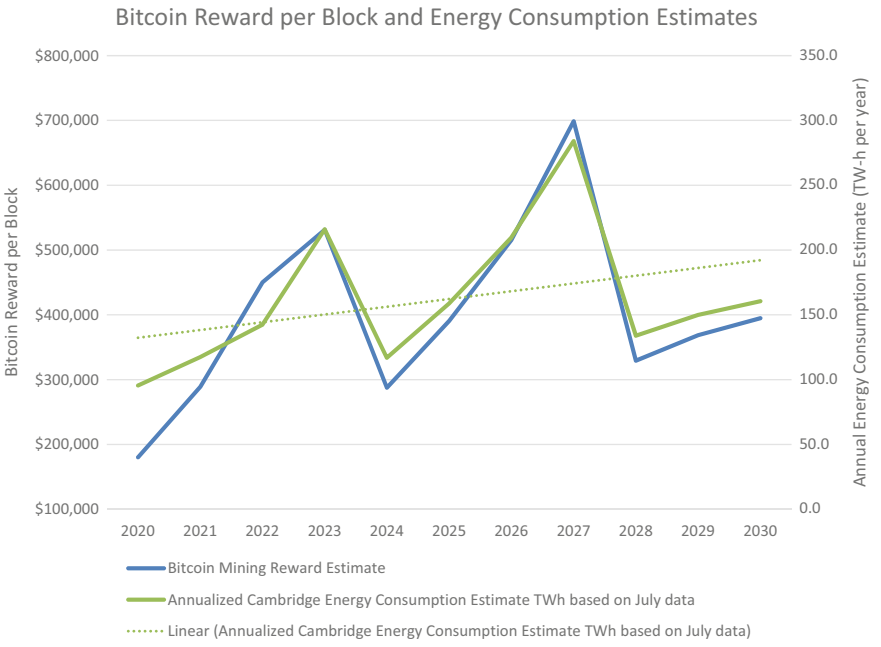

Fig. 20.1 Projections of bitcoin energy consumption

such trusted machine could easily meet all the needs of bitcoin supply. Likewise, the mining of ether using the new Ethereum Proof of Stake protocol with a block size eight times as large and block interval 50 times faster than bitcoin can be mined with but a small network of ASICs and contribute an insignificant amount to global warming.

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Greenwashing in the Bitcoin Industry

Hal Finney was concerned about carbon dioxide emissions in the early stage of bitcoin. He commented, "Thinking about how to reduce CO2 emissions from a widespread Bitcoin implementation.[1] He understood the bitcoin mining industry inevitably and unavoidably suffers from *The Bitcoin Dilemma* that electricity consumption from mining is proportional to the price of bitcoin. The vast majority of bitcoin commentators are confident that the price of bitcoin will rise as it has in the past, at a rate much faster than the corresponding half-life decay of mining rewards in bitcoin. The result is increased electricity demand over time and increased overall carbon emissions, as described earlier. Falling miner prices merely exacerbates this trend toward greater electricity consumption. Yet, like the robot HAL that took on a mind of its own in *2001—A Space Odyssey*, so too has bitcoin proven to be resilient to attempts to modify its energy consumption intensity. Satoshi noted, "The nature of bitcoin is such that once version 0.1 was released, the core design was set in stone for the rest of its lifetime."[2]

The industry surely understands the implications of higher bitcoin prices on energy consumption, but they often offer false hope that innovations in

[1] https://twitter.com/halfin/status/1153096538?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E1153096538%7Ctwgr%5E%7Ctwcon%5Es1_&ref_url=https%3A%2F%2Fwww.independent.co.uk%2Fclimate-change%2Fnews%2Fbitcoin-cryptocurrency-bad-mining-environment-b2041420.html, accessed March 26, 2022.

[2] https://bitcointalk.org/index.php?topic=195.msg1611#msg1611, retrieved February 7, 2022.

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miner efficiency will result in a reduced energy consumption and carbon footprint over time. For instance, the chip making giant Intel recently promised reductions in bitcoin mining energy consumption that should result in their new design of a chip that can more efficiently mine the SHA-256 bitcoin protocol.[3] In addition, bitcoin mining advocates who recently testified to a U.S. House of Congress committee hearing made a similar claim.[4] Miner manufacturer Canaan's Senior Vice President Edward Lu recently gave a speech entitled "Clean Energy: The New Revolution Of Bitcoin Mining," in which he claimed:

> Sustainable bitcoin mining is related to the future of human society, and the key lies in the construction of more advanced energy-efficient technologies and green mining infrastructure, as well as continued increase in the proportion of renewable energy use.[5]

Such claims defy economic theory and an econometric analysis of the correlation between bitcoin prices and energy consumption. *The Bitcoin Dilemma* shows that increased miner efficiency will merely further fuel the miner arms race and will result in more miners sold, and profits for Intel, Bitmain and Canaan, but with no commensurate decrease in electricity consumption miner industry-wide. Indeed, if the advertised cost of miners fall per kilowatt of power capacity, as Intel promises, electricity consumption may actually rise.

Even if a bitcoin mine derive all its power from a proprietary solar, wind, hydro, tidal, geothermal, or nuclear source rather than from the grid with its mix that includes fossil fuel plants, consumers are deprived of these sustainable sources that could have otherwise been deployed to reduce our reliance on fossil fuels. Ultimately, every electricity user shares some responsibility for continued dependency on fossil fuels and we all must explore how we

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[3] Senior Intel Vice President Raja Koduri stated "We are mindful that some blockchains require an enormous amount of computing power, which unfortunately translates to an immense amount of energy. Our customers are asking for scalable and sustainable solutions, which is why we are focusing our efforts on realizing the full potential of blockchain by developing the most energy-efficient computing technologies at scale." https://www.intel.com/content/www/us/en/newsroom/opinion/thoughts-blockchain-custom-compute-group.html, retrieved February 20, 2022.

[4] Expert witness Gregory Zerzan of law firm Jordan Ramis, "As the technology evolves it should be expected that the systems will become more energy efficient." Witness to HEARING ON "CLEANING UP CRYPTOCURRENCY: THE ENERGY IMPACTS OF BLOCKCHAINS," January 20, 2022, https://energycommerce.house.gov/committee-activity/hearings/hearing-on-cleaning-up-cryptocurrency-the-energy-impacts-of-blockchains, retrieved February 20, 2022.

[5] https://bitcoinmagazine.com/business/canaan-announces-a-new-bitcoin-asic-and-green-mining, accessed April 8, 2022.

can meet our electricity needs while we reduce our carbon footprint. From the perspective of crypto authentication, we must inevitably compare the efficiency of Proof of Work mining to its Proof of Stake alternative.

Smoke and Mirrors

Another argument often heard is that bitcoin farms tap energy from wind or solar power that the electric grid is unable to absorb at some times of the day. The inability of our grid to efficiently store and transport electricity is solved by a better grid and more extensive use of battery farms and pumped hydroelectric storage, not by more bitcoin mining.

Others claim that by adding a load to a grid, a bitcoin farm can somehow act as a battery for the grid. This highly misleading statement is a distortion of the opportunity for a bitcoin mine to participate in a voluntary load shedding program. Under such a program, a mining farm agrees to reduce their load when electricity demand is too high.

For instance, Mike Levitt, the Chief Executive Officer of Core Scientific, a large bitcoin mining operation that consumes roughly 500 megawatts of power, claimed that "We have arrangements with the communities and utilities wherein; when the grid needs it, we will down power…If we get a call from one of the utility companies in the geographies where we operate who need 30 megawatts available from two to five o'clock today, we put the machines into sleep mode, and it's literally a keystroke because we have a software program that manages the 160,000-plus mining rigs…Our industry really can quite legitimately, effectively and uniquely release energy utilization to the grid; it's almost as if we're acting as a battery." Levitt noted that utilities must often rely on peaker natural gas plants when electricity demand is high. He added that "Generally speaking, those peaker facilities are the old ones and the dirty ones and the expensive ones."[6]

The industry is taking credit for reduced demand for the costliest of power across the spectrum of commonly used generation facilities by claiming they may be willing to turn their miners off if need be, usually as part of a voluntary power shedding plan. They do not add that they are compensated well for their load shedding. However, there would be no need for such peaker plants had their load not been taxing the grid in the first place. To imagine that reducing a load that need not exist is somehow environmentally good is a form of greenwashing that defies logic. A mining farm willing to shed

[6] https://www.coindesk.com/business/2022/03/25/greener-bitcoin-mining-could-be-chinas-trillion-dollar-present-to-the-us/, accessed March 26, 2022.

load as part of a voluntary load shedding program and be paid well for that concession by the utility is preferable by the miner to involuntary brownouts without compensation. Such participation in compensated load shedding programs is not altruistic, especially since blockchain processing can be done in environmentally benign ways without the massive power consumption.

Similarly, mining farms claim that, by relying on flared methane at distant natural gas wellheads, they are reducing methane emissions. It is true that combustion of methane in diesel generators, at a thermal efficiency of about 30%, is better than emitting raw methane into the atmosphere. However, flaring is designed to convert those methane emissions to less damaging but still problematic carbon dioxide, based on the science that methane gas is between 20 and 40 times more damaging than carbon dioxide. After a number of years, methane (CH_4 molecules) combines with oxygen in the atmosphere to eventually convert to carbon dioxide and water according to:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Under good conditions, flaring is of similar efficiency as natural gas combustion in a diesel generator in its conversion of methane to carbon dioxide. However, a far better alternative for stranded gas is better well technology, including reinjection of excess gas, or capping if the well is obsolete. In addition, burning a fossil fuel through flare gas conversion to electric power at a 30% efficiency remains inferior to use of the same fossil fuel in a state-of-the-art natural gas cogeneration plant that can operate at between 60% and 80% thermal efficiency, depending on the degree to which waste heat can be used by adjoining facilities. The long-term solution is improved well capping or more effective natural gas retrieval as described by Bamji (2021), not by bitcoin mining.

Carbon Credits

Finally, mining farms that employ fossil fuel based energy, either directly or indirectly through their participation on the grid, sometimes claim that their fossil fuel consumption and resulting greenhouse gas emissions are offset through the purchase of carbon credits. The concept is that, by purchasing the credit, they enable some technology that will remove an equal amount of carbon dioxide from the atmosphere. Since mining is ongoing, such credits must be constantly repurchased, not just once to make a public relations statement to appease critics.

There remains a great deal of controversy about carbon market credits. Such carbon capture may merely represent a promise not to cut or burn down a forest. The policing of carbon markets in their infancy is insufficient to ensure that the same preserved forest is not sold multiple times over or may have gone unharvested regardless of the carbon credit market. Indeed, a poorly managed forest may actually result in carbon emissions over time as over-mature trees eventually fall and decay into carbon dioxide and methane, while some carbon-based materials may remain in the soil. A forest managed for true carbon sequestration would need trees to be selectively cut before they become over-mature and die and have the lumber sequestered in the form of building materials for homes and other products.

Alternately, there are new technologies for carbon capture, perhaps pumped into underground wells, or carbon sequestration by converting the carbon into limestone or other stable materials. Or, the carbon dioxide could be converted into a green fuel that could be substituted for the extraction of fossil fuels. Regardless, the price of true carbon sequestration is currently in the neighborhood of $700 per metric tonne of carbon dioxide. The price of sequestration must fall by 90%, to a more feasible $71 per metric tonne, consistent with carbon taxes proposed by advisors to the Biden Administration, and almost half Canada's goal of a $134 per metric tonne carbon tax by 2030.[7] The resulting additional price that a fossil fuel should charge ensures that their greenhouse gas emission externality is then internalized. Such a carbon tax would cause fossil fuels to be prohibitively expensive compared to solar, wind and nuclear power, but fossil fuels could remain in demand by miners desperate for power and profits.

Satoshi designed the bitcoin protocol to ensure that the cost of corrupting the bitcoin blockchain would exceed the advantages of doing so. In Satoshi's day, a block reward was valued in pennies and reached only $0.43 when Satoshi left the public eye, and had risen to $1.56 when collaborators received no more private correspondences. The reward is measured in hundreds of thousands of dollars now, with electricity the hostage in the Prisoners' Dilemma bitcoin mining creates. The fundamental unit of account of bitcoin mining is the price of electricity in cents per kilowatt-hour, while the kilowatt-hours depend on the intensity of mining activity.

Miners understand well the breakeven electricity cost that determines whether mining is profitable. This cost is currently a bit below the national

[7] https://foreignpolicy.com/2021/11/29/canada-carbon-pricing-club-theory-climate-imf/#:~:text=First%20implemented%20in%202019%2C%20the,per%20metric%20ton%20by%202030., accessed March 21, 2022.

average of electricity costs to businesses and residences, which means bitcoin mining is unprofitable unless power is cheaper.

A Summary of Bitcoin Mining Economics

The United States now has the greatest market share of bitcoin mining worldwide, and New York State has a plurality of mining among the states. Consider the mining economics in New York State. Electricity generation by resource is shown in Fig. 21.1. The blended electricity cost per kilowatt-hour for residences and businesses at the time of writing is $0.177. This represents the average cost of electricity sufficient to cover the costs of electricity generation using various energy sources, with a fair rate of return to energy providers as approved by the state's Public Service Commission. Industrial users are offered a subsidized marginal cost of $0.065. While bitcoin miners are often able to secure even more deeply subsidized rates, let us assume that they must pay the industrial rate.

As a consequence of this quirk in pricing, such bitcoin farms often receive an electricity subsidy of the difference between the average blended residential/commercial rate and the industrial rate of an amount $0.112 per kilowatt-hour. Miner rewards are approximately $0.111 per kilowatt-hour of electricity consumed, based on the current estimated mix of mining machines employed. When compared to the current value of bitcoin mining, this leaves a profit to miners of $0.046, based on the likely mix of miners in New York State. Goodkind et al. (2020) estimate environmental and health damages of $0.49 for every dollar of bitcoin mining rewards in the U.S. This converts to the equivalent premium $0.054 per kilowatt-hour of electricity consumed. When added to the electricity subsidy of $0.112, this results in total costs of $0.166 per $0.046 of gross profits garnered by miners

New York State depends on natural gas peaker plants for about 15% of its power. Bitcoin currently represents about 15% of electricity demand in the state, so the additional $0.066 in extra power costs per kilowatt-hour as fossil-fueled peaker plants are kept online is paid by ratepayers, not by fixed price bitcoin mining electricity consumers. Finally, holders of bitcoin also pay for mining electricity and profits because $0.111 reward offered miners per kilowatt-hour of electricity consumed is a dilution in the value of their bitcoin holdings, just as inflation is paid by those holding any currency.

The sum of these costs is then $0.343, compared to miner profits of $0.046 per kilowatt-hour diverted to bitcoin mining. Societal mining costs exceed miner profits by a ratio of 7:45 to 1. For every dollar of mining reward, others pay $7:45. The more electricity diverted, the worst the burden is on other members of the economy. Using these benchmarks, and compared to total annualized electricity consumption worldwide on April 29, 2022, of 150 TWh, bitcoin mining costs $52 billion globally. The average bitcoin transaction then costs the economy more than $500 all-in, based on 95 million transactions annually, and is paid by all members of the economy.

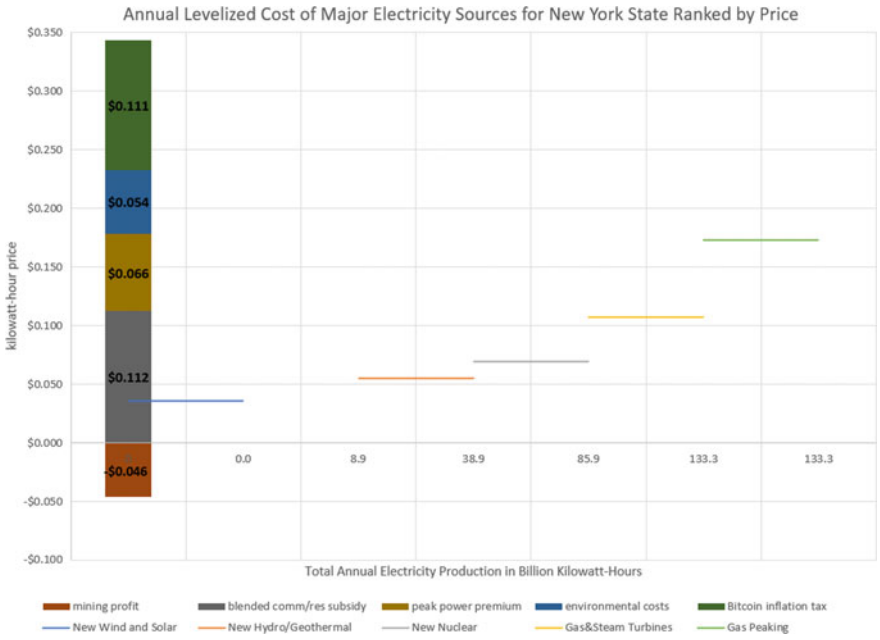

Fig. 21.1 Energy costs for various power sources in New York state, ranked by cost

The bitcoin mining industry insists that they rely more on sustainable energy than other sectors of the economy and have quoted sustainable power as fueling 40% to 75% of bitcoin activity,[8] but mining farms do so by denying other ratepayers access to such cheap and sustainable energy. This exacerbates *The Bitcoin Dilemma*.

To derive Fig. 21.1 that shows how bitcoin mining may profit in New York State compared to the costs it imposes on the economy, I used 2020 data from the Energy Information Agency of the U.S. Government and EIA data for the most extensive bitcoin mining state's electricity consumption and production patterns. The nature of the electricity industry is that there are a number of technologies. Figure 21.1 that represent new sources of power that have high initial costs but, once installed yield the lowest operating costs in the industry. These include new wind, hydroelectric, solar, and next generation nuclear plants. The industry is evolving toward investment in these technologies over time, regardless of the energy needs of any one sector. As electricity

[8] https://www.nytimes.com/interactive/2021/09/03/climate/bitcoin-carbon-footprint-electricity.html, retrieved March 9, 2022.

demand increases, for whatever reason, the industry is forced to expand their reliance on legacy fossil fuel plants to the right of the figure, which require construction of new natural gas plants, return online of obsolete coal plants, and the occasional use of natural gas peak power plants. Hence, new demand inevitably relies on fossil fuel power, with its commensurate high-marginal cost.

I show these ranked sources from least to most expensive, moving left to right on the graph. The graph includes these costs on the most expensive energy forms, natural gas generation, coal- fired plants, and peak power plants, adjusted for current natural gas and coal prices.

If bitcoin mining is able to extract an increasing share of renewable resources, especially from hydroelectricity or wind energy, it displaces other users who are then forced to purchase more expensive power that also create greenhouse gasses. More problematic is the lower price that mining farms secure. According to the economic model, lower negotiated electricity costs actually increased the number of miners, the industry processing capacity, and electricity consumption. In other words, less expensive renewable energy diverted to mining further accelerates the bitcoin arms race and worsens the effects of *The Bitcoin Dilemma*. The model predicts that the lower mining farm electricity rate further displaces other electricity users and results in an increase in electricity consumption from fossil fuels. If the mining industry is greener than average, the overall economy becomes substantially less green.

To the left of Fig. 21.1 is an estimate for the level of gross profits garnered by the bitcoin mining industry in New York State, expressed on the primary unit of measure for bitcoin profits, the cost and profit per kilowatt-hour of power secured. If the electricity cost offered miners is the average statewide industrial rate of $0.065 per kilowatt-hour, I calculate an average gross profit per kilowatt-hour consumed of $0.046. Note the subsidy offered to miners, calculated as the difference between the blended residential/commercial price other ratepayers pay and bitcoin miners pay, is $0.112, which is more than twice the profit rate of mining alone. In addition, about 15% of all electricity production fueled by natural gas generating plants produces the estimated amount of electricity the New York State bitcoin mining industry consumes.

Lazard publishes a regularly updated report on the levelized cost of various electricity sources. A revision of their assumption of a natural gas cost of $3.45 per Million British Thermal Units (MMBTU) and a thermal efficiency rating of 30% results in a peaker plant levelized electricity cost of $0.243, based on current natural gas prices. This results in an additional implicit subsidy of $0.066 per kilowatt-hour as states must retain obsolete plants.

Goodkind et al. (2020) determined that $0.49 of environmental and health costs are incurred in the United States for every $1.00 of bitcoin mined. This adds another $0.054 of social costs to the cost of mining. Finally, the owners of bitcoin ultimately pay for the cost of mining as well because every dollar of bitcoin mined results in a one dollar dilution in the collective value of existing bitcoin holders. This is similar to the inflation tax we all suffer when our currency is diluted through an expansion of the money supply. This cost adds another $0.111 to the cost of bitcoin mining.

When these various implicit costs are added up, they show that $0.343 is incurred by ratepayers, citizens, and bitcoin holders for every $0.046 generated in gross miner profit. Miners get rich but the economy overall is poorer by a much larger degree. If I then calculate these costs, which are estimated at over $127 million per day as a consequence of bitcoin mining, and compare them to the 254,442 total bitcoin transactions on a recent day, we find that the average bitcoin transaction incurs a cost of $503 on others. This is far in excess of the $0.44 average fee for a debit network transaction and the $25 fee for wire transfers. These bitcoin costs arise solely because of the excessive electricity consumption of Proof of Work mining as a consequence of a high-bitcoin price, as described by *The Bitcoin Dilemma*. If the price of bitcoin were $1.56 as when Satoshi left the bitcoin scene, with daily transactions then at 2,300 per day and a mining reward of 50 bitcoin, the transactions costs then were only about ten times higher than that of a debit card and environmental costs were minimal. Even so, Satoshi's primary goal was to increase transaction volume and bring down transaction costs to offer savings over debit and credit cards. At today's transaction volume, and the price of bitcoin in Satoshi's day, this cost would be less than five cents per transaction.

Using 2019 data for New York State recall that Benetton et al. (2021) calculated the cost of mining activity on residential and commercial power users to be $244 million annually because of the implicit subsidies offered miners and the necessity to secure additional power at higher costs. Ratepayers in the United States were estimated to pay an additional $1 billion annually because of bitcoin mining. Globally by 2030, I estimate that electricity demand will rise by an additional 43.1 TWh from bitcoin mining alone over 2021 values. In addition, *The Bitcoin Dilemma* model shows greenhouse gas emissions will rise by 43 million metric tonnes annually by the end of the decade.

The United States Becomes the World's Mining Haven

The United States has a greater share of fossil-fueled electricity generation compared to China. Following China's bitcoin mining ban, the industry has witnessed a dramatic migration of mining to the U.S.. According to Statistica, almost 60% of mining activity worldwide is concentrated in the U.S.[9]:

Within the U.S., Foundry USA, a mining pool employed commonly by large scale mining farms in the USA, reports the following distribution of mining activity across the states, based on statistics from their member pool[10]:

New York	Kentucky	Georgia	Texas	Nebraska	Other
19.9%	18.7%	17.3%	14.0%	10.4%	19.7%

We have seen a geographical migration by miners toward jurisdictions that offer lower electricity costs or more benign regulation as ways to expand their profits. In net, this migration has moved mining away from nations with substantial sustainable energy, most notably hydropower in China, toward nations such as Kazakhstan at first, until that nation subsequently rolled up its welcome mat. Mining also migrated to the United States that rely substantially on fossil-fueled power plants. As you recall from *The Bitcoin Dilemma* section, profits are proportional to cheap power, but once that inexpensive power is usurped, and other users displaced to higher cost power in each state, miners begin to look for the next best location that offers a combination of power and lax regulation.

Until there is abundant and almost resource-free electricity, no case can be made for the desirability of the bitcoin cryptocurrency from an environmental perspective, especially in light of the availability of competing cryptocurrencies that are environmentally benign and can perform better on every dimension but massive mining profits. Unfortunately, the way Satoshi designed the Bitcoin Protocol results in an extremely high cost for society to bear so that miners are enabled to garner their profits.

The Cost of a Bitcoin Transaction

Bitcoin mining imposes costs on the holders of the coin through dilution, equivalent to the inflation that occurs when monetary authorities print excess notes. Mining forces grids to continue to rely on peaker power, and the maintenance of fossil fuel power plants imposes additional health and environmental costs on the economy. Residential and commercial power users must pay the average

[9] https://www.statista.com/statistics/1200477/bitcoin-mining-by-country/, accessed March 7, 2022.

[10] https://www.cnbc.com/2021/10/09/war-to-attract-bitcoin-miners-pits-texas-against-new-york-kentucky.html, retrieved March 7, 2022.

costs of power that increases when miners secure cheaper industrial power on a marginal cost or reduced rate. These various costs were estimated in New York State to total $0.343 per kilowatt-hour consumed in mining.

When one considers the Cambridge Bitcoin Energy Index calculation of annualized mining electricity consumption worldwide of 150 Terawatt-hours per year as of April, 2022, and 92.9 million transactions annually, the total economic costs to support bitcoin mining is $52 million per year, or more than $500 per transaction. While bitcoin can successfully process three to five transactions per second, the Visa network transacts about 5,000 transactions per second in the United States.[11] The average bitcoin transaction cost of over $500 compares to $0.44 for a debit card transaction.

[11] https://www.cardrates.com/advice/number-of-credit-card-transactions-per-day-year/, accessed April 29, 2022.

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Infighting in the Crypto Bros Family

Satoshi created a mechanism for decentralized exchange that yields a decreasing miner reward structure and prophesized that transaction fees will outswamp mining fees by 2040 or 2044, unless a fork is agreed upon that advances this date. Yet, so long as the bitcoin price continues to double faster than rewards halve, mining rewards will continue to be profitable. A coin for which Satoshi was barely exceed a value of $1.00 is expected by some to exceed a valuation of $1 million. For instance, ARK Invest's Cathie Wood stated in her $1 million bitcoin price prognosis that bitcoin "represents only a fraction of the value of global assets amid increasing adoption each year."[1] This valuation would lead to a bitcoin market capitalization in excess of $20 trillion. If so, bitcoin will be a huge speculative play, a vehicle for illicit purchases and a mechanism for money laundering for the world's oligarchs. Meanwhile, mining will continue, funded by fees imposed on transactions once rewards transition away and the energy consumption and global carbon footprint will continue to increase.

Proof of Stake, especially when such a protocol supports an adequate Stablecoin tethered properly to a currency like the U.S. dollar, converts an environmentally problematic methodology to one that has a minimal carbon

[1] "Buffet's Recent Investment Supports $1 M Bitcoin Price," *Forbes*, February 17, 2022, https://www.forbes.com/sites/danrunkevicius/2022/02/17/buffetts-shocking-bitcoin-bet-supports-1m-bitcoin-price-prediction-meanwhile-bnb-solana-cardano-xrp-and-ethereum-prices-surge/?sh=4d2571727e6b, accessed April 11, 2022.

C. L. Read, *The Bitcoin Dilemma*,
https://doi.org/10.1007/978-3-031-09138-4_22

footprint. In doing so, the economy can garner the benefits and efficiencies of digital transactions without the environmental consequences.

Bitcoin remains a refuge for speculators and illicit activity, and it may be more so as other coin become regulated and bitcoin defies regulation. Even novel techniques to properly recycle heat, the other product of mining, are less efficient than other forms of electric heat, such as air-to-air or ground source heat pumps, heat recycling, or co-employment of heat from next generation nuclear power plants. In any regard, such recycling to heat homes and buildings is seasonal, but bitcoin heat production is year-round.

The various coins that use Proof of Stake and other authentication mechanisms use a tiny fraction of the electrical energy of bitcoin, and they also perform better in all important dimensions such as transaction complexity and latency. No coin serves all needs, but it is clear decentralized finance will not rely on bitcoin. The only case to be made for mining bitcoin is the huge profits it generates for miners, but at a much higher cost for the economy.

Satoshi surely could not have appreciated the environmental footprint of a coin that grew faster than anyone could have imagined in the early 2010s. Nor was the planet as aware of global warming to the same extent in 2009 as we are today. The bitcoin creator perhaps recycled part of the heat mining created to warm Satoshi's flat. But, the coin has a unique feature in that it finds its own level. Constrain the coin in one dimension will only cause it to expand in another. Satoshi noted: "Some places where generation will gravitate to (include) (1) places where it's cheapest or free, (2) people who want to help for ideological (sic) reasons, (and) (3) people who want to get some coins without the inconvenience of doing a transaction to buy them."[2]

The incredibly robustness and resistance to modification of the bitcoin protocol is an inconvenient truth for which we now see its implications. Yet, the profit motive remains powerful. Critics remain diligent in debunking the claims of bitcoin advocates that we can have bitcoin and protect the environment at the same time. I demonstrated that the technological innovations in bitcoin mining do not actually reduce the energy consumption as advocates assert. Indeed, continuous miner innovation can actually increase energy consumption. Overall, price is the primary predictor of long-term energy usage, and a price rise, on average, above 17.3% invariably overwhelms the reward halving Satoshi built into the algorithm. The rapid growth in bitcoin prices refutes the claim by Satoshi that a shrinking reward quantity would somehow moderate miner compensation that has only grown over the corporate era.

[2] https://bitcointalk.org/index.php?topic=813.msg9454#msg9454, accessed April 19, 2022.

We must remind ourselves too that electricity consumption of any sort represents a share of energy demand. We live in an era of prosperity that treats electricity access as a right. Most of the world's population live in nations that ensure the public is provided electricity at a reasonable cost. These nations provide electricity through a mix of generation methods. Today, sustainable energy in the form of wind and solar power is often the cheapest form once all pecuniary costs are included. Even the newest generation of nuclear power is estimated to produce at reasonably low costs. Legacy fossil fuel generation is typically the most expensive by far, especially when the cost of construction and the non-pecuniary cost of carbon dioxide and pollution are included.

However, too often we compare apples to oranges. We recognize the new investments needed for solar and wind, but the economy invests in new sustainable energy infrastructure only slowly. Instead, we remain reliant on natural gas and coal plants for which fixed investments have long since been recouped. In addition, natural gas and coal remain underpriced by their failure to include the costly greenhouse gas byproducts that they produce. It is also those fossil-fueled electricity generation plants that we must maintain past obsolescence because of the electricity demand by bitcoin miners.

There remains significant political resistance to the perceived travesty of leaving gas, oil, and coal in the ground or decommissioning functional fossil-fueled power plants. Some view this as a squandering of a resource for which they cannot afford. However, such squandering is the nature of any technology for which a backstop is available. Once the cost of using a resource, including the full cost of the environmental damage it may cause, is eclipsed by the lesser cost of a better backstop technology, resources inevitably remain stranded in the ground. This realization and the transition may be difficult for local or national economies that must reinvent themselves around sustainability. But such a transition is inevitable. It is just a matter of when.

The reality that every resource transition leaves unexploited resources in the ground is inherent in the very nature of innovation. When the automobile replaced the horse and buggy, horse farms and buggy manufacturers became obsolete and the wealth they once generated lost. When our economy moves beyond *peak oil*, at a point which new discoveries and existing extraction can no longer keep up with demand, prices rise and creative innovations substitute for oil until these fossil fuels are no longer needed and further extraction is no longer necessary. Inevitably, fossil fuels will become mostly obsolete economically someday, even though they may remain technically viable. Innovation is necessarily displacing.

Finally, if all of our consumption collectively constitutes demand, there is really no such thing as individual users purchasing green power as much as

it may assuage our conscience. The electrons that we rent come from a mix of resources that supply the grid. Unless we are off the electric grid or have personally invested in solar power, we constitute part of the overall energy demand mix. And, if we secure a large amount of sustainable power on the grid, presumably in the case of bitcoin miners, at a preferred price, that simply means others do not have access to that power. Instead, coal powered plants are kept online longer than necessary to fuel the excess demand that itself may not be necessary. In such a scenario, none of us are greener than another. We are all part of the problem, and we should all strive to be part of the solution. Indeed, Benetton et al. (2021) show that, when cheap power from the grid is diverted to bitcoin mining, it raises the cost to all others.

Local Solutions

When the City of Plattsburgh, a picturesque and historic urban setting on the shore of Lake Champlain, was inundated with applications from potential bitcoin operators in 2017, it imposed a moratorium to buy some time to research how other communities dealt with various nuisances this industry imposes on its neighbors, workers, and electric providers. In my research as mayor of the City of Plattsburgh at that time, I found no examples of building or safety codes elsewhere to ameliorate these problems bitcoin mining creates. We took six months to promulgate various codes to protect the community from nuisances that arise from mining.

The two provisions that contributed to greater environmental efficiency and economic justice included the successful petition to the New York State Public Service Commission for a new rate structure, called Rider A, and a provision for heat recycling.

Residents and businesses alike in Plattsburgh heat with electricity, typically in the form of electric baseboard resistance heaters or floor space heaters. Indeed, these floor space heaters draw about 1400 watts of power and generate about 5000 British Thermal Units (BTUs) of heat each hour. This consumption of electricity and creation of heat is about the same as an Antminer S9 bitcoin mining machine. While an Antminer S9 certainly creates more noise, it is an equally efficient heat producer, per unit of electricity, as a space heater. One provision in our code was that new mining farms must somehow recycle a portion of the heat they generate that would otherwise be dissipated in the atmosphere or artificially warm a lake or stream.

More recently, a firm named Heatbit began to market home space heaters that run off small bitcoin miners. One can heat a room and have the electricity partially or fully covered by mining revenue.[3] Certainly, such an innovation would be an improvement on dissipation of the heat considered by mining farms to be a waste product. A clever Plattsburgh engineer named Ryan Brienza even designed mining farm cubes that could be placed next to a gymnasium or civic center and provide warmth that would have otherwise been provided by electric resistance heaters.[4] Such recycling would have been a good start in a city that heats with electricity anyway. I note, though, that an even better technology than bitcoin heat recycling would be the installation of heat pumps, which operate between two to three times more efficiently than the resistance heat homes invariably employ.

With a residential electricity price in Plattsburgh of only $0.045 per kilowatt-hour, the economics to convert to heat pumps is not as strong as if residents faced the national average rate of $0.104 per kilowatt-hour. Given that almost everybody heats with electricity in Plattsburgh, in the absence of heat pumps, heat recycling is a reasonable alternative. Many hobby miners heat garages or basements with an S9 machine or two. With the low cost of electricity and the current state of sector economics, homeowners generate bitcoin profits that offset their heating costs, with some profits to spare. The City of Plattsburgh's electric supply is 100% sustainable energy, but with a fixed quota, so miner heat recycling is at least a partial solution that makes more environmental sense than the various greenwashing alternatives offered up by the industry. Heat recycling is an improvement, but not a panacea, and only in the cold season when the heat is needed.

Once Plattsburgh put into place this simple code requirement of heat recycling, it no longer received applications for bitcoin mining farms. The other provision that promoted economic justice was our request for a Rider A promulgated by the State Public Service Commission. Rider A ensured that should our city demand electricity beyond Plattsburgh's fixed 120-Megawatt electricity quota because of cryptocurrency mining, or any similar very high electricity density usage, these users must pay for the cost of additional power purchases at higher spot prices made on their behalf. Before that provision was put in place, expensive energy purchases to meet residents' needs on high consumption days were shared by all ratepayers rather than by the miners that caused the phenomenon in the first place. With the support of the State

[3] https://heatbit.com/#preorder, March 18, 2022.

[4] https://www.northcountrypublicradio.org/news/story/40483/20200130/plattsburgh-company-tries-to-keep-cryptocurrency-industry-alive-in-the-city, retrieved March 9, 2022.

of New York Public Service Commission, the ratepayers of the City of Plattsburgh, and similar communities in New York with fixed electricity quotas who have not yet dealt with cryptocurrency mining, could be protected from increased electricity rates as a result.

Similar Industries Learn to Recycle Heat and Be Good Neighbors

Data centers elsewhere have successfully recycled heat, and state regulators can encourage such applications. These data centers perform an essential function without substitutes and differ substantially from bitcoin farms. They generate upwards of fifty times the jobs compared to a mining farm per megawatt of power. In addition, a number of data centers are exploring such heat recycling so they may be good neighbors in their community and good stewards of the earth. For instance, in Odense, Denmark, a Facebook data server center uses excess heat from their machines to heat the adjoining community. Their innovation allows them to heat upwards of 6,900 homes that would have traditionally used fossil fuels for their heat. Likewise, Amazon has been heating one of their corporate buildings in Seattle with excess heat from processing as well.

Being green is not always easy. But it can be worthwhile and profitable, if one looks at the challenges over a longer and broader perspective. Unfortunately, bitcoin miners do not necessarily see the long and broad view in the face of substantial profits for their taking today. Regulators can provide the necessary inducements and allow the farms to capture some of the additional benefits to make it worth their while.

Of course, if one is to supply a mining farm with sustainable energy off the grid of their own construction, the only externality they induce is pecuniary. In other words, they may elevate the price of new sustainable energy construction by the solar and wind equipment for others as they divert resources to themselves. If a farm claims they are off the grid, but rely on their own coal or natural gas power plants or supplies, as venture capitalists are increasingly discovering to insulate themselves from grid dynamics and politics and ensure the steady supply of power regardless of grid condition, such an operation remains part of our fossil fuel consumption mix and our collective greenhouse gas emissions. Even this solution remains part of the problem.

The Industry Pivot

Given the nature of the Bitcoin Proof of Work industry, and the state of the environment, our inability to rid ourselves of fossil fuel power plants, and the existence of viable and superior Proof of Stake coins that are environmentally

benign and of much lower transaction costs, no case can be made for bitcoin mining.

Nevertheless, the crypto industry, especially the bitcoin sector, wishes to do whatever they can to divert the discussion away from the inevitable truth described by *The Bitcoin Dilemma*. They attempt to create a sense the industry can police itself so regulators do not impose the same consumer protections and apply the regulatory tools designed to administer sound monetary policy afforded traditional currencies.

To ward off criticism and regulation proactively, a subset of those who enjoy the profits of mining have assembled the *Climate Change Accord* (CCA), in an obvious attempt to attain a modicum of the same respectability the United Nations' Climate Change Initiative has earned under U.N.'s Sustainable Development agency. Surely, any ability for the industry to self-organize and self-police is advantageous for those who wish to deflect the brunt of the public's concern over global warming. Equally certain is the ability of the industry to fund research and develop talking points on behalf of their members so they too may ward off the significant resistance when bitcoin comes to town.

However, this effort by the CCA appears defensive at best and disingenuous at worst. *The Bitcoin Dilemma* demonstrates energy consumption will continue to increase if the bitcoin price can rise faster than rewards decay for at least two more decades. Unless abundant and affordable sustainable energy for all can be developed and made broadly available before then, cheap, and even sustainable, power diverted to Proof of Work mining will result in the prophecy *The Bitcoin Dilemma* predicts. The diversion results in higher energy costs to other ratepayers, as Benetton (2021) found, while the environmental and nuisance costs of $0.49 on the dollar calculated by Goodkind et al. (2020) also burdens citizens. In addition, Fig. 21.1 shows that not only do electricity ratepayers inevitably cover the profits of bitcoin mining, but they also pay a surcharge in addition as high cost and obsolete fossil-fueled power plants are forced to return or remain online to meet mining demand.

The CCA employs a number of arguments in a format and with sufficient confidence that the casual reader may be persuaded. For instance, they note that bitcoin mining currently produces less greenhouse gasses than gold mining and the jewelry industry,[5] even though they dramatically underestimate their greenhouse gas production when compared to research by

[5] https://www.businessinsider.in/cryptocurrency/news/what-is-the-crypto-climate-accord/articleshow/83946286.cms, accessed March 7, 2022.

Diginomics.[6] The research group concludes that the bitcoin mining industry actually produces a similar amount of greenhouse gasses as the CCA claims is generated in gold mining and jewelry production.

Even if such a claim was true, it compares apples to oranges. Gold mining and jewelry produces stores of value that last forever and have invaluable tangible uses as well. In fact, Krause (2018) showed that gold mining generates far more product per dollar invested than bitcoin, while Cocco et al. (2019) compared bitcoin and gold mining and demonstrated that bitcoin costs far more than the value created from traditional mining in minerals such as gold.

Bitcoin mining merely encodes a number of paper (or, more correctly, virtual) transactions in a way that can easily and more efficiently be done through existing financial institutions, or, if one wishes to live up to the Cypherpunk ideology, through competing but environmentally benign Proof of Stake cryptocurrencies. Bitcoin is valued primarily because of its hype as a speculative instrument that also affords some anonymity for those transacting illicitly, as Foley (2019) demonstrate.

The CCA also compares itself to the power used in holiday lights and household appliances such as air conditioners. These are human activities to selflessly give joy to others or comfort to ourselves, rather than a method to extract profits to an industry that is incredibly lucrative for the wealthy institutions that dominate bitcoin mining. Meanwhile, other cryptocurrencies employ less costly and more environmentally benign blockchain processing technologies such as Proof of Stake.

Finally, CCA claims it has a smaller carbon footprint than the financial sector as a whole, a sector that includes those who mobilize our mortgages, manage and invest our life savings, and ensure the capital that drives our industries and creative sectors. Obviously, to compare bitcoin mining to such a broad and beneficial brick-and-mortar sector is unwarranted. Equally spurious is the CCA's claim that it uses far less energy than the world's military-industrial complex, as if national defense is an appropriate comparison.

These forty-five companies that subscribe to the CCA accord instead rely on talking points created by the CCA to deflect criticism away from Proof of Work mining, without any willingness to discuss the discontinuation of but one large Proof of Work sector in bitcoin, as Ethereum shifts to Proof of Stake.

[6] https://digiconomist.net/bitcoin-energy-consumption/, accessed March 7, 2022.

The CCA knows that they have a greenhouse gas emission public relations problem. They seek refuge in claims they mine only using sustainable sources, even if miners divert to their own use the sustainable energy other ratepayers enjoyed. This diversion creates greenhouse gas emitters out of other ratepayers and necessitates the continuation of fossil fuel plants we hoped to close or by the claim that they purchase carbon credits to offset the damage they cause. They raise other ratepayers' electricity rates by an amount exceeding the profits miners earn.

Indeed, the greatest value of the offsets the bitcoin industry sponsored Crypto Climate Accord (CCA) recommend to *greenwash* their industry are carbon credits. A proper offset must, *on an ongoing basis,* raise the cost of the fossil fuels they consume. Nations have come to realize that such an ongoing carbon tax is politically acceptable if in the order of $70 to $200 per metric tonne of carbon dioxide emissions. Such a carbon tax may someday be sufficient, with an improvement in technology, to truly remove or sequester the carbon emitted in the burning of fossil fuels. However, the CCA knows that to impose such a tax then makes the use of electricity from fossil fuel generation unprofitable.

Recently, *Conservation International* burst the carbon credit myth. An organization since 1987, Conservation International works to better explain to the public how we might best sustain nature and the environment for humanity. In a recent article,[7] they note that the most common carbon credit is in payments to preserve forests. They found over two decades of research that carbon credits to preserve forests could work in principle but rarely does so in practice. While well-intentioned, such a one-time purchase cannot ensure that a forest remains a carbon sink in perpetuity. Indeed, even if it could, a forest must be well-managed to offer an ongoing carbon sink.

In a recent article entitled "The Biggest Crypto Effort to End Useless Carbon Offsets is Backfiring,"[8] Bloomberg reported that while bitcoin miners often take credit for their purchases of carbon offsets, these purchases rarely fulfill their promises. For instance, the sale of a carbon credit by someone who walks to work each day does nothing to reduce the impact arising when the purchaser of the credit is enabled to continue emitting greenhouse gasses. It is impossible to ensure that these markets actually have any effect on reducing emissions.

Even if carbon credit markets functioned as promised, such management would require continual removal of carbon at the height of tree maturity to

[7] https://www.conservation.org/blog/3-myths-about-carbon-offsets-busted, retrieved March 7, 2022.

[8] https://www.bloomberg.com/news/articles/2022-04-07/the-biggest-crypto-effort-to-end-useless-carbon-offsets-is-backfiring, accessed April 11, 2022.

ensure that these trees do not over-mature and die, and hence release back into the air some of their carbon in the form of methane and carbon dioxide. One-time payments, perhaps pledged to influence public opinion, invariably fail to meet their promised objectives. Indeed, carbon credits may support forests that would likely have remained in their natural state even in the absence of payments. Instead, these payments seem only to insure against the threat that the forest may be cut down someday.

Many markets instead cap the amount of such offsets a company can employ to ensure that one cannot disingenuously claim that 100% of the fossil fuel emissions created, for instance, by a coal- or natural gas-fired power plant are offset in a way that makes this unnecessary generation of greenhouse gasses environmentally benign.

An Industry Response to Greenwashing

The narrative advanced by the alliance of large bitcoin farm owners has met with resistance within the industry. Locke (2022) reports in a recent article in Fortune, entitled "Bitcoin's Judas,"[9] about how Ripple co-founder Chris Larsen met with a strong backlash at both the issue and personal level when Larsen advocated for a movement away from Proof of Work mining in bitcoin out of a concern for the sector's environmental footprint. Larsen has collaborated with Greenpeace, the Sierra Club, and others who are mounting a campaign to reform and make credible a sector that many now realize damages the environment unnecessarily in a campaign called "Change the Code, Not the Climate."[10] Bitcoin miners object that the recommendation to move bitcoin to Proof of Stake is almost impossible given that it would require the cooperation of those who currently benefit substantially from the current protocol.

Rather than applauded for his common sense, Larsen was attacked personally and accused of attempting to increase interest in Ripple products at the expense of bitcoin. Clearly, the Bitcoin Proof of Work mining sector is under increasing scrutiny for its carbon footprint and the economics of its industry. They appear to prefer to fight than switch, but advocates such as Larsen are concerned that to maintain the Proof of Work stance tarnishes the image of the entire cryptocurrency industry.

Ultimately, there is no escape from the reality of our interconnectedness. Satoshi certainly practiced an ideology of economic decentralization and a profound mistrust of large financial institutions. But such a libertarian or

[9] Locke, Taylor (2022), "Bitcoin's 'Judas': The Co-founder of a Rival Cryptocurrency is Pushing for a Green Revolution in Mining. It's Not Going Well," Fortune, April 2, 2022, https://fortune.com/2022/04/02/bitcoin-mining-green-campaign-chris-larsen/?queryly=related_article, accessed April 7, 2022.

[10] Kharif, Olga (2022), "Greenpeace, Crypto Billionaire Lobby to Change Bitcoin Code," Bloomberg, March 28, 2022. https://www.bloomberg.com/news/articles/2022-03-29/greenpeace-crypto-billionaire-lobby-to-change-bitcoin-s-code, retrieved April 11, 2022.

anarchistic streak does not insulate oneself from others. The legal philosopher Zechariah Chafee Jr. wrote an article in June 1919 for the Harvard Law Review with the title "Freedom of Speech in War Time." He asserted an imaginary monologue directed to a judge regarding competing rights:

> Each side takes the position of the man who was arrested for swinging his arms and hitting another in the nose, and asked the judge if he did not have a right to swing his arms in a free country. 'Your right to swing your arms ends just where the other man's nose begins.[11] (emphasis added)

We live in a market society, but one of many imperfections. One such imperfection is our failure to deal with negative externalities, often especially with regard to our actions that damage the environment and especially the generations that follow us. Any burning of hydrocarbons, by those who believe mining with energy derived from a proprietary coal or natural gas source, or from those displaced and must then collectively rely on fossil fuels, or even those miners who may do the displacing, all share in the net outcome. As an environmental and energy professor, I appreciate this interdependence and find unhelpful the folly of advocates who greenwash in a way that confuses and diverts our attention.

Someday, fusion promises to provide abundant and practically inexhaustible energy that may be inexpensive and does not produce radioactive byproducts. I recall back in 1980 when I was studying the physics of alternative energy in college that the promise of fusion was but a generation away. Fusion still remains a generation away, but there has been much interest and progress lately. Only time will tell. Hope, though, is not a solution.

Our best opportunity to combat global warming is not to hope for better technologies, but instead to evaluate the consumptive technologies we use daily and ensure that we are consuming what we need, but no more. Under that rubric, those who promote bitcoin mining to maintain and expand their own economic profits are irresponsible. Bitcoin mining is unnecessary when compared with other digital currencies that can perform better, and do so without the vast carbon footprint of bitcoin.

As this book approaches its final section, I note that there exist technologies to propel us into the digital era Satoshi envisioned, but without the environmental consequences we now well understand. The Gospel of Profit, so compelling to some, should not compel a collective irresponsibility. We can have our cake and eat it too, but perhaps without the vast profits

[11] https://quoteinvestigator.com/2011/10/15/liberty-fist-nose/, retrieved February 25, 2022.

earned by some who advocate for self-serving reasons to retain a technology of consequences Satoshi could not have imagined.