CLIMATE AND ENERGY IMPLICATIONS OF CRYPTO-ASSETS IN THE UNITED STATES

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THE WHITE HOUSE
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Table of Contents

Statement of Purpose 3
About the Interagency Process........ 3
Suggested Citation 3
About the Office of Science and Technology Policy........ 3
Summary and Recommendations 4
1. Motivation and Introduction 9
Solving the Climate Crisis Is a Key Biden-Harris Administration Priority........ 9
The United States Must Promote Responsible Development of Digital Assets 9
Crypto-Assets Use Digital Cryptography to Maintain Financial Records........ 10
2. Crypto-Assets Affect Electricity Usage and the Grid........ 13
Electricity Usage Varies for Different Types of Crypto-Assets 13
Electricity Usage from Crypto-Asset Activity........ 14
Comparison with Other Financial Transactions........ 16
Crypto-Asset Mining Can Affect Electricity Consumers and the Grid 16
Future Crypto-Asset Electricity Usage Projections Are Uncertain........ 18
3. Crypto-Assets Result in Greenhouse Gas Emissions and Other Environmental Impacts 21
Crypto-Asset Mining Using Grid Electricity Generates Greenhouse Gas Emissions — Unless Mining Uses Clean Energy 21
Crypto-Asset Mining Can Be Powered by Stranded Methane and Renewables........ 23
Environmental Impacts Include Air and Water Pollution, Noise, and Electronic Waste 25
4. Emerging Digital Asset Technologies Could Support Climate Monitoring or Mitigation........ 27
Blockchains and Distributed Ledgers in Environmental Markets 27
Blockchain as Enabling Technology for Distributed Energy Resources 29
5. Appendices........ 31
Table A.1 31
Table A.2 32
Table A.3 32
Table A.4 33
List of Acronyms........ 35
Interagency Policy Committee........ 36
6. Endnotes........ 37

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Statement of Purpose

On March 9, 2022, President Biden signed Executive Order 14067: "Ensuring Responsible Development of Digital Assets,"[1] to support responsible digital asset development, in line with our climate change objectives, and for the benefit of everyone in America. The President directed the White House Office of Science and Technology Policy (OSTP), and its partners from the Executive Office of the President and across federal agencies, to examine: the connections between distributed ledger technologies (DLT) and energy transitions, the potential for these technologies to impede or advance efforts to tackle climate change at home and abroad, and the impacts these technologies have on the environment. This report provides the assessment directed by Executive Order 14067.

About the Interagency Process

The creation of this report was coordinated through an interagency process led by Assistant to the President for National Security Affairs and the Assistant to the President for Economic Policy, as described in Section 3 of Executive Order 14067. A list of departments and agencies involved in this interagency process can be found in the Interagency Policy Committee section of the Appendices.

So this is meant to be the science group. Yet the paper is very unscientific (see my supplemental notes). Arguably, it wouldn't get a passing grade in a graduate level university course. Many of the references made in the paper were rejected by the Wikipedia page on Bitcoin for being insufficiently academic.

Suggested Citation

OSTP (2022). Climate and Energy Implications of Crypto-Assets in the United States. White House Office of Science and Technology Policy. Washington, D.C. September 8, 2022.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976 to provide the President and others within the Executive Office of the President with advice on the scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, the environment, and the technological recovery and use of resources, among other topics. OSTP leads interagency science and technology policy coordination efforts, assists the Office of Management and Budget with an annual review and analysis of federal research and development in budgets, and serves as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the federal government. More information is available at http://www.whitehouse.gov/ostp.

Summary and Recommendations

The U.S. National Climate Assessment and the Intergovernmental Panel on Climate Change (IPCC) show that reducing global anthropogenic greenhouse gas (GHG) emissions to net-zero by mid-century will prevent the most severe damages to human health, ecosystems, and infrastructure. These climate-driven damages include deaths caused by: heat waves; loss of forests, homes, and infrastructure from increasing wildfires; flooding and extreme weather events; property loss; damage to roads, bridges, public transit systems and the energy system; inundation of coastal areas by sea level rise and storm surges; droughts; damage to crops; and other harms to the ecosystems that sustain people.[2,3] The damages intensified by climate change are not borne equally; underserved communities are often disproportionately burdened with the most severe impacts from climate change.[4] Climate change is expensive: in 2021, climate disasters cost the United States $145 billion.[5] Climate change also poses risks to taxpayers, the federal budget, and federal facilities; without increased action, climate change could reduce U.S. gross domestic product by 3% to 10%, and U.S. federal revenue by 7% annually by the end of the century.[6] The United States is committed to combatting the climate crisis and reducing GHG emissions by 50% to 52% below 2005 levels by 2030, achieving a carbon pollution-free electricity grid by 2035, and reaching net-zero emissions no later than 2050, all while prioritizing environmental justice.

So citation 5 is a climate.gov article which lists _all_ natural disasters in 2021 and finds $145b in damages. The white house is literally redefining natural disasters as climate change related! This is incredibly misleading, and it isn't supported by the text they're citing.

'Environmental justice' - basically wokeism wrapped in a climate payload.
If you care about climate change, fine. Why further dilute your agenda by jamming wokeism in there too?

They're redefining weather disasters as 'climate disasters' - turns out all normal weather events are now 'climate change'. No mention of the fact that we've become vastly _better_ at dealing with these thanks to … industrialization!

No mention of the 'risks' 'posed' by a green agenda - nat'l security (see germany), grid failure, inflation, de-industrialization, famine, etc.

At the same, the use of digital assets based on distributed ledger technology is expanding. Digital assets are a form of value, represented digitally. As an emerging technological innovation, digital assets have provided some benefits and value for some U.S. residents and businesses, and have the potential for future benefits with emerging uses. Crypto-assets are digital assets that are implemented using cryptographic techniques, and have a total current global market capitalization of nearly $1 trillion. However, some crypto-asset technologies currently require a considerable amount of electricity for asset generation, ownership, and exchange. Electricity usage from digital assets is contributing to GHG emissions, additional pollution, noise, and other local impacts, depending on markets, policies, and local electricity sources. Depending on the energy intensity of the technology used, crypto-assets could hinder broader efforts to achieve net-zero carbon pollution consistent with U.S. climate commitments and goals.

Trying to replace thermal generation with intermittent renewables obviously poses a massive threat to growth as is evident in Europe which is careening towards a depression because of their overzealous green fantasies

Reframing 'climate' in GDP terms is comical. How does Europe's GDP look now they have been deprived of nat gas?

This isn't really true. If you think adding 0.1-1% of consumption will derail the US' climate agenda, your climate agenda is very brittle

The U.S. government has a responsibility to ensure electric grid stability, enable a clean energy future, and protect communities from pollution and climate change impacts. This report explores the challenges and opportunities of crypto-assets for energy and climate change issues in the United States, and answers four main questions asked in Executive Order 14067:

This report does not answer questions 1 and 2. It summarizes some research, mostly muddying the waters given the extremely poor quality of much of that research. If the US wanted to find out actual answers, they would have to do some original work rather than just coyping de vries' homework

1. How do digital assets affect energy usage, including grid management and reliability, energy efficiency incentives and standards, and sources of energy supply?
2. What is the scale of climate, energy, and environmental impacts of digital assets relative to other energy uses, and what innovations and policies are needed in the underlying data to enable robust comparisons?
3. What are the potential uses of blockchain technology that could support climate monitoring or mitigating technologies?

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4. What key policy decisions, critical innovations, research and development, and assessment tools are needed to minimize or mitigate the climate, energy, and environmental implications of digital assets?

Citations 7 and 8 are De Vries. These are categorically NOT RELIABLE. No de Vries citation is scientific or reliable. He is not a scientist or genuine academic - he creates paid opposition research based on a personal antipathy to crypto. Much of this he has created while working at the Dutch Central Bank. He is absolutely not impartial. CBECI by contrast (Cambridge) is impartial, academic.

De Vries/Digiconomist = Steele dossier of PoW research

How do digital assets affect energy usage, including grid management and reliability, energy efficiency incentives and standards, and sources of energy supply?

Crypto-assets use a significant amount of electricity.

From 2018 to 2022, annualized electricity from global crypto-assets grew rapidly, with estimates of electricity usage doubling to quadrupling.[7,8,9] As of August 2022, published estimates of the total global electricity usage for crypto-assets are between 120 and 240 billion kilowatt-hours per year, a range that exceeds the total annual electricity usage of many individual countries, such as Argentina or Australia. This is equivalent to 0.4% to 0.9% of annual global electricity usage,[10,11] and is comparable to the annual electricity usage of all conventional (i.e., non-crypto-asset) data centers in the world.[12] The United States is estimated to host about a third of global crypto-asset operations, which currently consume about 0.9% to 1.7% of total U.S. electricity usage. This range of electricity usage is similar to all home computers or all residential lighting in the United States.[13] Crypto-asset mining is also highly mobile. The U.S. share of global mining from Bitcoin, the largest crypto-asset, rose from 3.5% in 2020 to 38% today, with U.S. electricity usage for crypto-asset mining, while still relatively small, tripling since January 2021.

Comparing countries and Bitcoin is the wrong analogy - Bitcoin is able to draw from pockets of cheap / curtailed / underutilized power globally. (Eg, west texas where no one lives)

Countries have to construct a grid around demand centers.

Bitcoin can rely on a completely different energy mix than any country could.

This is true, and why Bitcoin mining has a better sustainability outlook than any other industry … period. It can go anywhere, adjust to anything. If miners want to be green, they can be green (assuming there's green power available for a decent price).

Despite the potential for rapid growth, future electricity demand from crypto-asset operations is uncertain. Electricity usage can change as crypto-asset miners ramp their activities up or down in response to market value fluctuations, and as they adopt new equipment and technologies. Annualized global crypto-asset electricity usage grew by more than 67% from July 2021 to January 2022, and then fell by 17% by August 2022. The ability for rapid growth in crypto-asset electricity usage raises concerns about fast increases in electricity usage, and subsequent impacts on consumers and the grid. For example, Texas has emerged as an increasingly attractive location for crypto-asset mining, which uses about 3% of local peak electricity demand. Over the next decade, Texas may see an additional 25 GW of new electricity demand from crypto-asset mining — equivalent to a third of existing peak electricity demand in Texas.[14] This increase raises potential challenges for maintaining electricity reliability.

A lot of the PoW fearmongering fails to take into account the halving (literally halves the ratio between price and energy) and assumes infinite BTC price growth. Neither is the case. Reasonable models (see NYDIG or Coinshares) have energy usage tapering off.

First real clanger of the article. This number does not at all reflect likely demand - just non-binding indications of interest from miners and brokers (during the crazy bull market of 2021). Small fraction will be permitted.

There is 0% chance anywhere near to this number gets turned on anytime soon.

See detailed endnotes on this topic

With the recent enactment of the Inflation Reduction Act, federal tax credits and other incentives will spur large-scale development of clean energy to enable the United States to electrify large portions of the transportation, buildings, and industrial sectors.[15] It is critically important that clean energy powers this demand from new electrification. Additionally, rapidly growing new power demand must avoid unmanageable impacts to the grid and use the most efficient technology available. It is also crucial that electricity remains affordable for homes and businesses. This is especially critical in this moment, when the Bipartisan Infrastructure Law is enabling investments in grid modernization and expansion, to ensure resilience in the face of climate-driven weather extremes and fires.[16]

These incentives mostly price out reliable thermal generation (like nat gas) or nuclear and subsidize wasteful, unreliable wind and solar, built far from population centers (requiring expensive transmission) and additional redundant thermal generation to act as a backstop

Eliminating these tax credits is the first step towards fixing our increasingly unstable grid

Electricity usage varies substantially with different crypto-asset technologies.

Nearly all crypto-asset electricity usage is driven by consensus mechanisms: the distributed ledger technologies used to mine and verify crypto-assets. The dominant consensus mechanism

Despite LCOE figures, a grid incorporating a high fraction of unreliable wind and solar is guaranteed to be more expensive for end users once everything is accounted for

The admin in this section is trying to lay the groundwork to suggest Bitcoin could be more efficient by switching to PoS - this is the crux of the issue really. Proof of Stake is simply the established model of governing financial systems - it's shareholder or corporate governance. The more coins you have, the more control.

PoW is a competing, new model, which explicitly breaks the linkage between coins held and political power. Only marshalling real world physical resources matters. Thats obviously harder to do than commandeering a big exchange or custodian (holding a lot of stake), which the state can do at the stroke of a pen. Naturally, the Biden admin prefers a controllable financial network to a non-controllable one. So they prefer PoS - using a climate agenda to promote it over PoW.

Long term though, open and non-controlled networks will win, because depoliticized finance is fundamentally better. No one (aside from the US government) wants SWIFT 2.0.

is called Proof of Work (PoW), which is used by the Bitcoin and Ethereum blockchains. Bitcoin and Ether, their respective crypto-assets, combined, represent more than 60% of total crypto-asset market capitalization. The PoW mechanism is designed to require more computing power as more entities attempt to validate transactions for coin rewards, and this feature helps disincentivize malicious actors from attacking the network. As of August 2022, Bitcoin is estimated to account for 60% to 77% of total global crypto-asset electricity usage, and Ethereum is estimated to account for 20% to 39%.

If you think PoS is identical in its assurances to PoW, you might say it's "more efficient" or "less energy intensive". This is obviously false if it's not the same product - and it certainly is not.

An alternative, less energy-intensive consensus mechanism, called Proof of Stake (PoS), was estimated to consume up to 0.28 billion kilowatt-hours per year in 2021, less than 0.001% of global electricity usage. Current discussions about reducing crypto-asset electricity usage primarily focus on PoW blockchains, particularly Bitcoin.[17,18] There have been growing calls for PoW blockchains to adopt less energy-intensive consensus mechanisms. The most prominent reaction has been Ethereum's promised launch of "Ethereum 2.0," which uses a PoS consensus mechanism.

No mention of the fact that ETH 2.0 makes it much more vulnerable to governments (via pressure easily imposed on large stakers like US domiciled exchanges).

What is the scale of climate, energy, and environmental impacts of digital assets relative to other energy uses, and what innovations and policies are needed in the underlying data to enable robust comparisons?

They are willing to cite a clearly conflicted partisan source, why not cite an industry source?

Coinshares, the Bitcoin Mining Council, NYDIG (2021) all offer recent estimates. None are any less credible than De Vries

(to derive a 'all-crypto' figure you could trivially combine the Bitcoin data from those sources with Kyle McDonald's ETH estimate)

Putting the De Vries number front and center and representing it as a fact (as opposed to an extremely uncertain guess) is completely irresponsible

So they don't put the citation here, but later on they cite this 140 Mt figure and … it's all Digiconomist/De Vries (citations 117, 118, 119).

This is a key figure in their paper and argument. It derives from a non peer reviewed, amateur… blog.

Run by an employee of the Dutch Central Bank (obvious COI) who demonstrates a clear antipathy towards btc and uses very questionable methods (easily debunked by industry professionals).

It's just not a defensible estimate, and even if it were, it's not coming from a reliable source that can be quoted in a scientific paper.

Also, it's worth noting if you look at the later usage of this figure, it's a 2022 figure. Last I checked, 2022 isn't over yet. Hashrate (and energy consumption) can change. So it's false to say "resulted". The 140 Mt estimate is a wild guess for all of 2022.

Global electricity generation for the crypto-assets with the largest market capitalizations resulted in a combined 140 ± 30 million metric tons of carbon dioxide per year (Mt CO_2/y), or about 0.3% of global annual GHG emissions. 🤥🤥🤥🤥🤥

Crypto-asset activity in the United States is estimated to result in approximately 25 to 50 Mt CO_2/y, which is 0.4% to 0.8% of total U.S. GHG emissions, similar to emissions from diesel fuel used in railroads in the United States. GHG emissions from electricity usage vary by region in the United States; some regions rely more on carbon-intensive fossil fuels, while others use more nuclear and renewable energy sources. Besides purchased grid electricity, crypto-asset mining operations also cause local noise and water impacts from operations, electronic waste, air and other pollution from any direct usage of fossil-fired electricity, and additional air, water, and waste impacts associated with all grid electricity usage. These local impacts can exacerbate environmental justice issues for underserved communities. Broader adoption of crypto-assets, and the potential introduction of new types of digital assets require action by the federal government to encourage and ensure responsible development. This includes minimizing impacts on local communities, dramatically reducing energy intensity, and powering with clean electricity. Digital asset research that emphasizes innovations in next-generation technologies can advance U.S. goals in security, privacy, equity, resilience, and climate objectives.

What are the potential uses of blockchain technology that could support climate monitoring or mitigating technologies?

There is potential for blockchain technologies to play a role in environmental markets, and DLT could potentially enable distributed energy resource coordination, as well as broader supply chain management.[19,20]

DLT is enabling technologies that are being explored in various markets. Still, other solutions might work as well or better. To help the United States meet its climate change commitments, DLT must be deployed in a manner that enables reductions in GHG emissions. The potential

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Notwithstanding the fact that this is patently a de-growth, neo-malthusian agenda, which would cause mass immiseration if actually carried out, crypto asset policy is largely irrelevant. The US is going to have to massively, massively increase its electrical generation if it plans to "electrify everything" (part of Net Zero), and PoW is a rounding error in that context - even in models where BTCUSD appreciates massively. They just aren't looking at the models.

benefits of DLT would need to outweigh the additional emissions and other environmental externalities that result from operations to merit its broader use in the carbon credit market ecosystem, relative to the markets or mechanisms that they are displacing. Use cases are still emerging, and like all emerging technologies, there are potential positive and negative use cases yet to be imagined. The U.S. government should facilitate innovation that addresses market challenges, aligns with environmental and equity objectives, and appropriately ensures customer and investor protection and market integrity.

What key policy decisions, critical innovations, research and development, and assessment tools are needed to minimize or mitigate the climate, energy, and environmental implications of digital assets?

To help the United States meet its climate objectives of a 50% to 52% reduction in GHG emissions by 2030, a carbon pollution-free electricity system by 2035, and a net-zero emissions economy no later than 2050, crypto-asset policy during the transition to clean energy should be focused on several objectives: reduce GHG emissions, avoid operations that will increase the cost of electricity to consumers, avoid operations that reduce the reliability of electric grids, and avoid negative impacts to equity, communities, and the local environment.

The following recommendations aim to: resolve data gaps, manage electricity demand, reduce GHG emissions, reduce electronic waste and pollution, support a clean energy transition that equitably benefits communities across the country, and address longstanding concerns of overburdened and underserved communities.

To ensure the responsible development of digital assets, recommendations include the following actions for consideration:

Unnecessary insertion of wokeism / cultural marxism is further discrediting.

Noise pollution is a local issue and easily dealt with (simply ban bitcoin mining in populated areas - not an issue at all). Is this a report on climate, or is it a report on general NIMBYist complaints people have about miners?

If climate is a very serious problem, why fixate on local and incidental issues like noise pollution?

- **Minimize GHG emissions, environmental justice impacts, and other local impacts from crypto-assets:** The Environmental Protection Agency (EPA), the Department of Energy (DOE), and other federal agencies should provide technical assistance and initiate a collaborative process with states, communities, the crypto-asset industry, and others to develop effective, evidence-based environmental performance standards for the responsible design, development, and use of environmentally responsible crypto-asset technologies. These should include standards for very low energy intensities, low water usage, low noise generation, clean energy usage by operators, and standards that strengthen over time for additional carbon-free generation to match or exceed the additional electricity load of these facilities. Should these measures prove ineffective at reducing impacts, the Administration should explore executive actions, and Congress might consider legislation, to limit or eliminate the use of high energy intensity consensus mechanisms for crypto-asset mining. DOE and EPA should provide technical assistance to state public utility commissions, environmental protection agencies, and the crypto-asset industry to build capacity to minimize emissions, noise, water impacts, and negative economic impacts of crypto-asset mining; and to mitigate environmental injustices to overburdened communities.
- **Ensure energy reliability:** DOE, in coordination with the Federal Energy Regulatory Commission, the North American Electric Reliability Corporation and its regional entities, should conduct reliability assessments of current and projected crypto-asset

'executive actions' = the administration should consider extra-judicially "choke pointing" the industry.

if this admin has their way, they'll politicize all formerly neutral utilities, like electricity, water, etc.

This is the mask off moment. They basically want to ban a specific kind of data center that has duly purchased energy, like any other company, based on the type of computation being done, because they don't like the computation.

What's the word for the merger of the private sector and the state? Starts with an F?

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mining operations on electricity system reliability and adequacy. If these reliability assessments find current or anticipated risks to the power system as a result crypto-asset mining, these entities should consider developing, updating, and enforcing reliability standards and emergency operations procedures to ensure system reliability and adequacy under the growth of crypto-asset mining.

Good idea, because the data that this report relies on is basically fantastical (every De Vries citation). There is a data gap in terms of what US miners are doing

- **Obtain data to understand, monitor, and mitigate impacts:** The Energy Information Administration and other federal agencies should consider collecting and analyzing information from crypto-asset miners and electric utilities in a privacy-preserving manner to enable evidence-based decisions on the energy and climate implications of crypto-assets. Data should include mining energy usage and fuel mix, power purchase agreements, environmental justice implications, and demand response participation. OSTP could establish a National Science and Technology Council subcommittee to coordinate with other relevant agencies to assess the energy use of major crypto-assets.
- **Advance energy efficiency standards:** The Administration should consider working with Congress to enable DOE and encourage other federal regulators to promulgate and regularly update energy conservation standards for crypto-asset mining equipment, blockchains, and other operations.

Agreed, the bitcoin mining council does some of this but more disclosures with more granular data would be welcome

- **Encourage transparency and improvements in environmental performance:** Crypto-asset industry associations, including mining firms and equipment manufacturers, should be encouraged to publicly report crypto-asset mining locations, annual electricity usage, GHG emissions using existing protocols, and electronic waste recycling performance.
- **Further research to improve understanding and innovation:** For improved analytical capabilities that can enhance the accuracy of electricity usage estimates and sustainability, the National Science Foundation, DOE, EPA and other relevant agencies could promote and support research and development priorities that improve the environmental sustainability of digital assets, including crypto-asset impact modeling, assessment of environmental justice impacts, and understanding beneficial uses for grid management and environmental mitigation. Research and development priorities should emphasize innovations in next-generation digital asset technologies that advance U.S. goals in security, privacy, equity, and resilience, as well as U.S. climate goals.

1. Motivation and Introduction

Solving the Climate Crisis Is a Key Biden-Harris Administration Priority

Under Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad," the President set a national goal of reducing GHG emissions to net-zero by 2050.[21] Under the Paris Agreement, the United States set a Nationally Determined Contribution of reducing GHGs by 50% to 52% below 2005 levels by 2030, and confirmed the goal to reach net-zero GHG emissions by 2050.[22] Executive Order 14008 recognizes that the nation faces "a climate crisis that threatens our people and communities, public health and economy, and, starkly, our ability to live on planet Earth." This Executive Order addresses this crisis, including through "a government-wide approach that reduces climate pollution in every sector of the economy… [and] protects public health," and directs EPA, OSTP, the Department of the Treasury, and other federal agencies to "prioritize action on climate change" in policy-making processes, among other actions. Executive Order 13990: "Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis" declared that the federal government must be guided by the best science to improve public health, protect our environment, reduce GHG emissions, ensure access to clean air and water, prioritize environmental justice, and create well-paying union jobs.[23]

On August 16, 2022, the President signed into law the Inflation Reduction Act (IRA),[24] which represents the single largest investment in clean energy, GHG emissions reduction, and climate resilience in U.S. history. This law provides $369 billion to fight climate change and enhance U.S. energy security. The IRA is projected to contribute to reducing carbon emissions by 40% from 2005 levels by 2030.[25] Together, the U.S. climate objectives, executive orders, Bipartisan Infrastructure Law,[26] CHIPS and Science Act,[27] and the IRA set the federal government's baseline for action to address the climate crisis.

At the same time, digital asset electricity usage has grown rapidly in the United States. For example, between January 2020 and January 2022, the United States' share of global Bitcoin mining rose from 4.5% to 37.8%.[28] Given the United States' commitment to reduce emissions, the federal government must ensure that use of digital assets in the United States does not impede our ability to meet our climate objectives. This report's assessment and recommendations for the climate and energy implications of digital assets align with federal actions that reduce GHG emissions to protect public health and welfare, and to improve environmental justice.

As I point out in the supplemental notes, the #1 best way to guarantee that bitcoin's emissions are as low as possible is to encourage miners to locate themselves in the (low CO2 intensity) US, rather than high-emissions Russia, Iran, Venezuela, Kazakhstan, etc.

The United States Must Promote Responsible Development of Digital Assets

President Biden's Executive Order on Ensuring Responsible Development of Digital Assets states, "the United States has an interest in responsible financial innovation," wherein the federal government “must take strong steps to reduce the risks that digital assets could pose to consumers, investors, and business protections…financial inclusion and equity; and climate change and pollution.” To this end, the Executive Order’s principal policy objectives recognize that the federal government “must protect consumers, investors and businesses,” and that the “United States has an interest in ensuring that digital asset technologies and digital payment ecosystems are developed, designed, and implemented in a responsible manner that…reduces negative climate impacts and environmental pollution, as may result from some cryptocurrency mining.”

Crypto-Assets Use Digital Cryptography to Maintain Financial Records

Crypto-assets are a type of private sector digital asset that depend on cryptography and DLT, or similar technology. While other assets may involve digital representations of value, assets are only crypto-assets if they rely on a cryptography and DLT, such as blockchain. A distributed ledger is a database in which participants on a common network can record transactions. This ledger provides a mechanism for all users to agree on the ledger entries and transactions — called consensus mechanisms. Different consensus mechanisms enforce different rules for when participants can submit ledger updates. For example, PoW consensus mechanisms,[29] which are currently used for Bitcoin, Ethereum, and other blockchains, require the completion of a computationally-intensive process before a set of transactions, or “block,” is validated and added to the ledger. This ensures that participants are willing to spend significant computational and energy resources in order to add blocks to the ledger. This approach makes it more difficult for malicious participants to force an inaccurate ledger, because they would need to amass a large amount of computing resources and expend a significant amount of energy to achieve a consensus. Participants who submit blocks to the network are known as miners. Miners are incentivized to add blocks to the consensus ledger by performing energy-intensive computations, because they receive compensation in the form of newly minted crypto-assets for adding a block to the blockchain, and they collect fees associated with transactions within the block.[30] Participants confirm the validity of new blocks, adding them to the blockchain ledger, and then store the latest copies of the ledger. Figure 1.1 provides an overview of PoW crypto-asset mining.

Not the worst description of mining i’ve read. At least they didn’t say “extremely complex computational puzzles”

As a crypto-asset becomes more valuable, the mining rewards also become more valuable. This attracts more miners and computing resources to solve the cryptographic math problem. As miners dedicate more computing resources to process transactions for a blockchain, the math problem adjusts to become more difficult. This keeps the average time required to find a solution approximately constant.[8] This PoW “economic model” means that a PoW network will generally use more electricity as the crypto-asset’s value (and network) grows, so long as the distribution of the crypto-asset among miners stays constant. The growth in total value of crypto-assets has attracted thousands of miners, who use computers and customized hardware, drawing total electricity amounts comparable to a mid-sized nation or a large metropolitan area.

Not necessarily, this report is mostly about Bitcoin and obviously the halving has to be taken into account. The ratio between the market cap and energy expenditure is constantly decaying. (there’s also fees, but those don’t look to be growing particularly quickly, certainly not offsetting the halvings)

This isn’t true for bitcoin, and this report is about bitcoin (mostly). so why make this claim?

The most popular alternative to the energy-intensive PoW consensus mechanism is PoS, which is used for networks such as Solana, Cardano, the proposed Ethereum 2.0, and others. In PoS, participants — called validators — typically “stake” an amount of crypto-assets for the

One thing that's rarely discussed is the fact that PoS also consumes capital (since it involves locking up otherwise-productive assets).

That's fine, but if your complaint is that energy resources are being used for PoW, the same is true of PoS- it's just financial resources which are being consumed. They could be used for building wind turbines, solar panels, nuclear plants, offsets, etc.

The government is proud of the fact that they spent $369B on the inflation reduction act to fight climate change (see page 9). PoS at scale consumes massive amounts of capital resources. it is certainly not a free lunch.

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opportunity to be chosen to add a new block of transactions to the ledger. The more crypto-assets a validator stakes, or the longer the stake is locked up, the larger the chance of being chosen. Validators who publish inaccurate data or fraudulent transactions risk losing their stake. Dozens of variations exist within the PoS consensus mechanism; variations generally share the principle that trust is inferred by a participant's willingness to risk their valuable crypto-assets. Because PoS validators rely on risking assets rather than computing power to validate transactions, the electricity use of PoS crypto-assets is much lower than PoW crypto-assets, as shown in Appendix Table A.1.

Beyond PoW and PoS, there are many other types of consensus mechanisms, including but not limited to Proof of Capacity and Practical Byzantine Fault Tolerance, both of which are currently used by existing crypto-assets, as discussed in Appendix Table A.2.[31] Besides electricity usage, there are other issues that affect a crypto-asset's application and market acceptance, including scalability, security against tampering and falsification, throughput, latency, and decentralization.[32] Every consensus mechanism has strengths and weaknesses. The crypto-asset community has not reached an agreement on what constitutes "best practices" for consensus mechanisms, and other consensus mechanisms with different strengths and weaknesses may emerge. Responsible development of digital assets would encourage consensus mechanisms that minimize energy usage and environmental impacts while maximizing benefits to consumers.

At least they have the decency to hedge a little and say this. It should already be obvious that PoS opens your network up to politicization and capture (there's already plenty of evidence of this actually happening in PoS), but we will have to witness this happening to ETH before we collectively admit that PoS gives you weaker assurances than PoW.

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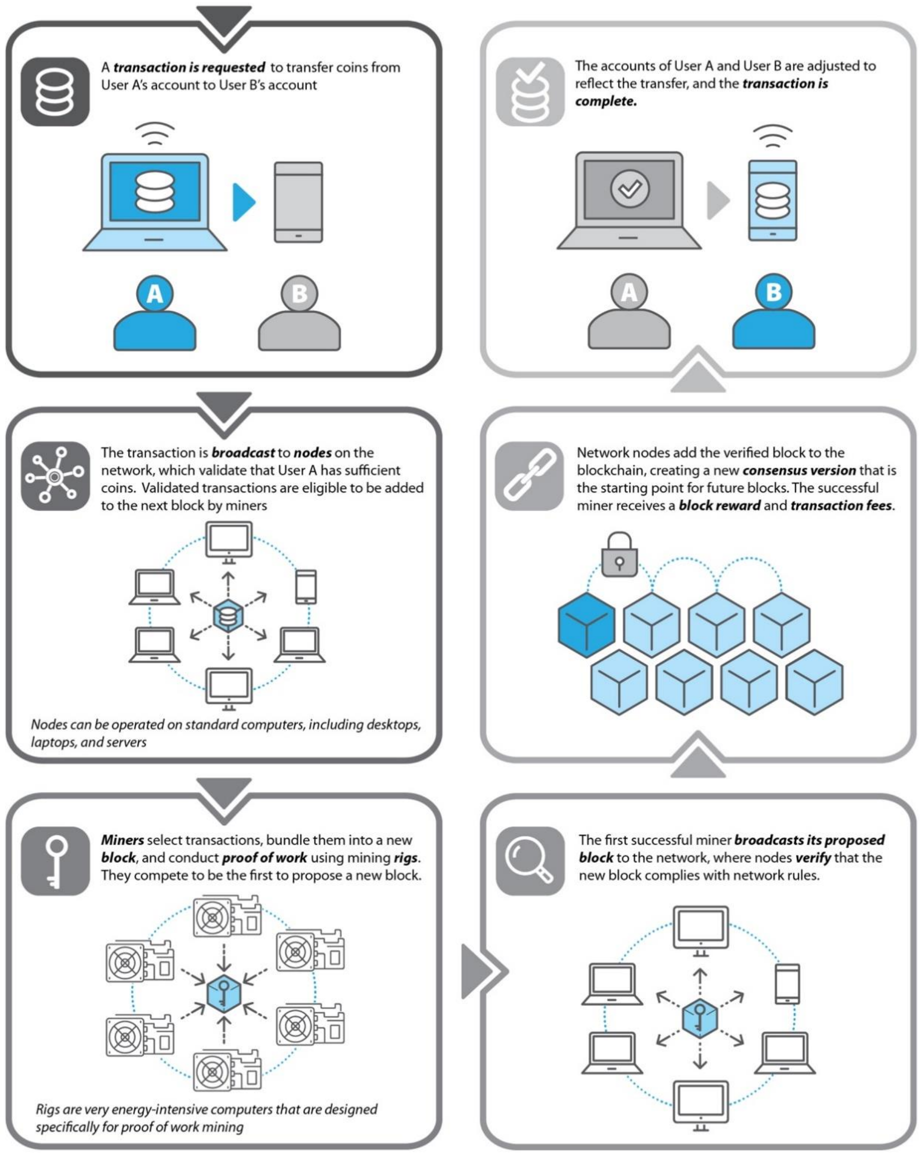


Figure 1.1: Understanding Proof of Work Blockchain in Crypto-Asset Mining. Adapted from Kilroy Blockchain.[33]

2. Crypto-Assets Affect Electricity Usage and the Grid

Digital assets, including crypto-assets, require electricity for generation, ownership, and exchange. Crypto-asset networks use electricity to power four major functions: data storage, computing, cooling, and data communications. Of these, computing uses the vast majority of electricity within crypto-asset networks.[34] Therefore, most studies have focused on estimating the electricity usage of computing devices, including the additional electricity required for cooling.[35] Electricity for cooling can add anywhere from a low percentage (for cool climates) to over 100% of the electricity consumed by the computing equipment itself.[36,37,38]

Electricity Usage Varies for Different Types of Crypto-Assets

The scale and sources of electricity used by computing devices depend on the technology that a crypto-asset uses to ensure security and validity, or its consensus mechanism. For PoS blockchains, computing tasks can be performed by general-purpose computers or servers. The latter can be located in conventional data centers across a network.[39] In PoS blockchains, these computing devices are known as validator nodes (which participate in consensus protocols and produce new blocks) and full nodes (which verify transactions).[40] Due to their high server densities, conventional data centers require additional electricity for onsite cooling. Most data centers in the United States purchase their electricity from the local grid, though some large data center operators are investing in large-scale renewable energy projects to offset their local grid emissions.[41,42] The same is true of international data centers, so the emissions footprints of international PoS blockchain participants depend on local generation sources.

This citation is Gallersdorfer, Klaassen, and Stoll (they are cited many times). Their research isn't as questionable as De Vries, but it is highly conflicted, as they own a consultancy that sells 'sustainability data' on blockchains, such that PoS protocols can claim to be 'pro-ESG' with their academic support.

These three have written academic papers, but they are deeply conflicted. Anytime they appear in this report (which is many times), readers should be aware. Neutral academics they are not.

PoW blockchains also use general-purpose nodes to verify transactions, validate consensus protocols, and store consensus copies of the blockchain. However, computing for popular crypto-assets that use PoW blockchains is also performed by specialized semiconductors, based on application-specific integrated circuits (ASICs) contained in "mining rigs" that perform PoW computations.[43,44,45] These mining rigs are often located in "mining" facilities that generally purchase grid electricity and can represent large local electricity loads.[46] These facilities often purchase electricity at lower industrial rates than what residential customers pay, and they sometimes receive special economic incentives, such as energy purchase tax waivers.[47,48,49]

You can't generalize here. There are plenty of behind the meter miners that are operating largely off grid. Greenidge, stronghold are just a couple examples. It's not correct to assume that miners are consuming generic grid power- they certainly arent, not the generic US grid.

Alternatively, PoW mining operations can build facilities to generate some or all of their own electricity. A mining operation might construct a dedicated solar energy farm with or without energy storage, or might install onsite generators using stranded natural gas.[50] Mining operations can also contract with individual power facilities to connect mining equipment directly to fossil-fired power plants, solar farms, wind farms, hydropower, and other electricity sources.

Table A.3 in the Appendix summarizes estimates of the numbers of computing devices and their typical power needs, for select PoS and PoW blockchain networks in 2021.[51,52] These estimates indicate that each PoS computing device required 10 to 500 times less power than a typical ASIC Bitcoin rig for PoW mining.

★ ★ ★ ★ ★ ★

Electricity Usage from Crypto-Asset Activity

While thousands of crypto-assets have been issued globally, published studies have focused on relatively few high market value crypto-assets. The majority of published estimates for crypto-asset electricity usage have focused on Bitcoin, which is estimated to consume the most electricity of any crypto-asset, due to its high market value, popularity among investors and miners, and energy-intensive PoW consensus mechanism. Researchers have also estimated electricity usage for other high market value PoW and PoS crypto-assets, as shown in Appendix Table A.1.

The total power usage of today's crypto-asset networks cannot be directly monitored, because many computing or mining centers do not disclose their location and do not report their electricity usage. Electricity usage can, however, be estimated analytically. Like all uses of electricity, crypto-asset electricity usage is measured in kilowatt-hours (kWh): the use of one kilowatt (kW) of power for one hour. The average U.S. home uses 10,715 kWh per year, or about 900 kWh per month.[53] For reference, all U.S. residential lighting consumes about 59 billion kWh annually, and total annual U.S. electricity consumption in 2021 was 3,930 billion kWh.[54,55]

This is definitely not true. Data centers are ramping up like crazy, especially with AI/ML (actually many former ETH miners have switched to this). A 2022 figure for data centers would be way higher.

Total global estimated electricity usage for blockchains that support crypto-assets in 2022 falls into a range of 120 to 240 billion kWh per year.[56] This is equivalent to 0.4% to 0.9% of annual global electricity usage.[57,58] This range is comparable with the annual electricity usage of all conventional (i.e., non crypto-asset) data centers in the world, which consumed between 200 to 250 billion kWh in 2020.[59] However, the electricity usage of crypto-assets can change quickly as miners ramp their activities up or down in response to market value fluctuations, and as they adopt new equipment. As a result, so far in 2022, the estimated range of global crypto-asset electricity usage has fallen as low as 105 to 178, and risen as high as 176 to 305 billion kWh per year, as shown in Appendix Table A.1.[60,61,62,63,64,65,66,67,68]

Two of these citations are de vries / digiconomist and should be automatically disregarded. The numbers may be directionally correct, but he generally overstates given his anti-crypto agenda. If Biden admin wants to be taken seriously on this they should construct their own estimates instead of relying on opposition research published by hobbyists

This is also a Gallersdorfer Klaassen and Stoll citation. see my earlier note on their COI. They sell a product which is focused on pointing out the harms from PoW and the benefit of PoS. They are not impartial.

As of August 2022, two PoW blockchains account for the vast majority of electricity usage: Bitcoin is estimated to account for 60% to 77% and Ethereum is estimated to account for 20% to 39% of the total global crypto-asset electricity usage.[69,70,71,72,73] Annual global electricity usage from the Bitcoin blockchain is estimated to be 90 to 145 billion kWh, with a theoretical range from 40 to 180 billion kWh. Ethereum blockchain electricity usage is estimated to be 23 to 94 billion kWh, with a lower bound of 16 billion kWh. The global electricity usage for analyzed PoS crypto-assets has been estimated as less than 0.28 billion kWh per year, which is less than 0.001% of global electricity usage, and about 0.25% of the lower bound of total global PoW electricity usage. Given the electricity usage estimates, most discussions about crypto-asset electricity usage have focused on PoW applications, particularly Bitcoin.[74,75] There have been growing calls for PoW blockchains to adopt less energy-intensive consensus mechanisms. The most prominent reaction has been Ethereum's promised launch of the "Ethereum 2.0" PoS blockchain.

The United States currently hosts the world's largest Bitcoin mining industry, accounting for around 38% of the global Bitcoin network hashrate, as of August 2022.[76] A hashrate is the total computational power used each second to mine and process PoW blockchains. As the number of miners on a PoW blockchain increases, it becomes more challenging to solve the cryptographic it absolutely is not. It depends on the efficiency of the rig. Newer more expensive rigs are more efficient. Older rigs are less efficient. the Venezuelan Bitcoin ASIC fleet is older and less efficient than the ASICs used by US pubcos. So you absolutely CANNOT assume a homogenous hashrate/electricity ratio. You need to incorporate estimates of what actual ASICs miners are using.

math problem, ultimately increasing the hashrate. Assuming Bitcoin electricity usage is proportional to hashrate,[77] the United States' share of global estimated Bitcoin electricity usage, as of August 15, 2022, would fall into a range of 33 to 55 billion kWh per year, or 0.9% to 1.4% of total U.S. electricity usage in 2021.[78] When the U.S. share of global Ethereum mining is also considered, U.S. PoW mining electricity usage rises to 36 to 66 billion kWh per year, or 0.9% to 1.7% of total annual U.S. electricity usage (see Table A.1). This makes U.S. PoW mining electricity usage comparable with the electricity usage of all U.S. conventional (i.e., non-crypto-asset) data centers, which was most recently estimated at 72 billion kWh per year.[79] Figure 2.1 demonstrates that crypto-asset electricity usage is also similar to electricity consumption for some countries, states, or critical energy services.

The Biden admin is being lazy here and relying on

a) lazy assumptions
b) estimates from hobbyists and non-academics

They really just need to do their own work if they want to get good data.

The US fleet is more efficient than the generic worldwide ASIC fleet, and so the electricity use estimate here is likely an overestimate.

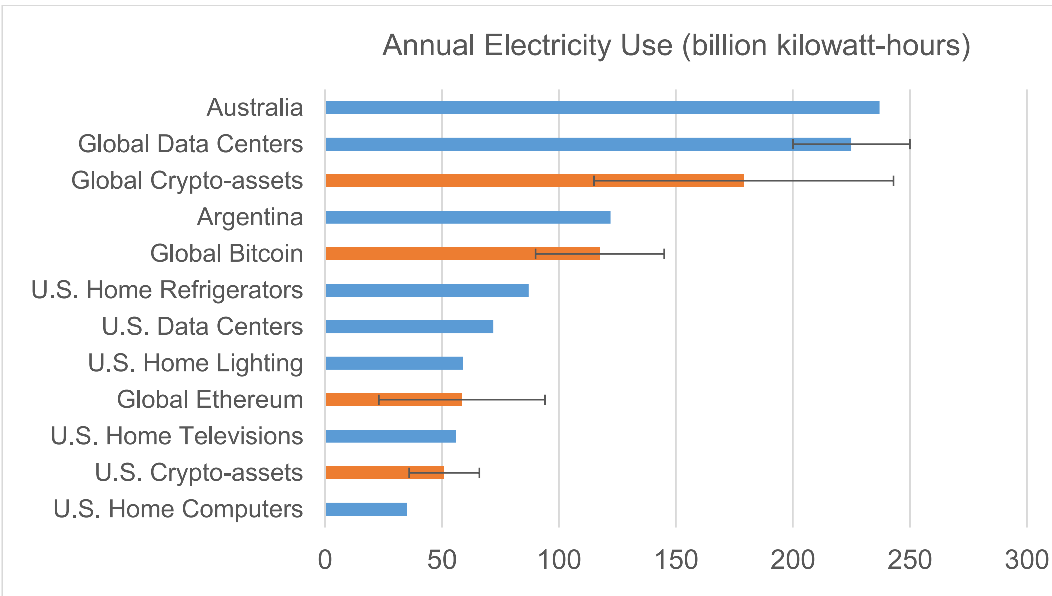


Figure 2.1: Comparison of Annual Electricity Use of Several Examples and the Best Estimates for Crypto-assets, as of August 2022, with error bars representing the best range of values.[80,81]

Yes, which is why lazily relying on work from unreliable sources like De Vries is worse than doing nothing at all. The biden admin should not be defaulting to bad estimates based on partial data. They should actually investigate the matter for themselves.

Given the differences in methodologies and the dates to which existing electricity usage estimates apply, electricity estimates must be interpreted with caution. The Bitcoin blockchain's estimated electricity usage rose steadily as Bitcoin's market value and network hashrates increased — conditions that may occur for other PoW blockchains that support crypto-assets. Additionally, the differences between upper and lower bound estimates have increased over time, reflecting uncertainties about the types of mining rigs that may be profitably deployed when crypto-assets experience higher market values. While large ranges can give policymakers indications of how large PoW electricity usage could be, they also suggest a need for miners to report their actual electricity usage to reduce uncertainties. Also, for time series studies, there can be variation in the estimated day-to-day power usage,[82] due to crypto-asset market value fluctuations. Market dynamics can quickly render any published estimate out-of-date.

We actually know now what kinds of rigs are being used at a given time. Spoiler: the average US miner is more efficient than a lot of these estimates suggest (especially de vries, who typically assumes very inefficient hardware so he gets the highest energy numbers for BTC), leading to a lower implied electricity usage rate.

Comparison with Other Financial Transactions

Crypto-assets can be used for investment or speculative purposes, as a means of payment, or as a store of wealth. While a credit card transaction only accounts for a single payment between parties, multiple Bitcoin transactions can be bundled together into one "on-chain" transaction, which can combine different types of financial activities into a single posted blockchain transaction. For example, when someone buys or sells bitcoin, or buys a coffee with bitcoin, these are each recorded as a transfer of bitcoins from one address to another, and a record of that transfer is added to the next block along with other transactions. A block on the Bitcoin blockchain typically contains 1,000-2,000 transactions, with the amount of transactions per block changing daily.[83] The average time to solve the PoW math problem and record a Bitcoin block to the ledger is about 10 minutes, so 52,560 blocks are added to the Bitcoin blockchain per year. Bitcoin's current global electricity consumption is 90 to 140 billion kWh per year. This requires about 1.7 to 2.7 million kWh per block, which can be further divided to estimate kWh per on-chain transaction. This is only an approximate estimate. With Bitcoin, as with other crypto-asset transactions, centralized crypto-asset trading platforms typically use off-chain transactions, and use on-chain transactions for certain activity, for instance, when sending crypto-assets to a participant outside of the platform. The result is crypto-asset platforms only send a portion of transactions to a blockchain, and electricity usage from off-chain activity is unlikely to be captured in estimates. Factors such as these provide challenges in estimating actual total per-transaction electricity usage compared to other financial services.

Nope. There's no such thing as a per-transaction energy cost. I have covered this so many times.

The energy is overwhelmingly associated with the issuance, not the transactions.

I'm amazed they actually admitted this. We've come a long way. Normally, PoW critics just naively compare Visa credit messages and BTC settlements.

BTC is of course more akin to Fedwire (avg txn size > $1m, fewer txn counts than Bitcoin per year).

This is one thing the Biden admin actually gets right. Good job.

The total number of on-chain crypto-asset transactions is currently small compared to those of traditional financial services. In 2020, Bitcoin and Ethereum together accounted for roughly 460 million reported on-chain transactions.[84,85] That same year, Visa, MasterCard, and American Express collectively processed an estimated 310 billion credit card payment transactions.[86] DLT, including Bitcoin's and Ethereum's blockchains, constitutes complete payment systems and allows for real-time gross settlement between parties. Credit card merchants, in comparison, need formal banking relationships to settle transactions, because a transaction only authorizes payment, and does not settle payments. For this reason, there is a fundamental difference between a digital asset transaction and a credit card transaction.

Ok i guess I take back my praise from my prior comment. This comparison of course is asinine.

1. it's an apples to koalas comparison. you cant compare settlement with payment messages on a layer far up the stack.

2. The energy isn't being used to process transactions. it is associated with issuance

3. The dollar requires military might to be enforced.. should we compare Bitcoin and USD in terms of the "dead Houthis killed by Raytheon missiles per transaction" ratio?

Noting direct comparisons are complicated, Visa, MasterCard, and American Express combined reported around 0.5 billion kWh of electricity usage in 2020,[87] inclusive of all operations, in addition to electronic payments.[88,89,90] In other words, these three entities consumed less than 1% of the electricity that Bitcoin and Ethereum used that same year,[91] despite processing many times the number of on-chain transactions and supporting their broader corporate operations. Responsible development of digital assets includes ensuring operations with dramatically lower energy intensity, as digital assets are adopted.

Crypto-Asset Mining Can Affect Electricity Consumers and the Grid

The electricity system is critical infrastructure for human health, the economy, and U.S. national security. It is also the backbone of a future U.S. clean energy economy, as electrification will increasingly displace fossil-fueled vehicles, buildings, and some industrial processes. The United

Ok… so you want electrification of everything to get to Net Zero .. youre going to have to triple electricity generation at least … and you're worried about ~1% of US consumption in 2022? Doesn't sound like youre too confident in your 'electrify everything' agenda.

Just to reinforce the issue here… Bitcoin is a buyer of ~5GW domestically. We need to add 100 GW every year according to this.

So the Biden admin thinks:
- having a flexible, location agnostic buyer of energy is bad in that context (??)
- a grid that's adding 100 GW a year can't handle 5-10 GW from BTC miners?

This is another curious thing. We need massive investment… funded by, presumably, consumers of energy. Bitcoin is a massive buyer of energy, and happily buys renewable energy that one one else is willing to pay for. And yet Bitcoin is a bad thing here?

Worth noting that the vast majority of new interconnections in the US are wind and solar. So a big buyer of future energy is a buyer of wind and solar. Again, this is considered a bad thing, for some reason.

States will need to accelerate the electrification of end uses in order to meet its climate objectives. The 2020s are a decisive decade for climate action in the United States, and up to 100 GW of clean electricity capacity needs to be added to the grid every year to meet the demand of these newly electrified end uses.[92] At the same time, electricity infrastructure is under stress from today's demands and climate-driven weather extremes,[93] and requires massive reinvestment. Twice as many power outages have occurred in the last six years in comparison to the previous six years, and reliability will have to increase in order to accommodate new electricity demands.[94] Electricity infrastructure that was designed for the climate of the 20th century now has to withstand hotter temperatures, more intense storms, and other extreme conditions exacerbated by climate change, which strain the grid and can reduce the amount of electricity provided when consumers need it most.[95] The United States requires a reliable, affordable, clean, equitable, and climate-ready electricity system. New demands on the system must help, not hinder, our nation's climate objectives.

We'll get to demand response later, but in case you were wondering, Bitcoin miners are perfectly able to curtai their operations in times of grid scarcity, and they already do this. It's trivial to arrange programs such that they are not online at peak times. Very few other industries are like this. BTC mining is incredibly benevolent to the grid, all things considered.

In most electricity grids, renewables with low fuel costs and nuclear plants are dispatched first to meet electrical loads. Flexible resources with higher fuel costs, such as natural gas or coal power plants, are then dispatched to follow load fluctuations through the day. As electricity demand increases from crypto-asset mining, more natural gas and coal power plants are dispatched by electricity system operators. These power plants generally cost more and pollute more than the average grid electricity, with the difference between average emissions and marginal emissions widening.[96]

Miners use energy when it's economical, but can also be economically incentivized to turn off during scarcity events through formal programs or by engaging in arbitrage themselves. They generally do not operate through peak demand periods. They are incredibly flexible - much more so than virtually any other industrial or residential load type. This is a massive point in bitcoin's favor.

I'm giving this Pinnochios because bitcoin miners are the most flexible, curtailable, and accomodating industry in existence - and the Biden admin knows this (as they acknowledge later in the report)

Crypto-asset mining operations typically have high load factors: they use power nearly constantly. When these facilities continue to operate through peak demand periods, they stress the power infrastructure, which can affect equipment life, cause blackouts for other customers, and create fire hazards.[97] The Public Utility District of Grant County, Washington adopted a rate class for crypto-asset miners to recover incremental costs associated with meeting electricity demand from mining.[98] The Public Utility District of Benton County, Washington also adopted a policy for crypto-asset customers, citing concerns about the distribution system safety and reliability.[99]

This paper is extremely questionable. It's certainly not sufficiently clear such that you could use language this stark.

The increased electricity demand from crypto-asset mining can also push up power prices for local consumers. Crypto-asset mining in upstate New York increased annual household electric bills by $82 and annual small business electric bills by $164, with net total losses from local consumers and businesses estimated to be $179 million from 2016-2018.[100] In 2018, The New York Municipal Power Authority created a new tariff in 2018 for high-volume data processing for crypto-assets to raise the cost of mining.[101] Plattsburgh, NY enacted an 18-month long moratorium on mining operations after community members and businesses complained of high energy bills and noise. Mining could also result in cost-shifting to local electricity customers, who will bear the risk if mining operations move to different places when conditions change. This could leave local customers to pay for unpaid infrastructure upgrades for mining operations.

Moreover, it's worth noting that there's at least 10GW of power in West Texas that is regularly curtailed - no transmission and no local load. prices are routinely negative. TX is also adding TONS of wind and solar (partly due to federal subsidies) so the energy glut in specific regions will only get worse.

Many crypto-asset miners have moved their operations to Texas. The Electricity Reliability Council of Texas (ERCOT) is the grid system operator for the majority of Texas, and has a peak summer electricity demand of about 76 gigawatts (GW), and current crypto-asset mining activity of about 2 GW. ERCOT has about 17 GW of crypto-asset facilities that are in the process of connecting to the grid, with an expected 5 to 6 GW of new demand in the next 12 to 15 months

Absolutely, patently, categorically false. They had 17GW of registered expressions of interest (during the bull market of 2021) when miners were super optimistic.

No number even remotely close to this will emerge (they put a moratorium anyway). There's ~1GW in TX right now. This is insane fearmongering. Total falsehood.

TX is a perfect example of how adding demand can be completely benign (either price wise on consumers, or emissions wise). What it actually does is make otherwsie uneconomical renewables economical - until such point that they can be connected to load centers via transmission (which takes a long time to build)

Here they kind of suggest (as many do) that it's some how 'unfair' or unjust that miners make money during scarcity events. But these programs exist to stabilize grids (which increasingly need it due to intermittent renewables).

Miners sell grid operators the right to shut them down when they need them to. They are going long volatility and the grid is short volatility. The grid wants to avoid a blackout so they will pay a premium for this. The miner is simply collecting that premium. Other industries do this (less well) like aluminum plants etc.

Miners getting paid is evidence that the system is working. Miners get paid because they are most capable of doing DR. Hospitals and commercial real estate and factories mostly can't do it, because they cant interrupt their usage the way miners can.

That's not how this works though. Let's say Bitcoin was able to subsidize the tens of billions of dollars of investment from miners into new installations. It would not just passively be imposed on the grid. It would necessarily be inducing the construction of new energy resources.

Totally fantastical numbers.

(equivalent to the power demand of the city of Houston). ERCOT may also see an additional 25 GW over the next decade.[102] While many of these projects may not be completed, the prospect of up to 25 GW of new electricity demand from crypto-asset mining — equivalent to a third of existing peak electricity demand in Texas — raises potential challenges for maintaining electricity reliability, especially with rising power demands and extreme temperatures over recent years.

Finally they acknowledge it.

You can't just assume massive, eye popping consumption from Bitcoin miners without realizing that in that case, Bitcoin would be inducing the creation of those energy resources.

Crypto-asset mining operations can quickly decrease the amount of electricity used by scaling back or switching off mining rigs. Bitcoin miners can participate in utility and grid operator programs that pay major electricity users to decrease consumptions during times of peak grid stress, or to balance supply and demand — a process called demand response. On July 11, 2022, high temperatures and high projected electricity demand caused ERCOT to declare a grid emergency event, and bitcoin miners using 1 GW of power reportedly responded to ERCOT's demand response request and reduced mining power usage.[103] In all of July 2022, a single publicly traded Bitcoin miner who operates a facility in Texas earned $9.5 million from the demand response program from the Texas grid, which was more than the value of the 318 bitcoins the facility produced in the same month.[104] Flexible electricity demand, rapid demand response, and the provision of electricity ancillary services are essential attributes of a decarbonized electricity grid comprised of variable renewable electricity such as wind and solar. Crypto-asset mining's flexibility to ramp up and down could contribute to these needed rapid response services. Increased electricity demands from crypto-asset mining also increase the overall peak level of grid demand. While reducing this peak during a grid emergency is valuable, the increased peak is often why demand response is necessary, establishing misaligned incentives between crypto-asset miners and grid operators. Full transparency of demand response participation and payments by crypto-asset miners and other demand response participants are essential. Transparency reduces the incentive for rent-seeking and gaming, protects local electricity consumers, and can improve electricity reliability.[105]

Nice of them to admit it. It's practically a mathematical identity that decarbonizing via wind/solar REQUIRES lots and lots more DR. Miners are uniquely flexible and can satisfy many more of these programs than regular interruptible loads.

Incredibly weird statement. Miners are not pushing grids over the edge. On net, they encourage more investment (so higher supply overall) and they can chop off the peaks. More mining = more grid flexibility.

This would be welcome. Miners are already pretty public about their DR activities.

Internationally, legislation and regulation have addressed environmental concerns about crypto-asset activity. The European Commission's pending Markets in Crypto-Assets legislation will likely require increased environmental and climate impact information and, within two years, the introduction of mandatory minimum sustainability standards for consensus mechanisms.[106] In China, the incompatibility of large-scale Bitcoin mining with the country's environmental goals has been cited as one several reasons that the government banned crypto-asset transactions in 2021.[107]

WTF

Yes, Biden administration, the notably pro-climate China (which is currently building more coal plants than the entire rest of the world combined) banned Bitcoin because of its climate goals. China definitely didn't ban Bitcoin because it's an oppressive authoritarian state which hates freedom and exercises financial control over its citizens.

Delusional.

Future Crypto-Asset Electricity Usage Projections Are Uncertain

Energy usage projections are estimated by energy systems models that capture the relationships between demands for services, technological efficiencies, energy supply options and prices, and changes in macroeconomic factors such as population size and economic productivity over time.[108] However, existing energy systems models do not adequately represent digital technologies such as data centers and telecommunications networks, let alone crypto-asset and blockchain networks. This is a well-known modeling gap that inhibits robust energy projections for digital systems.[109] Future projections determined by other estimation methods require

It's really not that difficult

forecasting network hashrates and profitable mining rig efficiencies, which are closely interrelated and further influenced by a crypto-asset's market value and prevailing electricity prices.

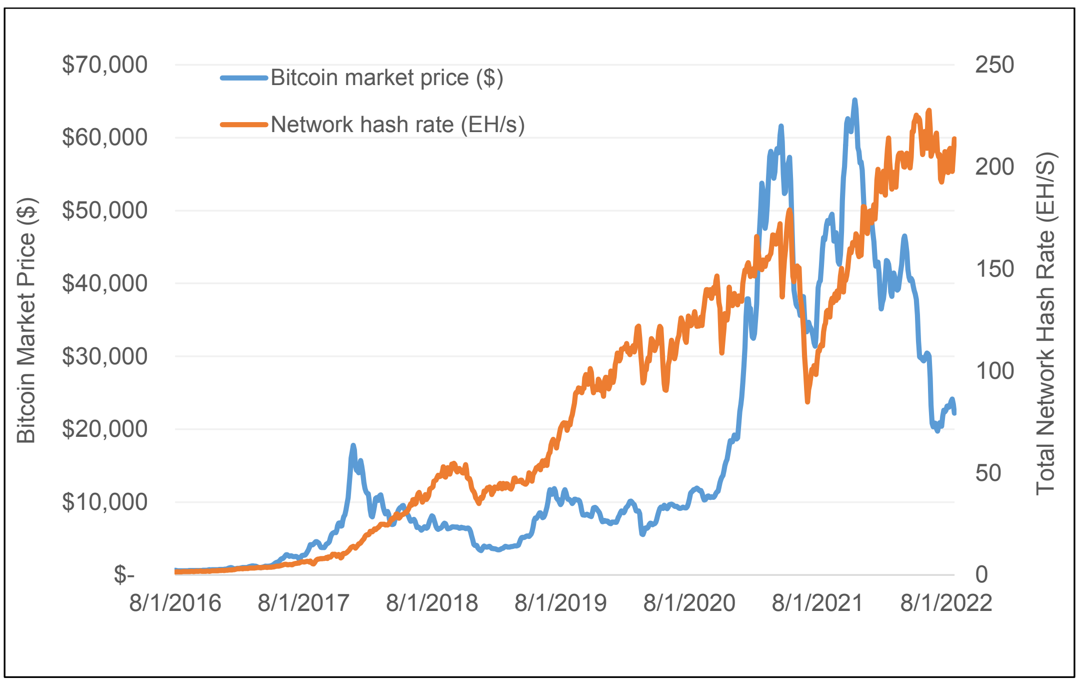
Thanks for acknowledging this, but it's really not that hard to do a simple back of the envelope estimate finding completely non-apocalyptic numbers for future BTC energy consumption

It's a good idea to ignore the crazy estimates by the insane academics that have predicted doomsday numbers about btc energy consumption, but that doesn't mean decent models are impossible.

see NYDIG's Bitcoin Net Zero estimate. we use fair and reasonable arrays of assumptions to derive BTC energy consumption estimates and projections under a variety of scenarios.

new gen rigs are more efficient. stop confusing hashrate and energy consumption. you have to filter hashrate through a network efficiency lens. biden admin is fixated on hashrate. totally wrong.

There is also considerable uncertainty about the number of crypto-assets that will emerge, how popular they will become, and which consensus mechanisms they will adopt. All of these factors will affect electricity demand. The risks associated with growth of PoS or other less energy-intensive network are considerably lower than the risks associated with PoW network growth. Figure 2.2 plots historical trends in the market value and network hashrates of the Bitcoin network between August 1, 2016 to August 24, 2022.[110] While the network hashrate dropped in response to the Bitcoin market value slump between July and September 2021, a similar correlation between market value and network hashrate has not been observed in the current market value slump that began in late 2021. Thus, projections of future network hashrates on the basis of forecasted coin market values come with significant uncertainties. Extrapolating current conditions into the future should be avoided, as these uncertainties and key system variables can change. In the past, simple extrapolations have often yielded unrealistic energy demand predictions for complex and evolving information technology systems like those that comprise blockchains.[111]



Irrelevant chart.

ASIC efficiency increases over time, changing the price-hashrate relationship.

Figure 2.2: Historical trends in Bitcoin market value and network hashrate (Exahash/second)[112]

Between August 2016 and July 2022, the average estimated deployed rig energy intensity decreased by around 85% due to computational efficiency improvements.[113,114] Over the same

This is painful. All you've done is arrived back at the development of Bitcoin price over the period ($200 to $20-50k)

Yes, the price went up a lot, and so did the energy consumption

Bitcoin price isn't going to increase 2000% every 6 years forever. The law of large numbers kicks in eventually. It's ultimately bounded by the amount of resources society will allocate to a hard money

This is similar to gold, worth around $10T. It's

You don't need to know this at all. All you need to make an estimate of future BTC energy draw is

- future price estimate (or scenarios)
- share of miner revenue spent on electricity (historically 30-50%)
- fee intensity estimate (or scenarios)
- supply is known

it's really very simple. Stop pretending that it's impossibly difficult. Trivial to put actual numbers on this.

Biden admin is probably refusing to do this because the numbers such a model would spit out are not scary at all - especially if they believe they will "electrify everything" and triple or quadruple energy generation.

★ ★ ★ ★ ★ ★

time period, network hashrates increased by over 14000%, leading to a 2000% rise in estimated network electricity usage.[115] This increase illustrates how, historically, mining rig efficiency improvements have been negated by rising hashrates as mining competition has increased. However, the future relationship between network hashrates and deployed mining rig efficiencies is uncertain. This is due to unknowns regarding the remaining computational efficiency improvement potential for mining rigs and, for certain crypto-assets like Bitcoin, how mining incentives will be affected by future reductions to the rewards for mining, which may limit the growth of Bitcoin electricity usage. These uncertainties, and the ability for crypto-asset electricity usage to grow rapidly, demonstrate the need to obtain better data to understand and monitor electricity usage from crypto-assets.

It really is curious that the main asset they're talking about here is Bitcoin yet they havent mentioned the decaying issuance rate at all, which is tremendously important. That is a huge hurdle rate (50% every 4 years) which limits the ability of price increases to be fully expressed in energy consumption terms

3. Crypto-Assets Result in Greenhouse Gas Emissions and Other Environmental Impacts

Crypto-Asset Mining Using Grid Electricity Generates Greenhouse Gas Emissions — Unless Mining Uses Clean Energy

Crypto-asset mining produces GHG emissions and exacerbates climate change primarily by burning coal, natural gas, or other fossil fuels to generate electricity in 1) an onsite dedicated power plant, 2) purchasing electricity from the power grid, and/or 3) producing and disposing of computers and mining infrastructure, and production of power plant fuels and infrastructure. These three categories correspond to scopes 1, 2, and 3 of the Greenhouse Gas Protocol,[116] a voluntary industry standard.

Current estimates of carbon dioxide (CO_2) emissions from crypto-asset mining in 2022 are 110 to 170 (or 140 ± 30) million metric tons, globally, and about 25 to 50 million metric tons in the United States.[117,118,119] This represents 0.2% to 0.3% of global emissions and 0.4% to 0.8% of U.S. emissions, respectively. Assessing emissions from crypto-assets is complex; consequently, the estimates are uncertain.

Because the electricity consumption of crypto-asset mining can fluctuate rapidly, and country shares of mining fluctuate depending on prices and activity, the associated GHGs from this electricity usage also fluctuate. Using economic and location-based estimates of mining activity, and data on country-level GHG intensity of electricity, researchers have estimated ranges of GHG emissions associated with major crypto-assets.[120,121]

Global crypto-asset mining emissions, at a rate of 140 Mt CO_2/y, are greater than the emissions of many individual countries, and equivalent to the global emissions from all barges, tankers, and other ships on inland waterways.[122] Bitcoin alone generates approximately two-thirds of global crypto-asset GHG emissions.[123,124,125,126] Bitcoin emissions have increased rapidly from a range of 2 to 16 Mt CO_2/y in 2017[127,128,129] to 100 ± 20 Mt CO_2/y from May 30 to June 16, 2022,[130,131,132] an increase of approximately 10 times in five years.

Estimates of the global energy mix used for crypto-asset mining have varied, due to the changing locations of mining operations and annual water flow cycles that affect hydroelectric generation. From September 2019 to August 2021, an average of 30% of the electricity used by Bitcoin came from hydroelectric, solar, wind, and other renewable sources.[133] Hydropower in China provided a majority of renewable electricity for Bitcoin during this period. Following China's ban on crypto-asset mining in September 2021, the renewable energy used for Bitcoin has decreased. Consequently, the estimated average carbon intensity of electricity used for Bitcoin mining increased from 480 to 570 grams of CO_2 per kilowatt-hour from 2018 to 2021.[134]

The GHG emissions intensity of electricity production has fallen by more than 33% in the United States since 2005, with average electricity GHG emissions at 373 g/kWh in 2020.[135] This

Coinshares for instance estimates Bitcoin emissions in 2021 at 41 Mt (Eth would be far lower). No way the combined figure is anywhere close to 170Mt.

The De Vries estimates are way, way high (especially as prices are coming way down and hence energy consumption).

But the White House doesnt give any space for alternative estimates. They just assert the De Vries fabrications as fact.

references are de vries / digiconomist.

Not a reliable estimate. At all. They should be totally disregarded.

'uncertain estimate' two paragraphs ago, now stated as a fact. Only problem: it's a partisan overestimate from a blogger employed by the Dutch Central Bank

De Vries again. These numbers are just not knowable. Massive over precision here. We have general ideas of where miners were located but not specific enough info to know their precise energy mix. We did know that Chinese hydro was very important though.

Completely bogus paper, relies on the assumption that Chinese hydro miners moved to coal-based mining in Kazakhstan, but Kazakhstan cracked down on miners and mining is trival there now. After china, many miners moved to the US, which is clean overall (US grid has a low carbon intensity and many miners are renewable in nature)

Unless we're talking about behind the meter (which is <5% of US mining), this isn't true. Miners purchase power from the grid. It's generation which produces GHG emissions. Not the consumption of power.

You can't mindlessly repeat De Vries' dross and then hedge by saying these estimates are uncertain. They're baseless is what they are.

Another Gallersdorfer Klaassen and Stoll (GKS) citation (working with, who else, De Vries). More questionable, conflicted junk "science"

Another conflicted GKS citation, as is 133 (below)

129 IS A f**** MORA ET AL REFERENCE. MORA ET AL. THIS IS NOT A DRILL

This entire section, which is incredibly important, just relies on a single blogger (De Vries) writing mainly non peer reviewed work on behalf of the Dutch Central Bank, who demonstrates a noted antipathy towards bitcoin.

it's really ludicrous that the US government is relying on his largely meritless body of work.

It bears repeating that the 129 citation above is a reference to the worst academic paper of all time, Mora et al 2018.

emissions rate is lower than the emissions rate of natural gas power plants (412 g/kWh) and about 63% lower than U.S. coal plants (1011 g/kWh).[136] About 61% of U.S. electricity generation in 2021 was from fossil fuels (38% natural gas, 22% coal, 1.3% other). The remaining 39% of U.S. electricity is generated by nuclear (18.9%) and renewables (9.2% wind, 6.3% hydropower, 2.8% solar, 1.3% biomass, and 0.4% geothermal).[137] Demand for electricity in the United States is met by power plants, energy storage assets, and grid management tools increasing or decreasing the amount of available electricity, as customer demand changes.

Regional electricity system operators, which are often spread over multiple states, generally balance electricity supply and demand, and trade electricity with neighboring grid operators.[138,139] An authoritative and accessible source of regional electricity emissions information is the Emissions & Generation Resource Integrated Database (eGRID), produced by the EPA.[140] The GHG emissions from electricity generation vary by region. The carbon intensity of the central Great Plains is about 700 g/kWh due to relatively more coal power, producing nearly three times the CO_2-equivalent emissions per non-baseload kWh of electricity of California (234 g/kWh). These are all average emissions rates, and new electricity demand from crypto-assets affects the sources used for electricity in both the near-term, generally requiring the use of non-baseload emissions factors, and in the long-term, as the grid composition changes.

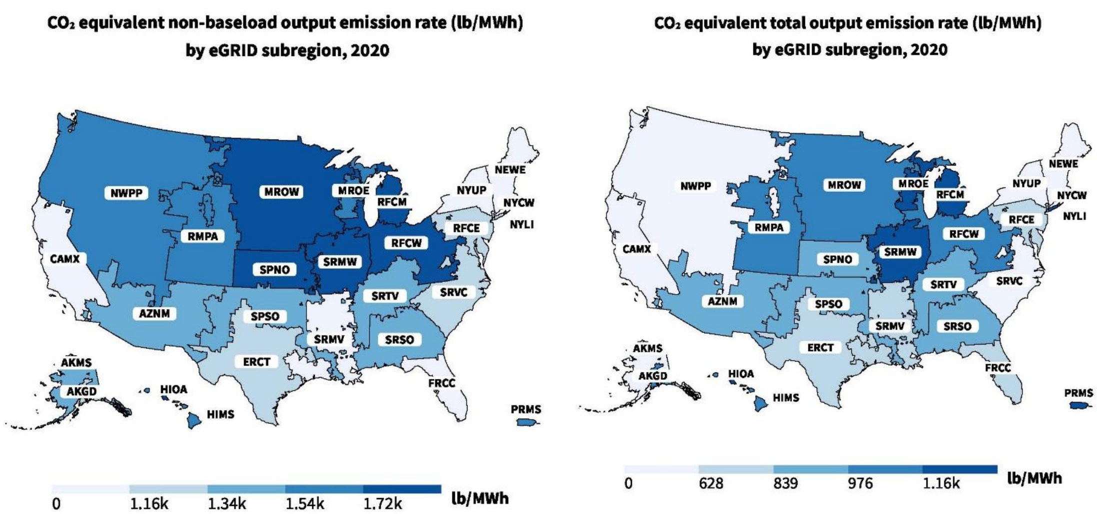


Figure 3.1. U.S. GHG intensity of electricity varies by region, for both non-baseload (left) and average electricity (right).[141]

Another conflicted Gallersdorfer, Klaassen, Stoll, and De Vries citation

According to a published study, in 2021, U.S. electricity generation for mining crypto-assets with the largest market capitalizations (Bitcoin, Ethereum, and Dogecoin) generated GHGs at a rate of approximately 15 Mt CO_2/year.[142] One year of U.S. crypto-asset GHG emissions at this rate is equivalent to the annual emissions from more than 3 million gasoline-powered cars for a year of average U.S. travel.[143] Since then, crypto-asset mining activity has increased in the United States, which now hosts more than a third of global Bitcoin activity.

U.S. electricity consumption to mine Bitcoin has increased from 8 to 11 billion kWh in early 2021, to 33 to 55 billion kWh in mid-2022.[144] Using EPA eGRID U.S. non-baseload GHG emissions, 33 to 55 billion kilowatt-hours for U.S. Bitcoin mining alone would generate about 21 to 35 Mt CO_2/y. To provide context for how regional U.S. electricity mixes affect GHG emissions, if all U.S. crypto-asset mining for the two largest crypto-assets (Bitcoin and Ethereum) occurred at 2022 rates in a single U.S. eGRID sub-region, an average of 42 billion kWh/y of electricity would generate GHG emissions ranging from a low of 17 Mt CO_2/y in upstate New York to 38 Mt CO_2/y in the central Great Plains. When the U.S. share of total global crypto-asset activity is considered, emissions estimates range from 25 to 50 Mt CO_2/y. Using average emissions rates instead of non-baseload rates, emissions would be lower by about half. As the grid decarbonizes, average emissions intensity of electricity will continue to decline. The uncertainty in the estimates of GHG emissions from crypto-assets, and the potential for future growth, are reasons for better, timely data from stakeholders on electricity usage and emissions.

In Montana,[145,146] New York,[147] Pennsylvania,[148] Indiana,[149,150,151] and elsewhere, media has reported cases where crypto-asset companies have reversed closure plans for fossil-fueled power plants, or have restarted previously closed electric plants.[152,153] Restarting coal and other fossil fuel plants erodes some of the progress that the United States has made in reducing GHG emissions.[154,155]

In addition to the emissions from electricity generation, the scope 3 emissions of crypto-asset operations include GHGs emitted in production, transportation, maintenance, and disposal over the life cycle of computers, buildings, motor vehicles, and other equipment. Mining minerals and producing steel and other materials for computing equipment also emit GHGs, but the majority of emissions associated with crypto-assets come from electricity generation to run crypto-asset mines, totaling about 79% to 99% of life cycle emissions.[156,157]

Crypto-Asset Mining Can Be Powered by Stranded Methane and Renewables

The crypto-asset industry can potentially use stranded methane gas, which is the principal component of natural gas, to generate electricity for mining. Methane gas is produced during natural gas drilling and transmission, and by oil wells, landfills, sewage treatment, and agricultural processes. Methane is a potent GHG that can result in 27 to 30 times the global warming potential of CO_2 over a 100-year time frame, and is about 80 times as powerful as CO_2 over a 20-year timeframe.[158] Reducing methane emissions can slow near-term climate warming, which is why the Biden-Harris Administration released the U.S. methane emissions reduction action plan in 2021.[159]

Venting and flaring methane at oil and natural gas wells wastes 4% of global methane production.[160] In 2021, venting and flaring methane emitted the equivalent of 400 million metric tons of CO_2,[161] representing about 0.7% of global GHG emissions.[162] This methane is vented or flared, because of the high cost of constructing permanent pipelines or electricity transmission that could transport the methane or its potential electricity generation from remote oil and gas

The Pennsylvania plant they complain about is Stronghold, which is a plant burning waste coal refuse which is leeching into the ground, creating an ecological disaster. This is an explicit, EPA-sanctioned program to abate the coal. It's an unequivocal ecological good that they are able to abate the waste coal.

The literal article they cite here about Hardin in Montana shows that Marathon is planning to SHUTTER that plant.

The Greenidge plant they complain about in footnote 147 is a converted coal -> natural gas plant. Natural gas is why the US electricity grid has decarbonized in the last decade. Greenidge sends natgas based power (much lower Co2 intensity than coal) to the NY market. It is absolutely a positive for NY overall.

They don't really explain why this is emissions-negative. Combusting vented methane or inefficiently flared methane and converting it into CO2 (and heat) is emissions negative, because methane is a much more potent gas than CO2.

Most oil wells are a mix of gas and oil. You get unwanted waste gas, and you often have no other use for it, hence flaring. Putting this to work (and improving combustion efficiency) is a carbon-negative outcome. Very good overall.

But why would you assume average regional energy mixes? Bitcoin miners can consume energy that is stranded, off grid (flared gas), negatively priced (wind power in SPP eg), etc. Bitcoin is truly location agnostic, unlike any other industry. It's not beholden to the same constraints as other industries - it doesnt have to locate near to its clients or population centers.

Why not profile or talk to any of the numerous renewable focused miners? Eg: Bitfarms, Cleanspark, Iris energy, Aspen Creek, Terawulf, Crusoe and many more

they are all able to run their operations on low emissions energy. they aren't buying energy with regional average emissions profiles.

operations to end-users, or because of the high cost of installing equipment on older landfills. Crypto-asset companies are now exploring ways to use electricity generation from vented and flared methane at oil and gas wells and at landfills.

This is correct. Cleanly combusting waste methane (a byproduct of oil extraction which is often uneconomical to pipeline and bring to market) to CO2 is an unmitigated net climate good.

While the EPA and the Department of the Interior have proposed new rules to reduce methane for oil and natural gas operations, crypto-asset mining operations that capture vented methane to produce electricity can yield positive results for the climate, by converting the potent methane to CO_2 during combustion. Mining operations that replace existing methane flares would not likely affect CO_2 emissions, since this methane would otherwise be flared and converted to CO_2. Mining operations, though, could potentially be more reliable and more efficient at converting methane to CO_2. While such operations can reduce wasted methane, another option is low-cost recovery of methane using existing vapor capture technologies at oil and gas wells, which can reduce global methane emissions up to 50% by 2030.[163]

This is false. methane flares are low efficiency, especially in windy conditions. so much of that methane goes uncombusted. combusting that waste gas in a controlled reaction in a generator is high efficiency (complete combustion) and can scrub further particulates. mining instead of flaring is a net win from an emissions perspective.

Crazy statement. So Net Zero means basically no oil and gas, because insisting on no flaring prices out cheaper gas wells that are not connected to pipelines.

Flaring is a natural part of O&G and if Net Zero means no flaring, it basically means no/ very expensive O&G. More totally utopian thinking

Climate policy aligned with achieving net-zero emissions would have zero methane venting and zero methane flaring. A combination of regulation and technological innovation can help realize this vision. Crypto-asset mining that installs equipment to use vented methane to generate electricity for operations is more likely to help rather than hinder U.S. climate objectives. However, unless the CO_2 is captured and stored, using vented methane at oil and gas wells will still generate CO_2 emissions and contribute to climate change. Using vented or flared methane for crypto-asset mining must also be assessed against other uses for this methane, such as hydrogen production or transporting the methane via pipeline to end-users.

The reason it is used for btc mining and not other purposes is because there is no immediate economic use and it cannot be pipelined (in many of these wells gas pipelines dont exist). The report basically second guesses the market here.

Imagine insisting this of ANY other industry? The FAANG data centers get away with buying offsets/ RECs. Why is crypto held to the highest standard imaginable?

The report assumes that a) renewables are fully monetized b) generation is all that matters, not transmission c) energy is temporally and locationally fungible d) no renewable buildout is occuring e) no renewables are under-monetized f) loads offer no ancillary benefits like grid flexibility/ demand response. All of these assumptions are wrong.

There are two primary ways crypto-asset mining using grid electricity would result in zero direct GHG emissions: 1) constructing or contracting for new clean electricity sources to power mining, or 2) using existing renewable electricity that would otherwise be curtailed by the grid. When a crypto-asset mine purchases electricity from existing renewable sources, it displaces the GHG emissions in the near-term, shifting users of renewable sources to fossil fuel sources. This is because coal and natural gas often supply electricity generation for each additional unit of electricity demanded in the United States. As the amount of renewable sources is held constant, but electricity demand increases, additional fossil power will likely be dispatched.[164] This displacement results in no net change or in increases in total global emissions through a process called leakage.[165,166,167,168,169,170,171]

I'm sorry this is crazy. So bitcoin miners using renewables (and improving their monetization) is bad, because those users are forced to use thermal.

No mention of: inducing more renewable construction, improving revenue of existing renewables.

This is a ludicrous standard which no industry in the US is held to, aside from Bitcoin mining.

If a crypto-asset operation builds or contracts new zero-carbon energy capacity, and matches both the annual electricity usage and temporal profile to the new zero-carbon electricity generated, then the direct mining activity would be emissions-free, since the mine would use all of the new zero-carbon generation it provides. To help U.S. climate objectives, industries could volunteer or be required to build zero-carbon energy capacity that produces more electricity than the crypto-asset mine requires, selling excess clean energy back to the grid.

This is totally zero sum thinking, contradicting the earlier portions of the reports stressing the need for a massive renewable buildout.

The crazy thing is that many Bitcoin miners are actually meeting this insanely demanding standard. See Aspen Creek - focusing on buildouts of new wind/solar and grid additivity.

In some areas of the United States, there is not enough demand or transmission capacity to use peak levels of generated renewables, and wind or solar generators temporarily reduce or eliminate output in a process called curtailment. This is wasted renewable electricity, because if sufficient transmission capacity or demand existed during these times, then generators would produce and sell renewable electricity. In 2019, 2.6% of wind power in the United States was curtailed, with the highest amount occurring in the Great Plains states. In Texas, 5% of annual solar power was curtailed, and in California, 2.4% of solar was curtailed.[172] Using curtailed

Another crazy thing to read. There's two main things that are deeply wrong here.

1. The report ignores the fact that Bitcoin miners are paying for the buildout of a high-energy industrial infrastructure using stranded renewables that otherwise wouldn't exist. this could be repurposed for other location-agnostic industrial applications, like green hydrogen (a key part of the renewable transition). Lancium is one example of a datacenter company doing this.

2. As wind and solar get cheaper and further penetrate grids, the costs of generation will go to effectively 0 and the costs of transmission will start to dominate the end cost of electricity. There is already a woeful lack of transmission in this country. I can assure you, the bottleneck there isn't "bitcoin miners eliminating the economic signal to build transition". It's the capacity to build transmission. There is no lack of urgency in building transmission - it needs to be built ASAP if renewables (located typically quite far from population centers) are going to contribute meaningfully. Some bitcoiners monetizing these stranded renewables and helping these projects get built in the first places is massively _accretive_ to the goal of having lots of renewables on grid, not subtractive. This is one of the worst individual statements in the whole document imo. The incentive is there. There will be a screaming demand for transmission in the coming decades. No one will be able to miss it

electricity can provide additional revenue to renewables developers and incentivize the construction of additional renewable energy capacity. However, it can also reduce the financial incentives to construct transmission from these renewables to existing users, or reduce the incentives to store excess renewable electricity to use when demand is higher. In addition, crypto-asset miners would not be likely to operate only during periods of curtailment, requiring consumption of grid electricity at all other times.

Environmental Impacts Include Air and Water Pollution, Noise, and Electronic Waste

Crypto-asset mining largely uses electricity purchased from the grid. The electricity generated at power plants to power crypto-asset mining and for all uses of electricity can damage the environment and human health with air pollution from fossil fuel burning, water withdrawals and thermal water pollution from power plant cooling, other water pollution, solid waste from fossil fuel combustion, land degradation from exploration and mining, and life cycle impacts of fuel cycles and power plant construction.

Lol shut up guys

The White House is just blatantly lying now. Atlas (greenidge parent co) converted the plant to clean nat gas on their own dime.

Crypto-asset mining raises environmental justice concerns because it can create disproportionately adverse public health and environmental burdens for communities of color, Indigenous communities, and low-income communities.[173,174] For example, within the ancestral homeland of the Onondaga Nation in upstate New York, a Bitcoin mining operation re-started the previously-closed Greenidge coal-fired power plant. With the support of the Onondaga Nation, the New York State Department of Environmental Conservation denied Greenidge's application for a renewal of its Clean Air Act Title V operating permit on June 30, 2022, because it violated the state GHG emission reduction law.[175] Restarting previously closed coal-fired plants for new crypto-asset mines erodes some of the previous improvements in air quality. Because underserved communities are already burdened by pollution and underinvestment in infrastructure, the additional impacts of crypto-asset mining can create cumulative burdens.

Five Pinocchios easily - the Greenidge plant was converted to much cleaner natgas - and it provides that clean power to NY. Thanks, Bitcoin!

They're still talking about Greenidge even though they aren't citing it here. The water wrangle is preposterous, and it's more about NIMBYism rather than any ecological issue. Greenidge has always been 100% compliant with the local regulations around water temp.

Crypto-asset mining operations also affect the environment through local noise and water impacts of mining operations, and through air and other pollution from any direct use of fossil-fired electricity. Similar to data centers, the groups of computers at crypto-asset mining operations generate substantial heat. Many crypto-asset mining facilities must use air cooling or liquid cooling to keep computers within acceptable temperature ranges. In standard computer data centers, a single, typical 10 kW rack of servers will require around 63,000 gallons of potable water per year for air cooling[176] — an amount comparable to the average indoor water use of an individual U.S. household each year.[177] When liquid cooling is utilized — which involves immersing the computers in liquid baths or removing heat directly from their computing chips via closed liquid loops — facility water requirements can be substantially reduced.[178]

Fossil-fired electricity that directly powers mining operations also impacts local water. At thermal power plants with traditional once-through cooling systems, water is withdrawn from rivers or lakes, and both the withdrawal process and the warmed water released back into the environment (including chemicals used to clean the cooling system) can harm fish and wildlife, and can negatively impact recreation and water quality. Heated effluents lower the solubility of oxygen in the water, increasing the metabolic rate of aquatic organisms, which further reduces dissolved oxygen as respiration increases. Rising water temperatures can also contribute to overpopulation of the organisms that form algal blooms, leading to toxic conditions in local waterways. Other water pollution results from fossil-fired electricity generation as well as the production of coal and natural gas for power plants.

Lol are they pretending that they are only using "published scientific research" in this report now? See supplemental notes document listing all the completely non-academic references they are relying on in this report.

Air-cooled mining computers contain high-velocity fans that can generate noise pollution. While there is a lack of published scientific research on fan noise, numerous media reports describe the loud, irritating, and nearly continuous noise caused by fans at crypto-asset mining centers.[179,180,181,182] Noise pollution can induce physical and mental stress, hearing loss, sleep loss, and cardiovascular disorders.[183] Noise can also reduce property values.[184] In general, noise pollution from industry, road traffic, and airports is higher in communities of color and other underserved populations.[185]

Literally just another "datapoint" which rests entirely on …De Vries! Every single bitcoin miner will tell you they keep their ASICs for (far) longer than 1.3 years, and they don't throw them out when they are uneconomical (they are sold), and they can be recycled.

Finally, discarded computers, circuit boards, cables, and other electronic waste from crypto-asset mining contribute to electronic waste. Without standards and enforcement of proper disposal methods, electronic waste can cause air and water pollution, expose workers to toxic substances, and damage public health. Lead and mercury are the most common toxic elements in electronic waste.[186] Additionally, valuable elements, including cobalt, indium, and gold are discarded, impeding a valuable recycling and circular economy opportunity. In May 2021, Bitcoin mining activity produced electronic waste at an estimated rate of 31,000 tons per year,[187] increasing by June 2022 to 35,000 tons per year,[188] equivalent to the annual electronic waste generation of the Netherlands.[189] A phenomenon driving the disposal of ASICs, the dedicated computer units for PoW crypto-asset processing, is a pace of innovations that can double computer processing speeds every one and a half years.[190] Currently, ASICs cannot be used for any other purpose, so companies often discard, sell, or reduce the use of older generations of ASICs after approximately one year and four months.[191] This is shorter than standard data center servers, which last three to five years.[192]

ABSOLUTELY FALSE. ASICs do not get trashed after 1.3 years. This is a complete fabrication by De Vries. It just isn't true, and it's shameful

Most mining firms depreciate ASICs over 3 years. There's empirical evidence of large portions of BTC hashrate being from 5y+ old ASICs.

ASICs are highly recyclable and contain no toxic parts (mostly aluminum).

See supplemental notes on De Vries' lies about e-waste.

The e-waste lie is one of hte stupidest ones out there. It literally comes from De Vries wrongly applying Koomey's law (an incredibly general observation about computing generally, nothing to do with ASICs) to BTC miners. It relies on no industry data. It's just a completely idle supposition from De Vries. It's incredibly shameful they are citing it here.

Electronic waste can be reduced by using certified electronics recyclers.[193] Currently, two accredited certification standards exist: the Responsible Recycling Standard for Electronics Recyclers and the e-Stewards Standard for Responsible Recycling and Reuse of Electronic Equipment. Both certification programs advance best management practices and are based on strong environmental standards that maximize reuse and recycling, minimize hazards to human health and the environment, ensure safe management of materials by downstream handlers, and require destruction of all data on used electronics. Recycling electronic waste presents an opportunity for the recovery of critical minerals, in addition to reducing GHG emissions and limiting disposal. When reuse or recycling is not possible, responsible disposal of electronic waste includes accurately characterizing the waste and sending it to proper permitted disposal sites.

This might be the worst section, because it's 100% based on a single paper from De Vries and Stoll (see my comments on them in the supplemental notes). The paper has not been validated by any actual academic, because the methodology is absurd (it relies on the misapplication of a totally ill-fitting computational "law", Koomey's law (a general observation around computing efficiency growth), and it naively applies it to BTC miners. If anyone actually read the paper they would see how absurd it is.

The whole thing is premised on the idea that ASICs are thrown away by miners after they are no longer economical (false), that they depreciate in the comically short period of 1.3 years (false), that they contain similar toxic components to cell phones (false), that they can't be recycled (false).

The entire thing is a fabrication. It's completely absurd that the government is citing it. See my comments on e-waste in the supplemental notes.

4. Emerging Digital Asset Technologies Could Support Climate Monitoring or Mitigation

All the parts from here on down are irrelevant

Executive Order 14067 calls for a discussion of the potential uses of blockchain that could support technologies for monitoring or mitigating climate impacts. Responsible development of blockchain and DLT would encourage innovation in applications, while reducing energy intensity, minimizing total environmental damages, improving environmental justice, and helping the United States meet its climate commitments. This section introduces some potential applications in this area, as well as opportunities for further innovation.

Blockchains and Distributed Ledgers in Environmental Markets

Generally, environmental markets use market-based approaches to address negative externalities, which occur when consumption or production causes a harmful effect or cost to a third party. In the consumption or degradation of environmental and natural resources, negative externalities include water and air pollution, decreased biodiversity, climate change, ecosystem threats, and economic impacts. These negative impacts can be uncertain in their scope and timing, can play out over many years, and can be difficult to account for using traditional accounting measures.[194] A key priority of this Administration is to effectively address negative externalities of climate and other environmental pollution in communities that are already overburdened and underserved.[195]

Carbon markets aim to reduce GHG emissions by trading and using carbon allowances and/or carbon credits. A carbon allowance is a tradeable instrument that authorizes a source to emit a set amount of GHGs (e.g., one metric ton of CO_2) pursuant to a regulatory program. A carbon credit is a tradeable instrument representing one metric ton of GHGs reduced or removed from the atmosphere. Regulatory markets, also known as "compliance markets," have typically been "cap-and-trade" programs.[196] The creation of allowances, plus a cap that can be ratcheted down, provide a pathway for lowering emissions from regulated sources. Some compliance markets allow regulated entities to use carbon credits in limited quantities as a supplement to allowances, but markets for carbon credits can also occur outside of regulation. These are known as voluntary carbon markets (VCMs). In VCMs, the current primary driver of demand is the corporations that are seeking to meet voluntary climate neutral commitments or other corporate sustainability commitments.

As with other markets, environmental markets depend on robust market infrastructure to enable market participants to transact with confidence. A robust market infrastructure should include mechanisms for trade execution; payments, clearing, and settlement; record-keeping; and security. Carbon markets are designed to ensure that carbon allowances and credits can be trusted to deliver the promised emissions reductions and climate objectives.

Blockchain and DLT may have a role to play in enhancing market infrastructure for a range of markets, including environmental markets. The rationale for replacing existing market infrastructure technologies with DLT will depend on the context in specific markets, including switching costs. In environmental markets specifically, those who propose to adopt DLT should ensure that the environmental benefits are clear, relative to the environmental footprint of existing market infrastructure technologies. DLT adopters should also ensure that the environmental footprint of the DLT does not negate the benefit of the associated environmental market products.

To date, administrators of compliance markets have not adopted blockchain or DLT. A central authority regulates and controls the process of issuing and surrendering carbon allowances. Covered entities have regulatory requirements to ensure the integrity of emissions reporting, and to ensure that emissions reductions are achieved. DLTs are designed to solve issues of decentralization. Because compliance markets are centralized, there may not be clear advantages for DLT in compliance markets.

In VCMs, some uses of DLT are emerging, though it is not yet clear if they reflect an improvement over existing market infrastructure. Crucially, some stakeholders have raised concerns that existing carbon credits may not represent additional, permanent reductions in GHG emissions. Institutions and market actors should ensure that credit-generating projects result in emissions reductions or removal. A blockchain-based scheme could undermine efforts to improve credit quality, if, for instance, credits were tokenized and the underlying quality of credits became more difficult to discern. Moreover, there is a growing consensus that carbon credits are a "complementary tool" that should not delay or be a substitute for viable emissions reductions within a company's own activities. Thus, ensuring the integrity of VCMs requires understanding the circumstances under which carbon credits are retired by companies. To the extent blockchain-based trading hides the identity of the end-user of carbon credits, they would be antithetical to high-integrity VCMs and broader efforts to promote progress towards net-zero objectives. Finally, while blockchain is often promoted as enhancing trust, it is often the integrity of the underlying carbon reduction or removal project that is questioned, not the counterparty's likelihood of completing the trade. This issue of trust in VCMs is not the trust issue that blockchain or distributed ledgers solve.

Ultimately, blockchain and DLT may have potential applications for environmental markets, just like these technologies have in any other market, provided they abide by established market rules. The challenge these markets face is verifying that the standards ensure that the particular market advances the desired environmental objective. This equates to verification of physical activities and outcomes against those standards and, as appropriate, enforcement of standards. These elements of successful environmental markets extend beyond the functionality and purported trust-enhancing features provided by blockchain or any other database or cryptographic technology. Once again, the challenges relate to verification of the real asset, not to trading of the title to the asset.

For market and trading infrastructure, the potential use cases for blockchain in carbon markets track existing market functions, and their adoption will depend on whether blockchain can offer an improvement over existing technologies in cost, speed, and security, without causing additional environmental harms. Responsible introduction of DLT into carbon markets would also assess environmental justice to determine how conditions for affected communities are made worse or improved as a result.

You definitely dont need Blockchain to do DERs

They're just playing word association here, because DER has 'distributed' in the name.

Blockchain as Enabling Technology for Distributed Energy Resources

Emerging uses of blockchain technologies for energy management include enabling California's Flex Alert system. This system enables the electricity grid operator to push out requests for energy conservation during a grid emergency, securely interact with customers, and understand participation rates while maintaining customer anonymity.[197,198] Beyond information exchanges, smart grid technology[199] has the potential to harness the services of millions of distributed energy resources (DERs), such as electric vehicles, fuel cells, residential and commercial battery systems, and solar power systems, to enhance grid reliability. DLT could potentially serve as the digital ledger for the registration, authentication, and participation of these DERs in a smart grid, enabling flexible grid operations as more variable renewables are adopted. As with any new and still-maturing innovative technology, the ultimate utility of DLT in the electricity sector is unknown. Today, the electricity grid and markets are highly centralized systems, where a small number of providers sell electricity to a large number of consumers. This dynamic could change in the decade ahead, as more electricity consumers also become providers. DLT-supported innovation could help digitize, automate, and decentralize the operation of the electricity grid.[200] A key feature of mature DLT is the ability to automatically negotiate and execute an agreement, a process known as smart contracting.[201] The automated and distributed nature of DLT makes it a candidate for supporting the evolving clean electricity marketplace with increasing numbers of DER assets.

More than 100 million new storage devices will be connected to the grid by 2040. All of these devices could operate as both electricity consumers and providers, if they can be coordinated. Efficient and secure market participation of 100 million DERs will require digital control of the electricity grid and more autonomous and distributed control than is possible with today's technologies.[202] Every DER is a potential physical-cyber security risk that could maliciously damage the physical grid, hardware systems, software systems, and data. Any introduction of DLT into this system should require enhanced security.

Additionally, in a more diverse system of providers and consumers, DLT could increase reliability. DLT could enable verification by allowing the grid-operators and aggregators to audit, in real-time, the services provided by every DER within the pool through analysis of the tamper-resistant distributed ledger. This is important because grid-operators will require verification that aggregators are providing the contracted services. In addition, the aggregator and grid operator will require evidence that a DER is not "double spending" by selling the same service to two different buyers. Using zero-knowledge proofs that are commonly used in the crypto-asset community,[203] DLT could potentially provide these services, while also protecting the identity and privacy of the aggregator and DER owners, such as information related to the type of DER, capacity, location, ownership, and contract arrangements.

As DERs increase in abundance, they could also enable community-created microgrids where resources are shared peer-to-peer (P2P) within the community. DLT could be helpful in managing the P2P relationships on these microgrids. These microgrids are typically “virtual grids,” in which electricity is traded across the grid operator-owned network. In addition to satisfying customers’ preference to produce and consume within their community, localizing the generation and consumption of electricity could reduce grid congestion, which benefits users inside and outside of the community. P2P energy trading requires some of the same enabling technologies as crypto-assets, namely cryptography-based user authentication, a market-making mechanism and payment system via smart contracts, a tamper-resistant ledger of transactions, and complete auditability. P2P energy trading on networks could use low-energy consumption consensus mechanisms, such as PoS.

There is potential for blockchain and DLT to facilitate the development of environmental and energy markets, including carbon markets,[204,205] distributed energy resource coordination, and general supply chain management. Blockchain and DLT are enabling technologies that are being explored in various markets. However, other solutions might work as well or better. The U.S. government should seek to facilitate innovation that addresses market challenges, aligns with environmental and equity objectives, and appropriately ensures customer and investor protection and market integrity.

5. Appendices

Table A.1

Summary of the most recent published electricity usage estimates of selected PoW and PoS blockchains (2021-2022)[206]

Cambridge is the only reliable source in this table

Crypto-Asset	Market Valuation in August 2022 ($billion)	Consensus Mechanism	Date of Estimate(s)	Global Electricity Usage (TWh/y)			Source
				Best Estimate	Lower Value	Upper Value	
Bitcoin	$389	PoW	8/15/2022	88.6	38.2	179.3	https://ccaf.io/cbeci/index
			8/15/2022	144.9	62.6		https://digiconomist.net/bitcoin-energy-consumption
Ethereum	$185	PoW	8/15/2022	93.9	15.6		https://digiconomist.net/ethereum-energy-consumption
			8/15/2022	22.9	16.5	32.2	https://kylemcdonald.github.io/ethereum-emissions/
Cardano	$15	PoS	9/6/2021		1.4E-04	4.4E-03	https://arxiv.org/abs/2109.03667
			8/8/2021	6.0E-04			https://www.carbon-ratings.com/dl/pos-report-2022
Solana	$11	PoS	10/9/2021	2.0E-03			https://www.carbon-ratings.com/dl/pos-report-2022
Dogecoin	$8	PoW	8/15/2022	3.8			https://digiconomist.net/dogecoin-energy-consumption
Polkadot	$8	PoS	7/5/2021		1.4E-05	4.4E-04	https://arxiv.org/abs/2109.03667
			8/29/2021	7.0E-05			https://www.carbon-ratings.com/dl/pos-report-2022
Avalanche	$6	PoS	10/23/2021	4.9E-04			https://www.carbon-ratings.com/dl/pos-report-2022
Algorand	$2	PoS	8/12/2021		5.4E-05	1.7E-03	https://arxiv.org/abs/2109.03667
			8/17/2021	5.1E-04			https://www.carbon-ratings.com/dl/pos-report-2022
Tezos	$1	PoS	8/12/2021		1.9E-05	5.9E-04	https://arxiv.org/abs/2109.03667
			8/25/2021	1.1E-04			https://www.carbon-ratings.com/dl/pos-report-2022

De Vries. unreliable source

Lobbyists that are paid for by PoS blockchains to attack PoW. Non academic. See supplemental notes

De Vries. unreliable source

See above

Table A.2

Current performance characteristics of selected permissionless blockchain consensus algorithms[207]

	Proof of Work (PoS)	Proof of Stake (PoS)	Proof of Capacity (PoC)	Practical Byzantine Fault Tolerance (PBFT)
How it works	Miners compete using computational power to solve a complex cryptographic problem	Validating nodes offer crypto-assets as a stake to establish trust instead of computational power	Miners compete using available storage disk space instead of computational power	Majority of voting nodes defines consensus
Examples	Bitcoin, Ethereum, Dogecoin	Ethereum 2.0, Cardano, Solana, Algorand, Tezos	Signa (formerly Burstcoin)	Zilliqa
Electricity consumption	High (0.4% to 0.9% of global electricity usage in August 2022)	Low (less than 0.001% of global electricity usage in 2021)	Expected to be low due to the energy efficiency of storage drives, but current adoption scale is low	Could be higher than PoS due to potentially high node counts, but lower than PoW
Scalability	High	High	High	Low to medium
Throughput	Low	Medium to high	Medium	Medium to high
Latency	Medium to high	Low to medium	Medium	Medium to high
Security	High	High	Subject to further testing	High
Decentralization	High	High	High	Medium to high

They're just making stuff up here

Table A.3

Computing device numbers and power requirements for select crypto-assets in 2021

Network	Consensus Mechanism	Date	Computing Devices in 2021		Power Use (Watt/device)[208]
			Number	Type	
Ethereum 2.0	PoS	5/7/21	183,753	Validator Nodes	6 – 168
Algorand	PoS	8/12/21	1,126		
Cardano	PoS	9/6/21	2,958		
Polkadot	PoS	7/5/21	297		
Tezos	PoS	8/12/21	399		
Bitcoin	PoW	5/14/21	2,900,000	Mining Rigs	1,975 – 3,472

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Table A.4

Compilation of published GHG emission estimates for crypto-asset mining using the PoW consensus mechanism. For appropriate precision, results rounded to two significant figures

		Emissions			Emissions factor		
		Average	Minimum	Maximum	Average		
Blockchain	**Time Period**	**Mt CO_2 eq./y**	**Mt CO_2 eq./y**	**Mt CO_2 eq./y**	**g CO_2/ kWh**	**Emissions Factor Spatial Unit**	**Source**
Ethereum, Litecoin, Monero	1/2016-6/2018	0.4	0.1	0.6		country	Krause and Tolaymat 2018
Bitcoin	1/2016-6/2018	3.2	1.2	5.2		country	Krause and Tolaymat 2018
Bitcoin	2017	2.8	2	3.6		country, province (China), state (USA)	Calvo-Pardo et al. 2022
Bitcoin	2017	16	2.9	35		country	Houy 2019
Bitcoin	2017	16				country	Masanet et al. 2019
Bitcoin	2017	69				country	Mora et al. 2018
Bitcoin	2018	16	14	18		country, province (China), state (USA)	Calvo-Pardo et al. 2022
Bitcoin	2018	17				country, province (Canada, China), state (USA)	Kohler and Pizzol 2019
Bitcoin	2018	22	22	23		country	Stoll et al. 2019
Bitcoin	2018	24	19	30	480	country, province (China), state (USA)	de Vries 2019
Bitcoin	2019	15	13	17		country, province (China), state (USA)	Calvo-Pardo et al. 2022
Bitcoin	2021	65			570	country, province (China), state (USA)	de Vries et al. 2022
Dogecoin	2022	2.2					Digiconomist 2022-05-30
Ethereum	2022	49					Digiconomist 2022-05-30
Bitcoin	2022	110				country, province (China), state (USA)	Digiconomist 2022-05-30
Bitcoin, Dogecoin,	2022	160				country, province (China), state (USA)	Digiconomist 2022-05-30

This is it . the mora et al citation. a citation that shall live in imfamy

Basically all conflicted (with exception of calvo) See supplemental notes

		Emissions			Emissions factor		
		Average	Minimum	Maximum	Average		
Blockchain	**Time Period**	**Mt CO_2 eq./y**	**Mt CO_2 eq./y**	**Mt CO_2 eq./y**	**g CO_2/ kWh**	**Emissions Factor Spatial Unit**	**Source**
Ethereum							
Dogecoin	2022	2.2					Digiconomist 2022-06-08
Ethereum	2022	47					Digiconomist 2022-06-08
Bitcoin	2022	110				country, province (China), state (USA)	Digiconomist 2022-06-08
Bitcoin, Dogecoin, Ethereum	2022	160				country, province (China), state (USA)	Digiconomist 2022-06-08
Dogecoin	2022	1.5					Digiconomist 2022-06-16
Ethereum	2022	30					Digiconomist 2022-06-16
Bitcoin	2022	81				country, province (China), state (USA)	Digiconomist 2022-06-16
Bitcoin, Dogecoin, Ethereum	2022	110				country, province (China), state (USA)	Digiconomist 2022-06-16

Literally all de vries. embarassing

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List of Acronyms

Abbreviation	Definition
ASIC	Application-Specific Integrated Circuit
CO_2	Carbon Dioxide
DER	Distributed Energy Resources
DOE	Department of Energy
DLT	Distributed Ledger Technologies
eGRID	Emissions & Generation Resource Integrated Database
EH/S	Exahash per Second
EPA	Environmental Protection Agency
ERCOT	Electricity Reliability Council of Texas
g CO_2 eq./y	Grams of Carbon Dioxide-Equivalent per Year
GHG	Greenhouse Gas
g/kWh	Grams per Kilowatt-Hour
GW	Gigawatts
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
J/GH	Joules per Gigahertz
kWh	Kilowatt-Hour
Mt CO_2/y	Million Metric Tons of Carbon Dioxide Per Year
MWh	Megawatt-Hour
OSTP	Office of Science and Technology Policy
P2P	Peer-to-Peer
PoS	Proof of Stake
PoW	Proof of Work
TH/S	TeraHash per Second
TWH/y	TeraWatt-Hours per Year
VCM	Voluntary Carbon Markets

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Interagency Policy Committee

- Commodity Futures Trading Commission (CFTC)
- Consumer Financial Protection Bureau (CFPB)
- Department of Commerce (DOC)
- Department of Defense (DOD)
- Department of Energy (DOE)
- Department of Homeland Security (DHS)
- Department of Justice (DOJ)
- Department of Labor (DOL)
- Department of State (DOS)
- Department of Transportation (DOT)
- Department of Treasury (Treasury)
- Environmental Protection Agency (EPA)
- Executive Office of the President (EOP)
- Federal Deposit Insurance Corporation (FDIC)
- Federal Reserve Board (FRB)
- General Services Administration (GSA)
- National Science Foundation (NSF)
- Office of the Director of National Intelligence (ODNI)
- Securities and Exchange Commission (SEC)
- U.S. Agency for International Development (USAID)

6. Endnotes

I'm not going to go through all of the references and enumerate all of the questionable ones - I cover all the most egregious ones (accounting for dozens and dozens) in the supplemental notes

[1] The White House. (2022, March 9). *Executive Order 14067 on Ensuring Responsible Development of Digital Assets*. https://www.whitehouse.gov/briefing-room/presidential-actions/2022/03/09/executive-order-on-ensuring-responsible-development-of-digital-assets/.

[2] Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., and Rama, B. (eds.). (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. *Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

[3] Reidmiller, D. R., Avery, C.W., Easterling, D.R., Kunkel, K.E., Lewis, K.L., Maycock, T.K., and Stewart, B.C. (eds.). (2018). Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. *U.S. Global Change Research Program*, 1515. https://doi.org/10.7930/nca4.2018.

[4] U.S. Environmental Protection Agency. (2021). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts (EPA 430-R-21-003)*. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.

[5] Smith, A. (2022, Jan. 24). *2021 U.S. billion-dollar weather and climate disasters in historical context*. U.S. National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical.

[6] Vahlsing, C., and Yagan, D. (2022, April 4). *Quantifying Risks to the Federal Budget from Climate Change*. The White House. https://www.whitehouse.gov/omb/briefing-room/2022/04/04/quantifying-risks-to-the-federal-budget-from-climate-change/.

[7] Digiconomist (2022). *Bitcoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[8] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[9] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed August 15, 2022, from https://cbeci.org/.

[10] U.S. Energy Information Administration. (n.d.). *Electricity Data Browser*. U.S. Department of Energy. https://www.eia.gov/electricity/data/browser/.

[11] International Energy Agency. (2022). *Electricity Market Report – January 2022*. Organisation for Economic Co-operation and Development. https://www.iea.org/reports/electricity-market-report-january-2022.

[12] International Energy Agency. (2021). *Data Centres and Data Transmission Networks*. Organisation for Economic Co-operation and Development. https://www.iea.org/reports/data-centres-and-data-transmission-networks.

[13] U.S. Energy Information Administration. (2022). *Annual Energy Outlook 2021 (Reference case tables).* https://www.eia.gov/outlooks/archive/aeo21/.

[14] Malik, N.S. (2022, April 27). *Crypto Miners' Electricity Use in Texas Would Equal Another Houston*. Bloomberg. https://www.bloomberg.com/news/articles/2022-04-27/crypto-miners-in-texas-will-need-more-power-than-houston.

[15] U.S. Congress. (2022). *H.R. 5376 - Inflation Reduction Act of 2022 (P.L. 117-169)*. https://www.congress.gov/bill/117th-congress/house-bill/5376/text.

[16] DOE (2021). DOE Fact Sheet: The Bipartisan Infrastructure Deal Will Deliver For American Workers, Families and Usher in the Clean Energy Future. U.S. Department of Energy. https://www.energy.gov/articles/doe-fact-sheet-bipartisan-infrastructure-deal-will-deliver-american-workers-families-and-0.

[17] Coroama, V. (2021, Sept. 27). *Blockchain energy consumption: An exploratory study*. Swiss Federal Office of Energy. https://www.aramis.admin.ch/Default?DocumentID=68053.

[18] de Vries, A. (2020, Dec.). Bitcoin's energy consumption is underestimated: A market dynamics approach. *Energy Res. Soc. Sci.* 70, 101721. https://doi.org/10.1016/j.erss.2020.101721.

[19] International Bank for Reconstruction and Development (2018). *Blockchain and Emerging Digital Technologies for Enhancing Post-2020 Climate Markets.* World Bank.

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https://openknowledge.worldbank.org/bitstream/handle/10986/29499/124402-WP-Blockchainandemergingdigitaltechnologiesforenhancingpostclimatemarkets-PUBLIC.pdf.

[20] Chow, A. (2022, May 26). *The Crypto Industry Was On Its Way to Changing the Carbon-Credit Market, Until It Hit a Major Roadblock*. Time. https://time.com/6181907/crypto-carbon-credits/.

[21] The Executive Office of the President. (2021, Feb. 1). *Executive Order 14008: Tackling the Climate Crisis at Home and Abroad.* U.S. National Archives – Federal Register. https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad.

[22] The United States of America. (2021). *The United States of America Nationally Determined Contribution: Reducing Greenhouse Gases in the United States*. United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/NDC/2022-06/United%20States%20NDC%20April%2021%202021%20Final.pdf.

[23] The White House. (2021, Jan. 20). *Executive Order 13990: Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis*. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-protecting-public-health-and-environment-and-restoring-science-to-tackle-climate-crisis/.

[24] U.S. Congress. (2022). *H.R. 5376 - Inflation Reduction Act of 2022 (P.L. 117-169)*. https://www.congress.gov/bill/117th-congress/house-bill/5376/text.

[25] U.S. Department of Energy. (2022, Aug. 18). *DOE Projects Monumental Emissions Reduction From Inflation Reduction Act.* https://www.energy.gov/articles/doe-projects-monumental-emissions-reduction-inflation-reduction-act.

[26] U.S. Congress. (2021). *H.R. 3684 – Infrastructure Investment and Jobs Act (P.L. 117-58)*. https://www.congress.gov/bill/117th-congress/house-bill/3684/text.

[27] U.S. Congress. (2021). *H.R. 4346 – CHIPS and Science Act (P.L. 117-167)*. https://www.congress.gov/bill/117th-congress/house-bill/4346/text.

[28] Cambridge Centre for Alternative Finance. (2022). *Bitcoin Mining Map*. University of Cambridge. https://ccaf.io/cbeci/mining_map.

[29] Bashar, G., Hill, G., Singha, S., Marella, P., Dagher, G.G., and Xiao, J. (2019, Dec.). *Contextualizing consensus protocols in blockchain: A short survey*. In 2019 First IEEE International Conference on Trust, Privacy and Security in Intelligent Systems and Applications (TPS-ISA). IEEE, 190-195.

[30] Additional context: In mid-2022, Bitcoin paid 6.25 bitcoins for each new block, with one new block published about every 10 minutes. This translates to $20 million to $60 million USD paid per day to miners for the service of maintaining and updating the Bitcoin ledger.

[31] Lei, N., Masanet, E., and Koomey, J. (2021). *Best practices for analyzing the direct energy use of blockchain technology systems: Review and policy recommendations.* Energy Policy 156, 112422. https://doi.org/10.1016/j.enpol.2021.112422.

[32] Ferdous, M.S., Chowdhury, M.J.M., Hoque, M.A., and Colman, A. (2020, Jan. 20). *Blockchain consensus algorithms: a survey*. arXiv. http://arxiv.org/abs/2001.07091.

[33] Kilroy Blockchain. (n.d.). *What is Blockchain? How Does Blockchain Work?* https://kilroyblockchain.com/what-is-blockchain.

[34] Coroama, V. (2021, Sept. 27). *Blockchain energy consumption: An exploratory study*. Swiss Federal Office of Energy. https://www.aramis.admin.ch/Default?DocumentID=68053.

[35] Avelar, V., Azevedo, D., French, A., and Power, E. N. (eds.). (2012). *PUE: a comprehensive examination of the metric.* Green Grid Association, 49.

[36] Stoll, C., Klaaßen, L., and Gallersdorfer, U. (2019, Feb. 16). *The carbon footprint of bitcoin*. Cell Press 3, 1–15. https://doi.org/10.2139/ssrn.3335781.

[37] de Vries, A. (2020, Dec.). *Bitcoin's energy consumption is underestimated: A market dynamics approach*. Energy Res. Soc. Sci. 70, 101721. https://doi.org/10.1016/j.erss.2020.101721.

[38] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed August 15, 2022, from https://cbeci.org/.

[39] Platt, M., Sedlmeir, J., Platt, D., Tasca, P., Xu, J., Vadgama, N., and Ibañez, J.I. (2021). *The Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work*. IEEE 21st International Conference on Software Quality, Reliability and Security Companion (QRS-C). https://doi.org/10.1109/QRS-C55045.2021.00168.

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[40] Gallersdörfer, U., Klaaßen, L., and Stoll, C. (2022, Jan.). *Energy Efficiency and Carbon Footprint of Proof of Stake Blockchain Protocols*. Crypto Carbon Ratings Institute (CCRI). https://www.carbon-ratings.com/dl/pos-report-2022.

[41] Shehabi, A., Smith, S.J., Horner, N., Azevedo, I., Brown, R., Koomey, J., Masanet, E., Sartor, D., Herrlin, M., and Lintner, W. (2016, June). *United States Data Center Energy Usage Report - Report LBNL-1005775*. Lawrence Berkeley National Laboratory, Berkeley, California.

[42] International Telecommunication Union. (2022). *Greening Digital Companies: Monitoring emissions and climate commitments*. https://www.itu.int/en/ITU-D/Environment/Pages/Events/2022/Greening-Digital-Companies.aspx.

[43] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed May 30, 2022, from https://cbeci.org/.

[44] International Energy Agency. (2020, Feb. 26). *Efficiency of bitcoin mining hardware.* https://www.iea.org/data-and-statistics/charts/efficiency-of-bitcoin-mining-hardware.

[45] de Vries, A., and Stoll, C. (2021). *Bitcoin's growing e-waste problem*. Resources, Conservation and Recycling 175, 105901. https://doi.org/10.1016/j.resconrec.2021.105901.

[46] Benetton, M., Compiani, G., and Morse, A. (2021, May 14). *When Cryptomining Comes to Town: High Electricity-Use Spillovers to the Local Economy*. SSRN. https://ssrn.com/abstract=3779720.

[47] U.S. Energy Information Administration. (2022). *Electricity Data Browser: Average Retail Price of Electricity*. U.S. Department of Energy. https://www.eia.gov/electricity/data/browser/.

[48] Saul, J. (2022, Feb. 7). *Georgia is becoming the new hot spot for growing crypto in the U.S. – and Bitcoin miners are taking notice.* Fortune. https://fortune.com/2022/02/07/georgia-hot-spot-bitcoin-mining-us-crypto-energy/.

[49] de Vries, A., and Stoll, C. (2021). *Bitcoin's growing e-waste problem*. Resources, Conservation and Recycling 175, 105901. https://doi.org/10.1016/j.resconrec.2021.105901.

[50] Uhler, A. (2022, Mar. 25). *Crypto miners use natural gas "stranded" in wells to power energy-hungry rigs.* Marketplace. https://www.marketplace.org/2022/03/25/crypto-miners-use-natural-gas-stranded-in-wells-to-power-energy-hungry-rigs/.

[51] Platt, M., Sedlmeir, J., Platt, D., Tasca, P., Xu, J., Vadgama, N., and Ibañez, J.I. (2021). *The Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work*. IEEE 21st International Conference on Software Quality, Reliability and Security Companion (QRS-C). https://doi.org/10.1109/QRS-C55045.2021.00168.

[52] de Vries, A., and Stoll, C. (2021). *Bitcoin's growing e-waste problem*. Resources, Conservation and Recycling 175, 105901. https://doi.org/10.1016/j.resconrec.2021.105901.

[53] U.S. Energy Information Administration. (2021, Oct. 7). *How much electricity does an American home use?* U.S. Department of Energy. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

[54] U.S. Energy Information Administration. (2022, March 7). *How much electricity is used for lighting in the United States?* U.S. Department of Energy. https://www.eia.gov/tools/faqs/faq.php?id=99&t=3.

[55] U.S. Energy Information Administration. (2022, May 3). *Electricity explained*. U.S. Department of Energy. https://www.eia.gov/energyexplained/electricity/use-of-electricity.php.

[56] Additional context: This range is based on published best guess estimates for August 15, 2022 for Bitcoin, Ethereum, and Dogecoin, and published in mid-to-late 2021 for Ethereum 2.0, Algorand, Cardano, Polkadot, Tezos, Solana, and Avalanche.

[57] U.S. Energy Information Administration. (n.d.). *Electricity Data Browser*. U.S. Department of Energy. https://www.eia.gov/electricity/data/browser/.

[58] International Energy Agency. (2022). *Electricity Market Report – January 2022*. Organisation for Economic Co-operation and Development. https://www.iea.org/reports/electricity-market-report-january-2022.

[59] International Energy Agency. (2022). *Data Centres and Data Transmission Networks*. Organisation for Economic Co-operation and Development. Accessed August 16, 2022, from https://www.iea.org/reports/data-centres-and-data-transmission-networks.

[60] Additional context: These ranges are based on the lowest and highest published best guess electricity use estimates for Bitcoin, Ethereum, and Dogecoin between January 1, 2022 and August 15, 2022 and on the lowest and highest published estimates for PoS crypto-assets since mid-to-late 2021 published in the sources listed in Table A.1.

[61] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed August 16,2022, from https://cbeci.org/.

[62] Digiconomist. (2022). *Bitcoin Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

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[63] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[64] McDonald, K. (2022). *Ethereum Emissions: A Bottom-up Estimate*. Accessed August 16, 2022, from https://kylemcdonald.github.io/ethereum-emissions/.

[65] Digiconomist. (2022). *Dogecoin Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/dogecoin-energy-consumption.

[66] Platt, M., Sedlmeir, J., Platt, D., Tasca, P., Xu, J., Vadgama, N., and Ibañez, J.I. (2021). *The Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work.* IEEE 21st International Conference on Software Quality, Reliability and Security Companion (QRS-C). https://doi.org/10.1109/QRS-C55045.2021.00168.

[67] Gallersdörfer, U., Klaaßen, L., and Stoll, C. (2022, Jan.). *Energy Efficiency and Carbon Footprint of Proof of Stake Blockchain Protocols*. Crypto Carbon Ratings Institute (CCRI). https://www.carbon-ratings.com/dl/pos-report-2022.

[68] International Energy Agency. (2022). *Electricity Market Report – January 2022*. Organisation for Economic Co-operation and Development. https://www.iea.org/reports/electricity-market-report-january-2022.

[69] Additional context: Ranges will not sum due to rounding, and they are based on best guess ranges of annualized electricity use estimates from the cited sources for August 15, 2022.

[70] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed August 16,2022, from https://cbeci.org/.

[71] Digiconomist. (2022). *Bitcoin Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[72] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[73] McDonald, K. (2022). *Ethereum Emissions: A Bottom-up Estimate*. Accessed August 16, 2022, from https://kylemcdonald.github.io/ethereum-emissions/.

[74] Coroama, V. (2021, Sept. 27). *Blockchain energy consumption: An exploratory study*. Swiss Federal Office of Energy. https://www.aramis.admin.ch/Default?DocumentID=68053.

[75] de Vries, A. (2020, Dec.). *Bitcoin's energy consumption is underestimated: A market dynamics approach*. Energy Res. Soc. Sci. 70, 101721. https://doi.org/10.1016/j.erss.2020.101721.

[76] Cambridge Centre for Alternative Finance. (2022*). Bitcoin Mining Map*. University of Cambridge. Accessed August 16, 2022 from https://ccaf.io/cbeci/mining_map.

[77] Cambridge Centre for Alternative Finance. (2022*). Bitcoin network power demand.* University of Cambridge. https://ccaf.io/cbeci/index.

[78] U.S. Energy Information Administration. (n.d.). *Electricity Data Browser*. U.S. Department of Energy. https://www.eia.gov/electricity/data/browser/.

[79] Siddik, M. A. B., Shehabi, A., and Marston, L. (2021, May 21). *The environmental footprint of data centers in the United States*. Environmental Research Letters 16(6), 064017. http://dx.doi.org/10.1088/1748-9326/abfba1.

[80] Digiconomist. (2022). *Bitcoin Energy Consumption Index*. Accessed May 30, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[81] U.S. Energy Information Administration. (n.d.). *Documentation of the National Energy Modeling System (NEMS) modules*. U.S. Department of Energy. https://www.eia.gov/outlooks/aeo/nems/documentation/.

[82] Digiconomist (2022). *Bitcoin Energy Consumption Index*. https://digiconomist.net/bitcoin-energy-consumption.

[83] YCharts. (2022, Aug.) https://ycharts.com/indicators/bitcoin_average_transactions_per_block.

[84] Blockchain. (2022). *Bitcoin transaction data*. Accessed May 30, 2022, from https://www.blockchain.com/.

[85] Etherscan. (2022). *Ethereum transaction data*. Accessed May 30, 2022, from https://etherscan.io.

[86] Nilson Report. (2022). *Charts & Graphs Archive.* https://nilsonreport.com/publication_chart_and_graphs_archive.php.

[87] Additional context: Mastercard, American Express, and Visa reported 104,100 MWh, 224,051 MWh, and 173,117 MWh of electricity use, respectively, in 2020.

[88] Mastercard. (2021). *Corporate Sustainability Report 2020.* https://www.mastercard.us/content/dam/public/mastercardcom/na/global-site/documents/mastercard-sustainability-report-2020.pdf.

[89] American Express. (2021). *2020-2021 Environmental, Social, and Governance Report*. https://s29.q4cdn.com/330828691/files/doc_downloads/esg_resources/AXP-2020-2021-ESG-Report.pdf.

[90] Visa. (2020). *2020 Environmental, Social & Governance Report*. https://usa.visa.com/content/dam/VCOM/global/about-visa/documents/visa-2020-esg-report.pdf.

★ ★ ★ ★ ★ ★

[91] Additional context: Based on 2020 average expected electricity use of 68 billion kWh and 8 billion kWh for Bitcoin (CBECI 2022) and Ethereum (Digiconomist 2022), respectively.

[92] U.S. Department of State and U.S. Executive Office of the President. (2021, Nov.). *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050.* https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

[93] U.S. Government Accountability Office. (2021, Mar. 10). *Electricity Grid Resilience: Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions*. https://www.gao.gov/products/gao-21-423t.

[94] McLaughlin, T. (2022, May 12). *Creaky U.S. power grid threatens progress on renewables, EVs*. Reuters. https://www.reuters.com/investigates/special-report/usa-renewables-electric-grid/.

[95] Zamuda, C., Bilello, D.E., Conzelmann, G., Mecray, E., Satsangi, A., Tidwell, V., and Walker, B.J. (2018). *Chapter 4 (Energy Supply, Delivery, and Demand) of Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program, 174–201. https://doi.org/10.7930/NCA4.2018.CH4.

[96] Holland, S. P., Kotchen, M. J., Mansur, E. T., & Yates, A. J. (2022, Feb. 14). *Why marginal CO2 emissions are not decreasing for US electricity: Estimates and implications for climate policy*. Proceedings of the National Academy of Sciences 119(8), e2116632119. https://doi.org/10.1073/pnas.2116632119.

[97] Public Utility District of Chelan County. (2018). *Cryptocurrency Staff Report*. Chelan County, Washington. https://www.chelanpud.org/docs/default-source/default-document-library/final-cryptocurrency-staff-report.pdf.

[98] Ciampoli, P. (2018, May 15). *Grant PUD sets cryptocurrency rate class, Chelan extends moratorium*. Public Power. https://www.publicpower.org/periodical/article/grant-pud-sets-cryptocurrency-rate-class-chelan-extends-moratorium.

[99] Benton Public Utility District. (2018, Mar. 20). *Electricity Intensive Load Policy Created for Data Mining*. Benton County, Washington. https://www.bentonpud.org/Newsroom/Electricity-Intensive-Load-Policy-Created-for-Data.

[100] Benetton, M., Compiani, G., and Morse, A. (2021, May 14). *When Cryptomining Comes to Town: High Electricity-Use Spillovers to the Local Economy*. SSRN. https://ssrn.com/abstract=3779720.

[101] New York Public Service Commission. (2018, Mar. 15). *PSC Allows Upstate Municipal Power Authorities to Charge Higher Electricity Rates for Heavy Electricity-Using Cryptocurrency Companies*. New York State Department of Public Service. https://www3.dps.ny.gov/pscweb/WebFileRoom.nsf/Web/52BF38680307E75E85258251006476F0/$File/pr18018.pdf?OpenElement.

[102] Malik, N.S. (2022, April 27). *Crypto Miners' Electricity Use in Texas Would Equal Another Houston*. Bloomberg. https://www.bloomberg.com/news/articles/2022-04-27/crypto-miners-in-texas-will-need-more-power-than-houston.

[103] Pan, D. (2022, July 11). *Bitcoin Miners Shut as Texas Power Grid Nears Brink*. Bloomberg. https://www.bloomberg.com/news/articles/2022-07-11/bitcoin-miners-shut-off-rigs-as-texas-power-grid-nears-brink.

[104] Pan, D. (2022, Aug. 3). *Bitcoin Miner Made Millions in Credits by Shutting Rigs During Texas Heat*. Bloomberg. https://www.bloomberg.com/news/articles/2022-08-03/bitcoin-miner-made-millions-by-shutting-rigs-during-texas-heat.

[105] Tech Transparency Project. (2022, July 21). *Cryptocurrency Miners' Sweetheart Deal with Texas Threatens an Already Fragile Grid*. https://www.techtransparencyproject.org/sites/default/files/Crypto%20Texas%20Report.pdf.

[106] European Council. (2022, June 30). *Digital finance: agreement reached on European crypto-assets regulation (MiCA)*. https://www.consilium.europa.eu/en/press/press-releases/2022/06/30/digital-finance-agreement-reached-on-european-crypto-assets-regulation-mica/.

[107] Quiroz-Gutierrez, M. (2022, Jan. 4). *Crypto is fully banned in China and 8 other countries*. Fortune. https://fortune.com/2022/01/04/crypto-banned-china-other-countries/.

[108] U.S. Energy Information Administration. (n.d.). *Documentation of the National Energy Modeling System (NEMS) modules*. U.S. Department of Energy. https://www.eia.gov/outlooks/aeo/nems/documentation/.

[109] International Energy Agency. (2017, Nov.). *Digitalization & Energy*. Organisation for Economic Co-operation and Development. https://www.iea.org/reports/digitalisation-and-energy.

[110] Blockchain. (2022). https://www.blockchain.com/.

[111] Koomey, J. (2008). *Turning numbers into knowledge: Mastering the art of problem solving*. Analytics Press.

★ ★ ★ ★ ★ ★

[112] Blockchain. (2022). https://www.blockchain.com/.

[113] Additional context: From around 0.29 Joules per Gigahertz (J/GH) in August 2016 to around 0.04 J/GH in July 2022, as estimated by CBECI (2022) "best guess" results over this time period.

[114] Cambridge Centre for Alternative Finance. (2022). *Cambridge Bitcoin Electricity Consumption Index*. University of Cambridge. Accessed August 16,2022, from https://cbeci.org/.

[115] Additional context: Total network hashrate rose from around 1.5 million TeraHashes per second (TH/S) in August 2016 to over 200 million TH/S in July 2022 (blockchain.com/charts/hash-rate); whereas the CBECI (2022) "best guess" network power estimate rose from around 0.5 GW to nearly 10 GW.

[116] World Business Council for Sustainable Development and World Resources Institute. (2004). *Greenhouse Gas Protocol*.

[117] Digiconomist (2022). *Bitcoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[118] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[119] Digiconomist. (2022). *Dogecoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/dogecoin-energy-consumption.

[120] de Vries, A., Gallersdörfer, U., Klaaßen, L., and C. Stoll. (2022*). Revisiting Bitcoin's carbon footprint*. Joule 6(3): 498-502. http://dx.doi.org/10.1016/j.joule.2022.02.005.

[121] Digiconomist. (2022). *Bitcoin Energy Consumption Index*. Accessed August 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[122] Shukla, P.R., Skea, J., Slade, R. Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., and Malley, J. (eds.). (2022). *Climate Change 2022: Mitigation of Climate Change.* Intergovernmental Panel on Climate Change (IPCC).

[123] Digiconomist (2022). *Bitcoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[124] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[125] Digiconomist. (2022). *Dogecoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/dogecoin-energy-consumption.

[126] Gallersdörfer, U., Klaaßen, L., and Stoll, C. (2020). *Energy consumption of cryptocurrencies beyond Bitcoin*. Joule 4(9), 1843-1846. http://dx.doi.org/10.1016/j.joule.2020.07.013.

[127] Calvo-Pardo, H.F., Mancini, T., and Olmo, J. (2022). *Machine learning the carbon footprint of Bitcoin mining*. Journal of Risk and Financial Management 15(2), 71. http://dx.doi.org/10.3390/jrfm15020071.

[128] Houy, N. 2019. *Rational mining limits Bitcoin emissions*. Nature Climate Change 9(9), 655. http://dx.doi.org/10.1038/s41558-019-0533-6.

[129] Mora, C., Rollins, R.L., Taladay, K., Kantar, M.B., Chock, M.K., Shimada, M., and Franklin, E.C. (2018). *Bitcoin emissions alone could push global warming above 2°C.* Nature Climate Change 8(11), 931–933. http://dx.doi.org/10.1038/s41558-018-0321-8.

[130] Digiconomist (2022). *Bitcoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[131] Digiconomist. (2022). *Ethereum Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/ethereum-energy-consumption.

[132] Digiconomist. (2022). *Dogecoin Energy Consumption Index*. Accessed from May 30 to June 16, 2022, from https://digiconomist.net/dogecoin-energy-consumption.

[133] de Vries, A., Gallersdörfer, U., Klaaßen, L., and Stoll, C. (2022). *Revisiting Bitcoin's carbon footprint*. Joule 6(3): 498-502. http://dx.doi.org/10.1016/j.joule.2022.02.005.

[134] de Vries, A. (2019). *Renewable energy will not solve Bitcoin's sustainability problem*. Joule 3(4), 893–898. http://dx.doi.org/10.1016/j.joule.2019.02.007.

[135] U.S. Environmental Protection Agency. (2022). *Emissions & Generation Resource Integrated Database (eGRID)*. https://www.epa.gov/egrid.

[136] U.S. Energy Information Administration. (2022). *How much carbon dioxide is produced per kilowatthour of U.S. electricity generation?* U.S. Department of Energy. https://www.eia.gov/tools/faqs/faq.php?id=74&t=11.

[137] U.S. Energy Information Administration. (2022). *What is U.S. electricity generation by source?* U.S. Department of Energy. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

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[138] Additional context: A notable exception is the Electricity Reliability Council of Texas, which covers 90% of Texas' electrical load, and has limited interconnections to the rest of the U.S. electricity system. Two-thirds of the U.S. electrical load is served by competitive wholesale electricity markets managed by Regional Transmission Organizations, with the remaining load served by traditional wholesale markets managed by utilities. For more, see FERC. (2021). *Electric Power Markets*. https://www.ferc.gov/electric-power-markets.

[139] de Chalendar, J.A., and Benson, S.M. (2021). *A physics-informed data reconciliation framework for real-time electricity and emissions tracking*. Applied Energy 304, 117761. http://dx.doi.org/10.1016/j.apenergy.2021.117761.

[140] U.S. Environmental Protection Agency. (2022). *Emissions & Generation Resource Integrated Database (eGRID)*. https://www.epa.gov/egrid.

[141] U.S. Environmental Protection Agency. (2022). *Emissions & Generation Resource Integrated Database (eGRID)*. https://www.epa.gov/egrid.

[142] de Vries, A., Gallersdörfer, U., Klaaßen, L., and Stoll, C. (2022). *Revisiting Bitcoin's carbon footprint*. Joule 6(3): 498-502. http://dx.doi.org/10.1016/j.joule.2022.02.005.

[143] U.S. Environmental Protection Agency. (2018). *Greenhouse Gas Emissions from a Typical Passenger Vehicle (EPA-420-F-18-008)*. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle.

[144] Based on assumed U.S total hashrate shares of 10.5% and 37.8% in January 2021 and August 2022, respectively, and on best-guess global power values of 12.1 GW and 10.1 GW on January 4, 2021 and August 15, 2022, respectively, from the Cambridge Center for Alternative Finance.

[145] U.S. Securities and Exchange Commission. (2022). *Marathon Digital Holdings, Inc., 2021 Form 10-K (2022)*. https://www.sec.gov/ix?doc=/Archives/edgar/data/0001507605/000149315222006446/form10-k.htm.

[146] Lutey, T. (2022, April 6). *Crypto miner plans to exit Hardin coal-fired power plant*. Billings Gazette. https://billingsgazette.com/news/crypto-miner-plans-to-exit-hardin-coal-fired-power-plant/article_cd2ca444-929a-511d-913d-903fbc570498.html.

[147] Additional context: One of the plants is Greenidge Generation Station, located on the western shores of Seneca Lake, among the productive vineyards and farms of the Finger Lakes. In its first year of mining operations, Greenidge operated seven-fold more than the year prior and its CO2 emissions increased 479%. Calculated from U.S. Environmental Protection Agency. (2022). *Clean Air Markets Program Data.* https://campd.epa.gov/.

[148] U.S. Securities and Exchange Commission. (2022). *Stronghold Digital Mining, Inc., 2021 Form 10-K (2022)*. https://www.sec.gov/ix?doc=/Archives/edgar/data/0001856028/000162828022007706/sdig-20211231.htm.

[149] Brown, A. (2022, Feb. 15). *Hallador Acquires Sullivan County Coal Plant*. Inside Indiana Business. https://www.insideindianabusiness.com/articles/hallador-acquires-sullivan-county-coal-plant.

[150] Global Newswire. (2022, May 11). *AboutBit launches one of nation's largest cryptocurrency mining facilities.* https://www.globenewswire.com/news-release/2022/05/11/2440883/0/en/AboutBit-launches-one-of-nation-s-largest-cryptocurrency-mining-facilities.html.

[151] Storrow, B. and Holzman, J. (2022, May 18). *Cryptocurrency's climate conundrum*, E&E News. https://www.eenews.net/articles/cryptocurrencys-climate-conundrum/.

[152] Additional context: Instances include Greenidge Generating Station, New York; Hardin Generating Station, Montana; Scrubgrass Generating Plant, Pennsylvania; Big Dog oil and gas wells, Pennsylvania; and an attempted reopening of Grant Town coal power plant, West Virginia.

[153] Additional context: The Onondaga Nation in New York State has opposed restarting the Greenidge Generating Station in New York due to the global climate change impacts and the local environmental impacts on their limited natural resources.

[154] U.S. Environmental Protection Agency. (2022). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020*. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

[155] U.S. Energy Information Administration. (2020, May 28). *Monthly Energy Review*. U.S. Department of Energy.

[156] Köhler, S., and Pizzol, M. (2019). *Life cycle assessment of Bitcoin mining*. Environmental Science and Technology 53(23), 13598-13606. http://dx.doi.org/10.1021/acs.est.9b05687.

[157] Roeck, M., and Drennen, T. (2022). *Life cycle assessment of behind-the-meter Bitcoin mining at US power plant*. International Journal of Life Cycle Assessment 27(3), 355–365. http://dx.doi.org/10.1007/s11367-022-02025-0.

[158] U.S. Environmental Protection Agency. (2022). *Understanding Global Warming Potentials*. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials.

[159] The White House Office of Domestic Climate Policy. (2021, Nov.). *U.S. Methane Emissions Reduction Action Plan*. https://www.whitehouse.gov/wp-content/uploads/2021/11/US-Methane-Emissions-Reduction-Action-Plan-1.pdf.

★ ★ ★ ★ ★ ★

[160] United Nations Environment Programme. (2021). *Emissions Gap Report 2021*. United Nations. https://www.unep.org/resources/emissions-gap-report-2021.

[161] International Bank for Reconstruction and Development. (2022). *2022 Global Gas Flaring Tracker Report*. World Bank. https://www.worldbank.org/en/topic/extractiveindustries/publication/2022-global-gas-flaring-tracker-report.

[162] Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B. (eds.). (2021). Climate Change 2021: The Physical Science Basis. *Intergovernmental Panel on Climate Change (IPCC).*

[163] United Nations Environment Programme. (2021). *Global Methane Assessment*. United Nations. https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions.

[164] Holland, S.P., Kotchen, M.J., Mansur, E.T., and Yates, A.J. (2022). *Why marginal CO_2 emissions are not decreasing for US electricity: Estimates and implications for climate policy*. Proceedings of the National Academy of Sciences of the USA 119(8), e2116632119. http://dx.doi.org/10.1073/pnas.2116632119.

[165] Intergovernmental Panel on Climate Change (IPCC). (2000). *Land Use, Land Use Change, and Forestry*. Cambridge University Press.

[166] U.N. Framework Convention on Climate Change (UNFCCC). (2017). *Methodological tool: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation, Version 03.0*. United Nations.

[167] U.N. Framework Convention on Climate Change (UNFCCC). (2022). *Methodological tool: Project and leakage emissions from biomass, Version 05.0*. United Nations.

[168] Atmadja, S., and Verchot, L. (2012). *A review of the state of research, policies and strategies in addressing leakage from reducing emissions from deforestation and forest degradation (REDD+).* Mitigation and Adaptation Strategies for Global Change 17(3), 311-336. http://dx.doi.org/10.1007/s11027-011-9328-4.

[169] Fischer, C., and Fox, A.K. (2012). *Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates*. Journal of Environmental Economics and Management 64(2), 199-216. http://dx.doi.org/10.1016/j.jeem.2012.01.005.

[170] Palmer, K., Burtraw, D., Paul, A., and Yin, H. (2017). *Using production incentives to avoid emissions leakage*. Energy Economics 68, 45-56. http://dx.doi.org/10.1016/j.eneco.2017.10.031.

[171] Palmer, K., Burtraw, D., Paul, A., and Yin, H. (2017). Using production incentives to avoid emissions leakage. *Energy Economics* 68, 45-56. http://dx.doi.org/10.1016/j.eneco.2017.10.031.

[171] Bistline, J.E.T., Merrick, J., and Niemeyer, V. (2020*). Estimating power sector leakage risks and provincial impacts of Canadian carbon pricing.* Environmental and Resource Economics 76(1), 91-118. http://dx.doi.org/10.1007/s10640-020-00421-4.

[172] Millstein, D., Wiser, R., Mills, A. D., Bolinger, M., Seel, J., and Jeong, S. (2021). *Solar and wind grid system value in the United States: The effect of transmission congestion, generation profiles, and curtailment*. Joule 5(7), 1749-1775. http://dx.doi.org/10.1016/j.joule.2021.05.009.

[173] Miranda, M.L., Edwards, S.E., Keating, M.H., and Paul, C.J. (2011). *Making the environmental justice grade: The relative burden of air pollution exposure in the United States*. International Journal of Environmental Research and Public Health 8(6), 1755-1771. http://dx.doi.org/10.3390/ijerph8061755.

[174] Thind, Maninder, et al. (2019). *Fine Particulate Air Pollution from Electricity Generation in the US: Health Impacts by Race, Income, and Geography*. Environmental Science and Technology 53(23), 14010 – 14019. http://dx.doi.org/10.1021/acs.est.9b02527.

[175] NYSDEC (2022). Notice of Denial of Title V Air Permit. New York State Department of Environmental Conservation. https://www.dec.ny.gov/docs/administration_pdf/greenidgefinal630.pdf.

[176] Uptime Institute. (2021). *2021 Data Center Industry Survey*. https://uptimeinstitute.com/resources/asset/2021-data-center-industry-survey.

[177] Water Research Foundation. (2016). *Residential End Uses of Water, Version 2: Executive Summary*. https://www.awwa.org/Portals/0/AWWA/ETS/Resources/WaterConservationResidential_End_Uses_of_Water.pdf.

[178] Ebrahimi, K., Jones, G.F., and Fleischer, A.S. (2014). *A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities*. Renewable and Sustainable Energy Reviews 31, 622-638. http://dx.doi.org/10.1016/j.rser.2013.12.007.

★ ★ ★ ★ ★ ★

[179] Williams, K. (2022). An Appalachian town was told a bitcoin mine would bring an economic boom. It got noise pollution and an eyesore. The Washington Post, March 18, 2022. https://www.washingtonpost.com/business/2022/03/18/bitcoin-mining-noise-pollution-appalachia/.

[180] Williams, K. (2022). A neighborhood's cryptocurrency mine: 'Like a jet that never leaves'. The Washington Post. August 31, 2022. https://www.washingtonpost.com/business/interactive/2022/cryptocurrency-mine-noise-homes-nc/.

[181] Monga, V. (2021). Bitcoin Mining Noise Drives Neighbors Nuts—a Giant Dentist Drill That Won't Stop. The Wall Street Journal. November 12, 2021. https://www.wsj.com/articles/bitcoin-mining-noise-drives-neighbors-nuts-giant-dentist-drill-that-wont-stop-11636730904.

[182] Danahy, A. (2022). For A Rural Pennsylvania Area, A Cryptocurrency Mine Brought Noise Pollution. The Allegheny Front. July 13, 2022. https://www.alleghenyfront.org/rural-pennsylvania-bitcoin-mine-cryptocurrency-noise-pollution/.

[183] Passchier-Vermeer, W., and Passchier, W.F. (2000). *Noise exposure and public health*. Environmental Health Perspectives 108 Suppl. 1, 123-131. http://dx.doi.org/10.1289/ehp.00108s1123.

[184] Cohen, J.P., and Coughlin, C.C. (2008). *Spatial Hedonic Models of Airport Noise, Proximity, and Housing Prices*. Journal of Regional Science 48(5), 859-878. http://dx.doi.org/10.1111/j.1467-9787.2008.00569.x.

[185] Casey, J. A., Morello-Frosch, R., Mennitt, D. J., Fristrup, K., Ogburn, E. L., and James, P. (2017). *Race/ethnicity, socioeconomic status, residential segregation, and spatial variation in noise exposure in the contiguous United States*. Environmental Health Perspectives 125(7), 077017. http://dx.doi.org/10.1289/EHP898.

[186] Althaf, S., Babbitt, C.W., and Chen, R. (2020). *The evolution of consumer electronic waste in the United States.* Journal of Industrial Ecology 25(3), 693-706. https://doi.org/10.1111/jiec.13074.

[187] de Vries, A. and C. Stoll. 2021. Bitcoin's growing e-waste problem. Resources, Conservation and Recycling 175: 105901. doi:10.1016/j.resconrec.2021.105901.

[188] Digiconomist. (2022). *Bitcoin Energy Consumption Index*. Accessed June 8, 2022, from https://digiconomist.net/bitcoin-energy-consumption.

[189] de Vries, A., and Stoll, C. (2021). *Bitcoin's growing e-waste problem*. Resources, Conservation and Recycling 175, 105901. https://doi.org/10.1016/j.resconrec.2021.105901.

[190] Koomey, J., Berard, S., Sanchez, M., and Wong, H. (2011). *Implications of historical trends in the electrical efficiency of computing*. IEEE Annals of the History of Computing 33(3), 46-54. http://dx.doi.org/10.1109/MAHC.2010.28.

[191] de Vries, A., and Stoll, C. (2021). *Bitcoin's growing e-waste problem*. Resources, Conservation and Recycling 175, 105901. https://doi.org/10.1016/j.resconrec.2021.105901.

[192] Shehabi, A., Smith, S.J., Horner, N., Azevedo, I., Brown, R., Koomey, J., Masanet, E., Sartor, D., Herrlin, M., and Lintner, W. (2016, June). *United States Data Center Energy Usage Report - Report LBNL-1005775*. Lawrence Berkeley National Laboratory.

[193] U.S. Environmental Protection Agency. (2022, Mar. 17). *Certified Electronics Recyclers*. https://www.epa.gov/smm-electronics/certified-electronics-recyclers.

[194] Stavins, R. N. (2011, Feb.) *The Problem of the Commons: Still Unsettled after 100 Years.* American Economic Review 100: 81-108.

[195] U.S. Environmental Protection Agency. (2021). *Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts (EPA 430-R-21-003)*. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.

[196] Additional context: A cap-and-trade program establishes a maximum limit or "cap" on overall emissions from a group of identified sources, such as power plants. The cap is calibrated to reduce emissions to achieve a desired environmental effect. Based on the cap, a designated authority, typically established by a statute and/or regulation, issues "allowances" that permit regulated sources to emit a set amount of a pollutant for each allowance (frequently one ton). Sources subjected to the cap are required to monitor and report emissions, and surrender to a designated authority one allowance for every unit of pollution that they emitted during the relevant compliance period. These allowances are typically tradeable instruments, thus the name "cap and trade." An example of this is EPA's Acid Rain Program established under Title VI of the Clean Air Act. *See*, Acid Rain Program at https://www.epa.gov/acidrain/acid-rain-program.

[197] Jones, J.S. (2021, Sept. 23). *California ISO turns to blockchain to enhance flexibility alerting*. Smart Energy International. https://www.smart-energy.com/industry-sectors/energy-grid-management/california-iso-turns-to-blockchain-to-enhance-flexibility-alerting/.

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[198] Murtaugh, D., Eckhouse, B. (2022). *A Text Alert May Have Saved California From Power Blackouts*. Bloomberg. September 7, 2022. https://www.bloomberg.com/news/articles/2022-09-07/a-text-alert-may-have-saved-california-from-power-blackouts.

[199] U.S. Department of Energy. (n.d.) *Statement of Policy on Modernization of Electricity Grid.* https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/EISA_Title_XIII_Smart_Grid.pdf.

[200] Mollah, M. B., Zhao, J., Niyato, D., Lam, K.-Y., Zhang, X., Ghias, A. M. Y. M., Koh, L. H., & Yang, L. (2021). *DLT for Future Smart Grid: A Comprehensive Survey*. IEEE Internet of Things Journal, 8(1), 18–43. https://doi.org/10.1109/jiot.2020.2993601.

[201] Khan, S. N., Loukil, F., Ghedira-Guegan, C., Benkhelifa, E., and Bani-Hani, A. (2021). *DLT smart contracts: Applications, challenges, and future trends. Peer-to-Peer Networking and Applications*, 14(5), 2901–2925. https://doi.org/10.1007/s12083-021-01127-0.

[202] O'Neil, C. (2022, Feb. 18). *From the Bottom Up: Designing a Decentralized Power System*. National Renewable Energy Laboratory. https://www.nrel.gov/news/features/2019/from-the-bottom-up-designing-a-decentralized-power-system.html.

[203] Ben-Sasson, E., Chiesa, A., Virza, M., Garman, C., Green, M., Miers, I., and Tromer, E. (2014). *Zerocash: Decentralized Anonymous Payments from Bitcoin.* 2014 IEEE Symposium on Security and Privacy, 459–474. https://doi.org/10.1109/sp.2014.36.

[204] International Bank for Reconstruction and Development (2018). *Blockchain and Emerging Digital Technologies for Enhancing Post-2020 Climate Markets.* World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/29499/124402-WP-Blockchainandemergingdigitaltechnologiesforenhancingpostclimatemarkets-PUBLIC.pdf.

[205] Chow, A. (2022, May 26). *The Crypto Industry Was On Its Way to Changing the Carbon-Credit Market, Until It Hit a Major Roadblock*. Time. https://time.com/6181907/crypto-carbon-credits/.

[206] "Best estimate" refers to authors' expected, central, or "best guess" published value when available; market valuation data are as of 26-Aug-22, based on https://coinmarketcap.com/; upper and lower values refer to ranges or bounds published by authors

[207] Adapted from Lei et al. (2021) https://doi.org/10.1016/j.enpol.2021.112422 and Ferdous et al. (2020). Blockchain consensus algorithms: A survey. https://arxiv.org/abs/2001.07091; decentralization refers to decentralization potential in theory; in practice, decentralization can be reduced through concentration of mining rigs or validators into a limited number of operators

[208] For PoS networks, the validator node numbers and power use range are estimated by Platt et al. (2021); for Bitcoin, the mining rig number is estimated by DeVries and Stoll (2021) and the power use range is based on the range of power use by rigs estimated to be economically viable by DeVries and Stoll (2021) on 5/14/21.