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Review

100 Important Questions about Bitcoin's Energy Use and ESG Impacts

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Abstract: Bitcoin critics have argued that energy-intensive Bitcoin production and adoption will exacerbate global warming. Conversely, Bitcoin advocates have been dismayed by critics' apparent lack of willingness to scrutinize Bitcoin's potential role in helping to improve the economics of renewable energy investments, reduce net emissions from methane venting and flaring, increase electricity grid efficiency, and provide higher-order environmental, social, and governance (ESG) benefits. Given the disparate views, there is a pressing need to identify key knowledge needs regarding Bitcoin's net energy use, carbon emissions, and direct and indirect ESG impacts. I used a variation on the 'key questions' horizon scanning approach to identify 100 questions that, if answered, could help provide credible evidence to support policymakers', investors', and research funders' decision-making on issues relating to the impact of Bitcoin production and adoption. The questions are distributed across 13 themes (ranging from energy use to social impacts). The breadth of knowledge required to answer key questions highlights the need to build research capacity, encourage collaborative cross-sectoral and -disciplinary research, and develop a prioritized research agenda. Defensible evidence for investors, regulators, and policymakers needs to consider Bitcoin's complex net impacts on energy use and environmental, social, and governance benefits.

Keywords: Bitcoin; energy transition; ESG; horizon scan; key questions; research priorities

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1. Introduction

Bitcoin was created by the pseudonymous Satoshi Nakamoto [1] and is a technological and financial innovation that enables globally uncensorable, private, low-cost, peer-to-peer financial transactions. Bitcoin (the protocol) uses a decentralized digital currency, bitcoin (the currency), that has a fixed supply schedule and is incentivized for cooperation. The Bitcoin protocol uses cryptography and functions as a 'trust machine,' using computer code to facilitate near 'trustless' financial transactions in situations where, previously, the risks of being cheated were high or the costs of risk reduction outweighed the benefits of transacting [2].

As of early-December 2022, Bitcoin 'miners' ran a global network of high-performance computers ('mining rigs') that solved >250 exahash (2.5×10^{20} cryptographic calculations/second, https://www.blockchain.com/explorer/charts/hash-rate (accessed on 18 December 2022)) and accounted for ≈0.4% of global electricity consumption (https://ccaf.io/cbeci/index/comparisons (accessed on 18 December 2022)). Bitcoin critics have argued that widespread Bitcoin adoption will waste huge amounts of energy and exacerbate global warming, e.g., [3,4]. Despite criticisms regarding unrealistic assumptions, methodological flaws, or inappropriate interpolations [5–8], a handful of high-profile publications have strongly shaped the Bitcoin-energy-climate discourse and have had substantial policy influence, e.g., [9].

Bitcoin developers, miners, node operators, and investors (henceforth 'Bitcoiners') have been dismayed by critics' apparent lack of willingness to scrutinize Bitcoin's potential role in helping to improve the efficiency of energy production, control methane emissions, and provide higher-order social and environmental benefits. That may be changing, however, as: best practice guidelines for modeling blockchain energy use have been outlined [7]; there have been calls for increased participation by Bitcoin miners in developing more accurate energy-use models [9,10]; and the 2021 annual horizon scan of emerging environmental conservation issues [11] highlighted Bitcoin's potentially positive impacts arising due to miners' ability to used stranded and waste energy sources for bitcoin mining.

Given the disparate views on Bitcoin's potential environmental, social, and governance (ESG) impacts, it is essential to clarify what information could help policymakers, regulators, and investors to make evidence-based decisions about Bitcoin. The consequences arising from ill-informed decisions—either adding emissions to the atmosphere at a time when every possible reduction is needed or missing the chance to expediently embrace new technology to help combat climate change—potentially have serious opportunity costs for society. Bitcoin's direct social and governance impacts, the provision of financial services access for the world's two-billion unbanked citizens, for example, may also have very important impacts. The wide range of often-intersecting factors points to a need for research into Bitcoin's energy use and direct impacts on carbon emissions, as well as higher-order ESG factors affected by Bitcoin adoption.

One method to elucidate research needs is to conduct a horizon scan [12]. There are several options, including: periodic scans of novel technologies and issues of emerging importance, e.g., [11]; and 'key questions' exercises that identify questions that, if answered, could be of most use to decision-makers. Key questions exercises have been used extensively in the environmental science and policy fields, with topical and regional studies on: biodiversity conservation and management, e.g., [13–15]; environmental contaminants, e.g., [16–18]; agriculture and food production, e.g., [19,20]; international development challenges [21]; water management, e.g., [22]; energy efficiency [23]; and state-level responses to climate change [24].

In this paper, I identify questions that, if answered, would support policymakers', investors', and research funders' decision-making on issues relating to Bitcoin's net energy use and ESG impacts. The list of 100 questions was developed based on issues raised in publicly available podcast and video interviews with Bitcoin experts. A second phase of future research would logically engage environmental and energy experts outside the Bitcoin space to help identify gaps not captured in this initial scan and develop a prioritized Bitcoin-environment research agenda. As with results from other key question exercises, where questions derived in expert workshops diverged in priority from later surveys of the broader research and policy communities [25,26], the list presented here should be viewed as provisional. The list should be interpreted as '100 important'—not 'the 100 *most* important'—questions in the field. Stimulating evidence-based debate about research priorities is one of the primary functions of horizon-scanning exercises [12].

2. Methods

Most key questions exercises started with open, e.g., [15] or targeted, e.g., [18] solicitations of candidate questions but some exercises start with preliminary interviews with thought leaders in government [13] or academics with subject area expertise [23] to help focus exercise scope. Two recent developments now make it possible to greatly expand the scope of the role of thought leader interviews in the initial stage of a key questions exercise: (1) there has been an explosion in publicly available, long-form podcast and video broadcast interviews with Bitcoin experts; and (2) low-cost, accurate AI-based transcription services can now be used directly on source broadcasts. In the past, it was simply not feasible from a time and funding perspective to conduct a large number of interviews due to scheduling challenges with thought leaders and the need to manually transcribe interview results.

Bitcoin-oriented broadcasters explore a wide range of topics on Bitcoin's design, utility, financial performance, and use cases. The goal of this research was to construct, based on a selection of publicly available interviews, a list of potentially important candidate questions about Bitcoin's impact on energy use, the environment, and environmentally relevant social and governance issues. Note that: (1) broadcast guests were all, with the exception of one conference panel, pro-Bitcoin interviewees; and (2) the interviews were unstructured (due to the variance in how broadcasters ran their interviews). The unstructured, and often free-wheeling, interview format was well-suited for identifying a broad range of candidate questions regarding Bitcoin's ESG impacts.

To summarize, the compilation of candidate questions involved:

- Collecting transcribed interview notes (for all broadcasts and for all topics for which transcriptions were posted in show notes) and creating transcriptions (Sonix AI) for a range of other broadcasts specifically about Bitcoin's energy use and ESG impacts ($n = 747$ transcriptions in total);
- Using text mining software (QDA Miner 5.0.011, Provallis Research) to identify keywords and phrases potentially relevant to energy use and ESG issues, and flag transcriptions for further review;
- Conducting a light-touch review of selected transcriptions ($n = 154$) to verify whether the interview contained substantive and credible discussions about energy, environment, or higher-order ESG impacts;
- Conducting an in-depth review of original broadcasts and transcriptions for cases with substantive energy and ESG discussions ($n = 73$ transcriptions); and
- Extraction of 330 candidate questions from 68 broadcasts by 18 different broadcasters (80 interviewees, >88 h of interviews) (see Supplementary Materials S1 for a list of broadcasts, interviewees, and links).

While the number of candidate questions in this exercise ($n = 330$) was less than that for other exercises (typically 400–850) that eventually settled on 100 important questions, candidate question quality was high in this exercise as many of the trivial or redundant questions submitted in open solicitations were avoided.

After candidate questions were identified, I iteratively edited, combined, and refined questions to eliminate redundancies and reduced the final number of questions to 100. My interpretation of questions was necessarily subjective but drew upon extensive experience in conducting and reporting key questions exercises, so questions were broadly consistent in scope and phrasing to questions from other horizon scanning efforts.

At this early stage of a Bitcoin research agenda development, it is not possible to prioritize the research questions. However, some data from my own transcription dictionary and screening process (keyword frequency counts and cluster analysesare included in Supplementary Materials S1) may help put current research themes in the broader context of discourse within the Bitcoin community.

3. Results

3.1. Bitcoin Energy Use—The Big Picture

When considering Bitcoin's direct and indirect ESG impacts, it is important to be able to put the network's energy use in context. There is a widely recognized carbon dioxide equivalent (CO2e) emissions gap [27,28], the difference between the current and more conservative trajectories leading to 1.5° to 2.0° C warming. Bitcoin's marginal impact on emission-reducing pathways is an important consideration when putting Bitcoin's climate impact into context.

Efforts to quantify Bitcoin's total and comparative energy use are underway (e.g., Cambridge's Centre for Alternative Finance) but more research will be needed to assess and integrate Bitcoin's energy consumption into regional and global energy market supply and demand forecasting [29,30]. It will also be important to understand how rapid Bitcoin adoption could affect the speed of transition to renewable energy sources, including alternative low-emission fuels [31], or slowing the transition by extending the life of aging fossil fuel plants, e.g., [32] or economically marginal oil and gas drilling operations.

1. How best can Bitcoin's future energy use be predicted?
2. How much of the world's currently wasted and stranded energy could be used for Bitcoin mining without increasing CO2e emissions?
3. How will Bitcoin mining affect the flow of investment funds to renewable energy infrastructure, beyond what would happen through organic growth in renewable energy demand?
4. What novel low-emissions energy and storage technologies might power Bitcoin mining in the future, and how would they compare to established energy technologies in terms of ESG impacts?
5. How much otherwise unprofitable fossil fuel extraction and generating capacity might Bitcoin mining help keep in production?
6. How do environmental damages caused by Bitcoin mining compare to those caused by gold and precious metals mining?
7. How much energy does Bitcoin consume relative to legacy financial systems, and on which metrics might they be best compared?
8. How can total historical Bitcoin carbon emissions be calculated, and can and should they be compensated for to make Bitcoin mining carbon neutral over its entire history?

3.2. Mitigating Methane Emissions

Methane (CH_4) is emitted from both natural and anthropogenic sources and is potent, trapping about 25% more heat in the atmosphere than carbon (see Global Methane Initiative, https://www.epa.gov/gmi (accessed on 18 December 2022)). About 60% of methane emissions originate from human activities; emissions from wetlands comprise a large proportion of the 40% originating from natural sources [33,34]. Of the human-caused emissions, agriculture, the energy sector, and waste disposal account for about 24%, 23%, and 12% of global emissions, respectively [35]. Methane emissions are currently far higher than required to achieve global net zero emissions status by 2050 [30] but represent one of the fastest and best near-term CO2e mitigation opportunities [36,37].

In the oil and gas sector, methane can be vented, flared, or captured [38]. Flaring still emits carbon but the relative impact on warming is significantly reduced because of carbon's lower impact on warming relative to methane. Bitcoin miners can deploy container-based facilities to oil drilling sites, using waste methane to power high-efficiency generators and mining rigs. While not a long-term solution or one that is applicable in jurisdictions where flaring is prohibited by law, Bitcoin mining does offer a solution that could help reduce emissions from venting and increase the efficiency of uncontrolled flaring. Mining could be particularly useful at remote oil drilling sites or in jurisdictions that currently have no anti-venting regulations.

Methane capture and flaring can also power Bitcoin miners deployed to landfills, potentially reducing methane emissions while generating revenue for operators (often budget-constrained municipal governments). There may also be unexplored opportunities for methane reduction by Bitcoin mining conducted in conjunction with agricultural operations.

9. How much methane can be mitigated by Bitcoin mining operations co-located with oil and gas wells?
10. How could Bitcoin mining be used to most effectively reduce methane emissions from landfill sites and agricultural operations?
11. How much time could large-scale, methane-based Bitcoin mining buy in the global energy industry's transition to net-zero CO2e emissions?
12. How best can methane emission opportunities be prioritized so that Bitcoin mining deployment could have a rapid and substantive impact?

3.3. Electricity Grid Transition

Bitcoin may affect electricity grid management because of Bitcoin miners' ability to rapidly (i.e., within minutes) power up or shut down mining rigs. Grids use a combination of baseload energy suppliers (e.g., coal-fired plants, hydroelectric, nuclear) along with more flexible generation facilities (e.g., oil-fired plants), sometimes in conjunction with clients (e.g., steel mills), that can adjust their electricity consumption relatively rapidly during times of high overall grid demand. As new wind and solar installations, with their intermittent generating capacity, come online, grid operators need to have options, such as battery storage and Bitcoin mining, to rapidly manage risks arising from electricity supply and demand imbalances.

Wind and solar facilities often produce power in excess of grid needs and need to be 'curtailed' (prevented from adding electricity to the grid) when the market does not need the energy. The rationale for co-located Bitcoin mining is that miners can buy electricity directly ('behind the meter') from renewable energy producers when generating capacity exceeds grid demand. That is, bitcoin mining uses the power that cannot be sold and would otherwise be curtailed—wasted—during periods of relatively low market demand [39]. Improving the profitability of renewable energy installations should allow for more extensive renewable build-out or the addition of new electricity storage infrastructure, thus helping to speed the renewable energy transition.

Grid operators can also contract Bitcoin miners as grid assets, meaning grid managers can switch mining rigs on and off within minutes, rapidly addressing imbalances between electricity supply and demand. In addition, pricing incentives can be used to shape miners' behavior. For instance, if a miner had contracted to buy bulk electricity at a fixed price over a year, they are incentivized to stop mining when electricity demand is high. As electricity market prices surge, they can shut down mining rigs and sell their low-cost contracted power into the spot market to earn more than if it was used for mining.

13. What combinations of contextual factors, including the presence or absence of Bitcoin mining, help a grid to successfully transition to renewable energy?
14. How does the addition of Bitcoin mining affect the economic viability, net carbon emissions, and risk profile of electricity grids transitioning to renewable energy?
15. How does the addition of Bitcoin mining to an electricity grid affect the need for new generation and transmission infrastructure investments?
16. How do mandates about grid objectives and management responsibilities vary, and when and how can different types of Bitcoin mining strategies best help fulfill those mandates?
17. How does Bitcoin mining affect electricity grid resilience in the face of extreme weather events or other shocks?
18. How does large-scale Bitcoin mining affect electricity availability and costs for other electricity customers?

3.4. Bitcoin Mining—Site Choices and Costs

Understanding factors influencing Bitcoin's cost-of-production is important for understanding miners' site choices and their potential impact on energy use and carbon emissions, as well as on other UN Sustainable Development Goals, e.g., [40]. Miners are highly mobile, tending to cluster near sources of cheap energy [41]. How Bitcoin mining compares to other mitigation and negative emissions technologies, e.g., [42], in terms of the potential magnitude and cost of mitigation, may have a substantial impact on how accommodating governments are towards Bitcoin mining. Ascertaining where mining fits along the carbon mitigation marginal abatement cost [MAC] curve, e.g., [43] may be particularly useful. In some areas, Bitcoin mining may also help to bootstrap other kinds of mitigation technologies [44].

19. What are the determinants of Bitcoin miners' site, energy source, and technology choices, and how do changes in the availability or quality of those factors affect miners' production strategies and mobility?
20. How does the balance between small-, medium-, and large-scale miners affect Bitcoin's net carbon emissions profile?
21. How important are Bitcoin miners' upstream and downstream carbon emissions relative to emissions from mining itself?
22. How and why do Bitcoin's production costs vary globally, and how can they be assessed in the absence of financial reporting from private mining firms?
23. What is the levelized cost (revenue required to build and operate a facility over a specified cost recovery period) of Bitcoin mining for different regions, technologies, and energy types?
24. What is the marginal abatement cost of reducing greenhouse gas emissions by Bitcoin mining and how does that compare to other mitigation options?
25. How do motives other than profit maximization influence Bitcoin miners' investment choices and production strategies?
26. When and how can aging Bitcoin mining rigs best be re-used or recycled, and what is the true lifetime of a rig?
27. How widespread is small-scale (e.g., household) Bitcoin mining and, if significant, how can its energy use and carbon emissions be reduced?
28. How can waste heat from Bitcoin mining best be used as a resource for other purposes?

3.5. Bitcoin Security

Security is of utmost importance for the Bitcoin network and the reason that the Proof-of-Work (PoW) consensus, one of many different types of consensus algorithm [7], was chosen for Bitcoin. Bitcoin miners compete to solve SHA-256 cryptographic hashes (SHA-2 family algorithms were designed by the USA National Security Agency and are used widely beyond Bitcoin, including in the internet SSL/TSL certificates that keep web commerce secure) that give the first miner that correctly guesses the answer to the hash the right to write the next block of information to the globally distributed Bitcoin ledger and receive a bitcoin block reward (see [1,45,46] for accessible Bitcoin overviews). Solving an SHA-256 hash is random, so guessing and checking solutions ensures bitcoin is distributed, proportional to computing power, across the mining industry. Mining itself is open to anyone who wants to participate

Every transaction block created by a miner, and sequentially added to the blockchain about every 10 min, is verified independently and stored, along with the full ledger of all historic transactions, on every one of the >14,000 reachable computers currently acting as 'nodes' in the Bitcoin network (node count available at https://bitnodes.io/(accessed on 18 December 2022)). Any attempt to attack the network—to alter and falsify past ledger entries—would be prohibitively expensive and increases exponentially in cost over time as the network grows.

Questions relate to issues of whether Bitcoin provides an excessive level of energy-intensive security, beyond what is needed for the type of transactions it allows and the level of security it provides. If Bitcoin 'over-securitizes' transactions, there may be justification for using a different consensus mechanism with lower direct energy use for some types of transactions. The specialized Application-Specific Integrated Circuits (ASICs) used in Bitcoin mining computers to solve the SHA-256 algorithm are rapidly becoming more efficient, so technological development may, to some degree, offset the amount of energy needed to secure a growing Bitcoin network.

29. Can a truthful and secure record of global transaction history be maintained without the Proof-of-Work consensus and, if so, how do alternative consensus algorithms differ in their net ESG impacts?

30. For which use cases can less energy-intensive proof-of-stake ‘altcoins’ match or exceed Bitcoin’s potential direct and higher-order ESG benefits, and, conversely, which use cases and ESG benefits can only be fulfilled by the Bitcoin network?
31. How much security is ‘enough’ for the Bitcoin network?

3.6. Retail, Institutional, and National Bitcoin Adoption

Market demand drives bitcoin price action and miners’ profitability and, thus, changes in energy demand and carbon emissions. ESG certification schemes can, in theory, provide signals that correct for market failures (much like a fair-trade label, ESG certification is a ‘credence attribute’ [47] that can affect market price). Holding bitcoin as part of a portfolio can also change the portfolio’s aggregate carbon intensity, e.g., [48]. Similar considerations apply at the institutional level, where other criteria (e.g., portfolio allocation limits, daily ESG holdings mandates) may further affect bitcoin demand.

State-level investment options vary from incorporating bitcoin holdings into sovereign wealth funds to full adoption of bitcoin as legal tender, a measure that El Salvador took in 2021. Issues of USA dollar hegemony and geopolitical conflict appear to be increasingly important in the context of Bitcoin (and central bank digital currency—CBDC) adoption internationally [49].

32. What are the key technical, economic, social, political, and cultural determinants of the adoption of bitcoin as money?
33. How best can Bitcoin reduce the transaction costs of payments, banking, and other financial transactions?
34. How will the adoption of Layer 2 technological advances (e.g., Lightning Network’s capacity to bundle and process small bitcoin transactions off-chain) affect Bitcoin’s electricity consumption and ESG performance?
35. How do ‘green mining’ certification schemes affect retail and institutional investors’ willingness to pay for sustainably mined bitcoin?
36. How much could carbon offset and renewable energy certificate (REC) schemes reduce net carbon emissions, and how do the strategies compare?
37. How do levels of trust in a society affect the likelihood, rate, and impact of Bitcoin adoption?
38. What is the relative importance of environmental, social, and governance criteria for institutional ESG-oriented Bitcoin investors, and how do they make trade-offs among different factors?
39. How could bitcoin’s widespread adoption as money affect international trade patterns and wealth distribution?
40. What are the economic and ESG opportunity costs for nations not adopting Bitcoin?

3.7. Governance

How might Bitcoin transform governance and, conversely, how could governance transform Bitcoin? For governments, there is likely tension between embracing a financial innovation that lowers transaction costs for consumers and firms, but possibly erodes the capacity of governments to use monetary and fiscal policies to manage domestic interest rates, employment rates, and social programs, and shape societal wealth distribution. Governments may be reticent to adopt Bitcoin, opting instead for other blockchain-based solutions such as government-controlled CBDCs. Within governments, there is no guaranty of consistent goals, policies, or regulations across departments.

Decentralization’s impact on economic performance is complex [50]. The impact of bitcoin as a decentralized currency likely has important impacts on governance transaction costs (i.e., the costs of running a governance system, including those arising from negotiation, litigation, and strategic behavior) and the efficiency-maximizing scope of governance, the degree to which governance should be centralized, decentralized, or devolved (more power to non-government actors). Williamson [51] first applied transaction cost economics to firms but it is also applicable to governance systems e.g., [52]. In some cases, devolution may enable non-state actors to coordinate and cooperate on problem-solving for issues of common concern e.g., [53]. Climate change mitigation needs to consider international free-riding incentives and adaption to climate change will require shared international financing; both may benefit from increased levels of trustless transactions [2] and blockchain-enabled cooperation [54].

41. Under which circumstances and in what contexts would governments prefer to adopt Bitcoin rather than a CBDC?
42. What environmental, social, and governance outcomes are most important to governments, and how does Bitcoin adoption help or hinder them to achieve that?
43. How might governments balance the costs and benefits of regulating Bitcoin mining and adoption relative to the benefits they derive from tax revenues?
44. How will Bitcoin redefine and restructure political power over time?
45. How could widespread international Bitcoin adoption lead to more participatory forms of governance?
46. How could widespread international Bitcoin adoption affect the ability of G7 countries and international financial institutions to shape international relations?
47. How can Bitcoin mining and adoption best be aligned with national and international ESG-oriented treaties and commitments?
48. If, in the future, Bitcoin was adopted as a reserve currency, how would that affect nations' capacity to govern domestically and influence international relations?
49. How does Bitcoin affect governments' capacity to enact monetary and fiscal policy, and does that constrain or catalyze good governance?
50. How can poor nations leapfrog richer countries with regard to Bitcoin adoption, and what would the impact be on trade, development, and poverty alleviation?
51. How best could Bitcoin be used to implement universal basic income (UBI) and other targeted social support initiatives?
52. How can governments create a stable and internally consistent regulatory environment for Bitcoin miners and investors?
53. How do different government regulatory and non-regulatory intervention options affect Bitcoin mining profitability and behavior?
54. How can regulatory and non-regulatory market mechanisms incentivize sustainable Bitcoin production, and how do options compare with regard to emissions levels and control costs?
55. How do ESG and other political factors influence the regulatory options available to governments to manage Bitcoin mining and adoption?
56. When and how might Bitcoin mining and adoption be strategically supported by governments in order to build prosperous national and regional economies resilient to external shocks?
57. How does the 'optimal' amount of governance decentralization or devolution change as Bitcoin increasingly decentralizes financial transactions?

3.8. Values and Beliefs

People's willingness to adopt Bitcoin is potentially affected by many factors. One of the core issues is how and why individuals perceive adoption as a threat or as an opportunity, and how constraints affect their intended behavior. Intentions are shaped by a person's worldview and the information they can mobilize; actual behavior also depends on resource constraints, regulations, and social norms [55].

A number of interviewees highlighted how many Bitcoiners believe that Bitcoin adoption causes a shift in personal values and, subsequently, influences their purchasing behavior. For example, the terms 'fiat food' and 'fiat education' were used to describe changes in individuals' time preferences, and their shift from low- to high-quality products that provided households with enduring value and resilience. Confluence in perspectives among right-leaning Bitcoiners and degrowth-oriented ecosocialists [56] might be a surprising region of common ground if Bitcoin adoption really influenced time preferences and consumption patterns.

58. How does Bitcoin adoption affect the values, time preferences, and behavior of individuals, firms, and governments?
59. How do Bitcoiners and non-Bitcoiners differ in their willingness to make trade-offs among different liberties?
60. What influence does a person's life experience have on his or her willingness to adopt Bitcoin?
61. How does Bitcoin adoption affect peoples' perceived threats and opportunities, and influence their visions of feasible futures?
62. How does Bitcoin adoption and use vary among individual- and community-oriented cultures?
63. Does Bitcoin adoption affect consumer preferences and, if so, what impact could that have on energy consumption and waste streams for consumer products?
64. How does the libertarian goal of self-sovereignty influence the lens through which people view their environmentally relevant personal health and lifestyle choices?
65. How does the availability of credible information affect Bitcoin adoption?
66. How does Bitcoin adoption directly and indirectly affect freedom, innovation, prosperity, and societal flourishing?
67. Does using bitcoin make a person unpatriotic?

3.9. Inflation and Discount Rate

A low discount rate is critically important to firms and governments making long-run climate mitigation investments that require substantial up-front financing but for which the flow of future benefits may not accrue for decades. Rampant inflation is a reflection of high levels of social and economic uncertainty that, in severe hyperinflationary cases, renders information about the recent past irrelevant and reduces humanity's capacity to predict the near future [57]. The choice of an appropriate discount rate for climate change investments has been contentious among environment economists for over a decade [58–60].

If Bitcoin can truly help hedge against inflation, lower discount rates may increase the likelihood of private and public sector investors taking the long-term view needed to fill the CO2e emissions gap. In a high-inflation world, there is little financial incentive to invest in mitigation; the default position would likely be to wait to see what happens and adapt to environmental change only when it becomes absolutely necessary to do so even if, by that time, major environmental tipping points had been exceeded.

68. How does, and could, Bitcoin help control inflation and reduce the discount rate?
69. How would Bitcoin's impact on discount rates differentially affect high-, medium-, and low-income households and nations?
70. How would low discount rates affect the quantity and quality of goods and services sold in an economy, and would it result in lower aggregate energy use, household consumption, and carbon emissions?
71. Would liberals, who may tend to favor inflationary fiscal policies, be more likely to adopt Bitcoin if it helped lower discount rates and increased the financial viability of long-run mitigation efforts?

3.10. Adaptive Capacity

Widespread Bitcoin adoption may play a role in helping to build adaptive capacity among households, communities, and governments, helping to buffer the adverse effects of climate change when they manifest. Vulnerability to a shock is often viewed as a function of a household's or nation's (1) exposure, (2) sensitivity, and (3) adaptive capacity [61]. Access to capital, literacy, health factors, civil liberties, political rights, and governance effectiveness are all factors that influence vulnerability at multiple levels [62]; mobility, e.g., [63], social capital [64], and institutional constraints [65] are other factors affecting household-level adaptive capacity. Bitcoin adoption has the potential to affect many of those determinants, so higher-order impacts on adaptive capacity may well be anticipated.

72. How does Bitcoin adoption affect the resiliency and adaptive capacity of households, communities, firms, and governments?
73. How could decisions by government to constrain or encourage Bitcoin adoption affect the country's capacity to adapt to social and environmental change over the long run?
74. When and how do government monetary and fiscal policies affect the capacity of households and communities to mitigate against, or adapt to, environmental change?

3.11. Narratives

While blockchain narratives often address the promise of controlling climate change [66], Bitcoin mining and adoption are now the focus of competing, acrimonious narratives. Interview transcriptions suggested that some of the classic misinformation strategies [67,68] are now mobilized—by both sides—in the Bitcoin space. There is a need to build an understanding of how and why narratives develop and spread, how misinformation can be combatted, and how different actors with different motives might form coalitions to advance or undermine particular policy positions. Policy research theories or methodologies—the advocacy coalition framework [69], narrative policy analysis e.g., [70], instrument constituencies e.g., [71], etc.—may prove useful when sorting out motives for strategic policy alliances of groups advocating particular Bitcoin narratives.

One point clear from the interviews was that even Bitcoiners who view climate change as a serious threat were still very skeptical of the Bitcoin-ESG narrative. Bitcoiners' often perceived BlackRock's advancement of the ESG narrative [72] as a profit-maximizing corporate strategy.

75. How and why do organizations with differing worldviews and core values cooperate to advance or oppose Bitcoin mining and adoption?
76. How and why does Bitcoin mining and adoption become politically polarized when it has the potential to address issues that both conservatives and liberals prioritize?
77. What role have BlackRock and other large institutional investors played in the development of the global ESG narrative and how do the company's actions affect Bitcoin's institutional adoption?
78. How can Bitcoin skeptics become more 'solution agnostic' if and when credible evidence points to the potential for Bitcoin mining and adoption to help control climate change?
79. How can Bitcoin mining and adoption be framed in terms of modern sustainability and degrowth narratives?
80. To what extent do Bitcoin critics and advocates have undisclosed conflicts of interest that would compromise the credibility and legitimacy of their messaging?
81. What are the financial, human, and social costs arising from cryptocurrency scams or investors' confusion over the purpose and capabilities of altcoins relative to Bitcoin?

3.12. Knowledge Creation and Communication

Research on Bitcoin's impact on ESG factors will require complex, transdisciplinary research that engages researchers, industry practitioners, investment firms, and government policymakers in the co-production of knowledge. There is a need for high-quality research [73] but there also needs to be recognition that the boundaries between credible and non-credible evidence may be disputed. For example, should industry-based knowledge about Bitcoin mining economics be integrated into research by academic economists? Asking miners and academic economists may lead to very different opinions on what constitutes credible knowledge.

Credible research on Bitcoin's energy use and ESG impact is only one step in the process of mobilizing knowledge. There is still a need to synthesize research from many sources and communicate those findings to decision-makers [74]. The 'honest broker' role that bridges science and policy usually falls to specialized knowledge brokers at the science-policy interface [74,75], who sometimes may be senior scientists trusted by, and with access to, decision-makers e.g., [76,77]. Complicating the communications and knowledge mobilization challenge, some types of governments frame climate change differently (i.e., economic, environmental, technological mitigation, or adaptation orientations) and prefer different types of policy solutions [78].

82. How can credible scientific evidence be created, synthesized, and effectively communicated to skeptical Bitcoiners and Bitcoin skeptics?
83. How can a systematic research program on Bitcoin's net energy use and ESG impacts be structured, funded, and incentivized?
84. How can Bitcoin research results be framed and disseminated to ensure that key findings are available for integration in international energy and climate change syntheses?
85. How and why do academic researchers, industry researchers, and policymakers differ in how they prioritize Bitcoin energy use and ESG research needs?
86. What measures could synergize industry–academic–government collaboration in Bitcoin research projects?
87. How can the Bitcoin narrative best be framed so that its net effect on energy use and ESG impacts is effectively communicated to the public, investors, and policymakers?
88. How best can knowledge brokers facilitate communication between decision-makers and Bitcoin researchers?
89. What resources could best help communications professionals to ensure the veracity of their reporting on Bitcoin's energy use and ESG impact?
90. How can Bitcoin's core purpose and features best be communicated to people who see little or no utility in Bitcoin?

3.13. Social Impacts

Bitcoin advocates wove together many stories about how Bitcoin influences household, community, and national social and economic well-being, with particular emphasis on vulnerable individuals and communities, and those living in nations with repressive governments. Bitcoin's social impacts—arising from Lightning Network's capacity to provide virtually free, permissionless financial transactions to anyone with a cell phone—are likely to be significant and have complex spin-off effects on environmental and governance issues.

The links between poverty alleviation and climate change action are well known [79], as is the role that reducing women's financial exclusion plays in shifting intrahousehold bargaining power and improving household well-being [80]. Human rights abuses and financial censorship, e.g., [81–83] also have important impacts on human well-being. All these factors suggest that there are likely higher-order Bitcoin impacts on households' capacity to adapt to climate change and other stressors. Higher-order impacts are, of course, much more challenging to research as an attribution of outcomes to specific causal factors can be difficult to tease out.

91. How much money can be saved by expatriate workers using international Bitcoin remittance services, and how do those savings impact poverty alleviation, resilience, and wealth inequity in their home countries?
92. How could Bitcoin adoption affect the ability of the world's unbanked to access financial services and how would that impact poverty and household well-being?
93. How does Bitcoin enhance and unlock human capital globally, and what effects would that have on poverty alleviation?
94. How best can Bitcoin be used to empower women?
95. How can Bitcoin adoption affect the capacity of individuals and organizations to escape, cope with, or challenge repressive political regimes?
96. How does Bitcoin mining and adoption influence human migration, rural regeneration, and regional economic development?

97. Under which circumstances and in which regions could Bitcoin mining displace existing industries, and what are the net economic and ESG impacts of displacement?
98. How can Bitcoin be used to enhance the ability of donors and charities to operate more efficiently and better achieve their philanthropic goals?
99. How best can Bitcoin be used to reduce losses due to administrative costs, theft, and graft along the foreign aid and disaster relief funding supply lines?
100. What are the benefits and dangers to vulnerable households and communities from a 'Bitcoin adoption experiment'?

4. Discussion

For this paper, I modified the standard participatory key questions methodology [12] and drew from Bitcoin-oriented, long-form, social media interviews with a variety of experts to identify 100 questions that, if answered, would provide credible evidence to support policymakers', investors', and research funders' decision-making on issues relating to Bitcoin's energy use and ESG impacts. Thought leader interviews have sometimes preceded public candidate question solicitations [13] but, due to past technology limitations, not at the scale used in this exercise (>88 h of interviews).

The choice of the 100 questions included in this list was by necessity subjective. First, the interviews were drawn from Bitcoin-oriented broadcasts with pro-Bitcoin experts, so not all relevant energy and ESG issues were necessarily covered. Second, my own disciplinary training (environmental economics and policy research) may have an impact on how various questions were framed. Third, not all 100 questions on the list will remain when they are subject to scrutiny by subject matter specialists and decision-makers. Some may already be answered in sufficient detail that they could be relegated to a FAQ for Bitcoin energy and ESG impacts; other questions may prove to be of marginal salience for decision-makers.

This list of 100 questions should be viewed as a first step in prioritizing a Bitcoin-energy-ESG research agenda. A logical second phase would be to next identify potential gaps in the list, prioritize research needs, and frame high-level questions in terms of specific research objectives and tasks. Several options could be used: (1) a cross-disciplinary and -sectoral group of experts tasked with narrowing the pool of important questions and clarifying high-priority research e.g., [16]; (2) a survey of a broad selection of scientists, policymakers, and industry and NGO actors, from which research questions could be prioritized, e.g., [25,26]; and (3) semi-structured interviews with senior researchers, industry and NGO actors, and government regulators and policymakers, from which it may be possible to identify potential alignments in research priorities among interviewees (i.e., the 'low hanging fruit'). Given the difficulty in defining a sample frame and constructing an adequate sample in the nascent Bitcoin research field, the first and third options seem most suited for follow-up efforts.

4.1. Taking Bitcoin Seriously in Policy Analyses

There is a pressing need to reduce net greenhouse gas emissions [27,29] and to increase society's adaptive capacity with regard to climate change [61,65]. Many solutions will play a part in the emissions reduction portfolio, e.g., [28,42,84]. Bitcoin is generally not recognized as a potential greenhouse gas emissions control lever in climate or energy research, e.g., [85], nor the syntheses [27,30] that are critical for getting emerging technologies onto the mitigation radar screen. If Bitcoin does affect net emissions, mitigation likelihood, and adaptive capacity, serious efforts to understand its role as an option in the climate change toolkit should be implemented as soon as possible.

Answers to well-articulated research questions can help ensure appropriate scenarios are used in policy analyses, and that their relevant direct and indirect outcomes and impacts are fully considered. Having an understanding of what questions are already answered and where the key knowledge gaps remain can help immediately eliminate poorly conceived alternatives from the pool of candidate policy solutions, e.g., [86] or identify policy options 'that nobody hates' and on which consensus might be possible, e.g., [77]. Key questions exercises may change the way decision-makers think [87] because of an exercise's 'conceptual impact' [88], which sensitizes decision-makers to emerging policy challenges. While decision-makers may not act immediately, conceptual impact implies they will be pre-disposed to act when an appropriate opportunity arises.

The range of important questions in this exercise highlights the need to undertake sophisticated cross-disciplinary and -sectoral research that supports credible decision-making regarding Bitcoin mining and adoption. There are a number of steps in the knowledge mobilization process, each of which requires effort and the application of best practices [74]. The core needs are for: (1) the production of credible, defensible knowledge from individual research projects and programs; (2) the synthesis of Bitcoin-oriented research results to help integrate relevant findings into the broader energy and climate change research landscape and the international syntheses that are central for advancing international mitigation and adaption policy; and (3) effective communication of research and synthesis findings to decision-makers in the investment, regulatory, and policy communities.

4.2. Advancing Research on Bitcoin's ESG Impacts

Bitcoin is a recent invention and, to date, has attracted relatively little academic research interest and, to my knowledge, no major, cross-disciplinary research programs. This suggests that a concerted effort will be needed to rapidly build up the human (technical expertise) and social (network connections) capital needed to increase cross-disciplinary research capacity and undertake credible cross-cutting research on Bitcoin.

Given the diversity and complexity of the 100 questions, multiple major research projects would likely be needed to address the highest priority issues arising from this list. Some may be stand-alone projects while, in other cases, it may be possible to incorporate smaller Bitcoin-specific work packages within larger energy- and ESG-oriented research projects. It is readily apparent that funding and incentivizing cross-disciplinary Bitcoin-energy-ESG research, and building research capacity will take time. Even if funders were to emerge quickly, research outputs will require a significant lead time. Integrating Bitcoin research within broader energy and ESG research efforts would require researchers who understand how the environmental science enterprise functions, have productive relationships within the energy and climate research fields and are able to advocate for the inclusion of Bitcoin-relevant work packages in cross-cutting research proposals being submitted to large funding programs.

5. Conclusions

The breadth of knowledge required to answer key questions from this analysis highlights the need to develop a prioritized research agenda, build research capacity, and encourage collaborative cross-sectoral and -disciplinary research on Bitcoin and its energy and ESG impacts. The key questions process could help to stimulate wide debate on the knowledge needs in the Bitcoin space and plans for initiating and funding specific research activities. The results from this study may help lay the groundwork for further work prioritizing Bitcoin academic and industry research needs, catalyze communications among actors at the Bitcoin science–policy–practice interface, and stimulate discussions on how best to build the evidence base that supports investment decisions and policy-making efforts regarding Bitcoin mining and adoption.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/challe14010001/s1, Supplementary Material Table S1—Sources from which questions were drawn. Table S2—Comparison of top 50 keywords from all (n = 747) and selected (n = 68) transcriptions (green are keywords common to both lists). Figure S1—Top 20 keywords in n = 68 interviews (% of total keywords in transcripts). Figure S2—Top 20 keywords in all n = 747 interviews (% of total keywords in transcripts). Figure S3—Cluster analysis of keywords for the n = 68 selected interviews. Figure S4—Cluster analysis of keywords for all n = 747 interviews.

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