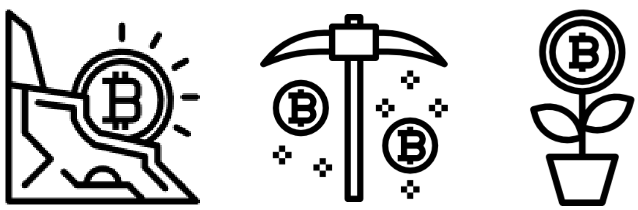

The Positive Externalities of Bitcoin Mining

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Saad Imran, Head of Research (@xsaadimran)

www.nodeblockchain.io | @node_blockchain

Node Blockchain
300 – 100 Broadview Ave
Toronto, ON M4M 3H3
info@nodeblockchain.io | www.nodeblockchain.io

Introduction

If your understanding of Bitcoin mining was limited to what most mainstream media outlets have reported since December, you would think the environmental impact to date has been disastrous. Some have even gone as far as noting Bitcoin as a serious climate threat[1]. Although this coverage makes for some great click-generating headlines, it has focused solely on the perceived negative externalities of Bitcoin mining.

This paper will provide an alternative view, as we look to explore the positive externalities of Bitcoin mining. We hypothesize that Bitcoin will improve the efficiency and allocation of our energy usage worldwide. This is through to Proof-of-Work mining, a process critical to ensuring the decentralization and security of the network, in which there is a direct incentive for individual miners to efficiently utilize energy and allocate their capital accordingly.

The first stage – hardware innovation

We believe mining will evolve in stages. The first stage focused on innovation within the hardware used in the process. It evolved from CPU mining in the early days, to GPUs, to ASIC mining. This brought with it an enhanced security model for the network. Furthermore, the introduction of ASICs resulted in the beginnings of organized large-scale, industrialized mining. During this stage, the majority of costs associated with Bitcoin mining (50-70%) were the upfront cost of capital. This was largely due to the break-neck pace at which innovation in the hardware was happening, resulting in a contraction of the useful life of the equipment. The most profitable miners during this stage were those producing and innovating mining hardware. Naturally, this drew many new competitors into the hardware space following the success of the incumbent, Bitmain, leading to what is now a growing ecosystem of hardware options available for prospective miners.

The second stage – reallocation and innovation within energy markets

As the industry matures, the rate of incremental hardware improvement will slowly taper down due to the rising marginal costs of such improvements, a development we are slowly seeing come to fruition. This leads to what we believe to be the second stage within this industry, one with a heightened focus on improving the efficient use of energy. As the cost dynamics shift from hardware to optimizing operating costs (the biggest of which is electricity), the incentive system rewards those that innovate with their usage of energy.

This starts with optimizing PUE, or power usage effectiveness of the data centers setup for mining. PUE is a measure of efficiency within electricity usage and is calculated as a ratio of total electricity used vs electricity used directly by the equipment for mining. We believe best practices and innovations developed in mining (such as in cooling technology and other aspects of operations) can be translated to the traditional data center sector (an industry that utilizes 133x the electricity Bitcoin mining does today).

The next step revolves around a global energy arbitrage opportunity. Our world is increasingly connected digitally, however, due to physical limitations, is still quite fragmented in many areas. This is

[1] https://www.theguardian.com/technology/2018/jan/17/bitcoin-electricity-usage-huge-climate-cryptocurrency

evident in energy markets worldwide. Since the physical location of mining centers is not important to the Bitcoin network, miners flock to areas generating surplus electricity for the lowest marginal costs. In the long-run, this has the potential to produce more efficient worldwide energy markets with Bitcoin miners performing an arbitrage of electricity between global centers.

As miners continue to optimize their marginal costs, they will look increasingly towards utilizing renewable energy sources. The renewable energy sector has reached an inflection point; increasing innovation within the space has lead to an environment where the marginal cost of renewable energy is lower than the marginal cost of fossil fuel powered energy[2]. As a result of this dynamic, in the long-run we expect Bitcoin miners to shift the majority of their energy usage to renewable energy sources. Once existing sources of excess supply have been utilized, we expect miners to deploy their own sources of renewable energy that have cheap/low marginal costs. If the long-term economics make sense, they will make such commitments pushing down our global usage of fossil fuels for electricity.

Lastly, we expect to see an innovation push from miners to reuse what would have otherwise been 'wasted' energy. We highlight a few early examples of this today and expect this trend to grow in the future.

Bitcoin mining – Proof-of-Work

Before we dive further into the paper, we must first explore Bitcoin mining and Proof-of-Work. When Satoshi Nakamoto introduced Bitcoin to the world in 2009[3], it was presented as 'a system for electronic transactions without relying on trust'. They cited the need for such a system due to what they believed to be a dangerous reliance on financial institutions as trusted third parties in commerce. This was after the fall-out of the '09 financial crisis. In fact, the Bitcoin genesis block holds the message "The Times 03/Jan/2009 Chancellor on brink of second bailout for banks" highlighting their distaste for the current financial system.

The biggest fallback with proposed e-cash systems prior to Bitcoin was the 'double-spending' problem. This was because the only proposed solution to resolve this issue was introducing a trusted central authority that would check each transaction. This is no different than the primary weakness in the system which already exists. To solve this problem, Satoshi proposed a peer-to-peer distributed timestamp server that generates computational proof of the chronological order of transactions. This was dubbed "Proof-of-Work".

How this works is as follows: once transactions are broadcast within this network, nodes (known as miners in this network) collect transactions within a block and compete to find the solution to a difficult 'Proof-of-Work'. The first to solve this, broadcasts the block to all nodes within the network who would only accept the block if all transactions within are valid and not already spent. Blocks are chained as they are solved and broadcast within this network. This means that a single block cannot be changed without redoing the 'work' for this block and all those that are chained subsequent to it. This public history of transactions quickly becomes computationally impractical for an attacker to change. The peer-to-peer network is distributed and decentralized and as a result it has no single point of control or failure.

[2] https://ase.tufts.edu/gdae/education_materials/modules/RenewableEnergyEcon.pdf
[3] https://bitcoin.org/bitcoin.pdf

There is an incentive for nodes to support the network, which is also the mechanism through which coins are initially distributed into circulation (no central authority issues them). This incentive encourages nodes to stay honest. An attacker that is able to assemble greater than 51% of the compute power within the network has the choice to either defraud users by stealing back their payments, or use it to generate new coins. Satoshi asserts that they will find it more profitable to play by the rules, as generating new coins would be more beneficial than undermining the system and therefore the validity of their own wealth.

In summary, Proof-of-Work mining is what secures Bitcoin as a decentralized and distributed tamper-resistant network and ensures coins are distributed fairly within a competitive system. Now that Bitcoin mining is conducted using specialized hardware (ASICs), miners have significant skin in the game. If you wanted to control a majority of the compute power on Bitcoin today (>51% which you would need to either attack or control the network through changes) you would need to spend over $1.1 billion in hardware alone. If instead you use this resources to power the network, you have the shot to earn up to $11.7M daily.

Bitcoin's energy footprint

There have been multiple studies performed on Bitcoin's energy footprint. We find Marc Bevand's work as one of the most accurate representation of this today[4]. This methodology estimates a lower and upper bound based on the efficiency of mining hardware available, as well as, the hashrate currently active on the network (a bottom-up approach). Using this methodology, we have calculated the estimated direct power consumption of the network as of July 2018.

JULY 2018

	Lower bound	Estimate	Upper bound
Power Consumption (MW)	2,269	3,115	3,960
Energy Consumption (TWh/yr)	19.90	27.31	34.73
Percentage of world's energy consumption	0.0121%	0.0166%	0.0211%
Percentage of world's electricity consumption	0.0904%	0.1241%	0.1577%
Energy Efficiency (J/GH)	0.057	0.079	0.1
Electricity cost (million USD/yr)	$ 995	$ 1,366	$ 1,736
Global Hashrate (TH/s)	39,602		

Source: Marc Bevand[5], Enerdata, Blockchain.info, Node Blockchain calculations[6]

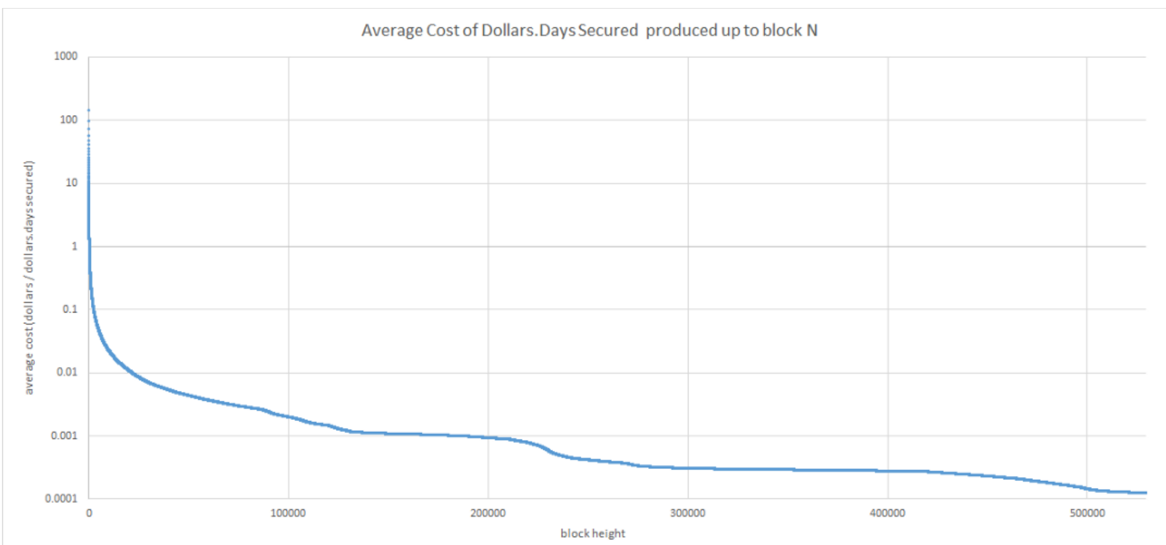
Through our calculations above, it is evident that relative to the total energy consumption in the world today, Bitcoin's energy footprint is miniscule. You can present these numbers in a way that make them look extremely large (Bitcoin uses as much energy as 1M transatlantic flights[7] or Bitcoin uses more energy than the Czech Republic[8]) or the opposite (Bitcoin uses less electricity than decorative Christmas

[4] http://blog.zorinaq.com/bitcoin-electricity-consumption/#fn:elec
[5] http://blog.zorinaq.com/bitcoin-electricity-consumption/#fn:elec
[6] Enerdata figures are for year-ended 2017, electricity cost of $0.05 USD/kWh assumed for calculations.
[7] https://www.theguardian.com/technology/2018/jan/17/bitcoin-electricity-usage-huge-climate-cryptocurrency
[8] https://www.forbes.com/sites/francescoppola/2018/05/30/bitcoins-need-for-electricity-is-its-achilles-heel/#7f023f572fb1

lights around the world[9] or idle appliances in the US use three times more electricity than Bitcoin mining[10]).

We note from Marc's work in July of 2017 that energy consumption has increased 3-fold within a year and the global hashrate has increased 6.57x. This is due to a doubling in the average energy efficiency of Bitcoin mining hardware within a year. To add further context to these figures, in the same time frame, the market value of the network has increased to $110B from $40B within a year.

Those critical of this increasing energy usage will often compare and calculate 'Bitcoin's energy usage per transaction'[11]. This metric is used to compare Bitcoin's energy footprint to that of traditional payment transaction processors such as Visa. This comparison is often cited to show that Bitcoin uses several thousands of times more energy per transaction than Visa[12]. Calculating and comparing this metric is a fundamental misunderstanding of what Proof-of-Work is. As we discussed, to modify a past transaction, an attacker would have to redo the Proof-of-Work of the block it was included in and all blocks after it until they catch up and surpass the ongoing Proof-of-Work on the blockchain. Essentially, the current electricity usage doesn't just secure active transactions on the network, it secures the combination of all previous transactions before them as well. A recent article posted by 'LaurentMT' summarizes this concept brilliantly – **"The main utility of Bitcoin's Proof-of-Work is to secure an economic history"**[13]. His work shows that, Bitcoin's Proof-of-Work is becoming more efficient over time:



Source: 'LaurentMT'[14]

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[9] The US alone spends 6.63 TWh/yr on Christmas lights: https://www.energy.gov/sites/prod/files/maprod/documents/Energy_Savings_Light_Emitting_Diodes_Niche_Lighting_Apps.pdf

[10] Idle appliances and electronics utilize 100 tWh annually https://www.usatoday.com/story/tech/columnist/komando/2012/10/26/komando-electric-bills/1649195/

[11] https://digiconomist.net/bitcoin-energy-consumption

[12] https://digiconomist.net/bitcoin-energy-consumption

[13] https://medium.com/@laurentmt/gravity-10e1a25d2ab2

[14] https://medium.com/@laurentmt/gravity-10e1a25d2ab2

As concluded above, although it may seem counterintuitive that efficiency is increasing as the absolute cost of Proof-of-Work (increased energy usage) increases over time, **it is counterbalanced by the increasing total value secured by the system**.

The positive externalities of Bitcoin mining

There's no denying that looking at absolute figures, the Bitcoin network utilizes a lot of energy. The focus to date for most mainstream coverage has been the negative externalities of mining. We explore several positive externalities of Bitcoin mining.

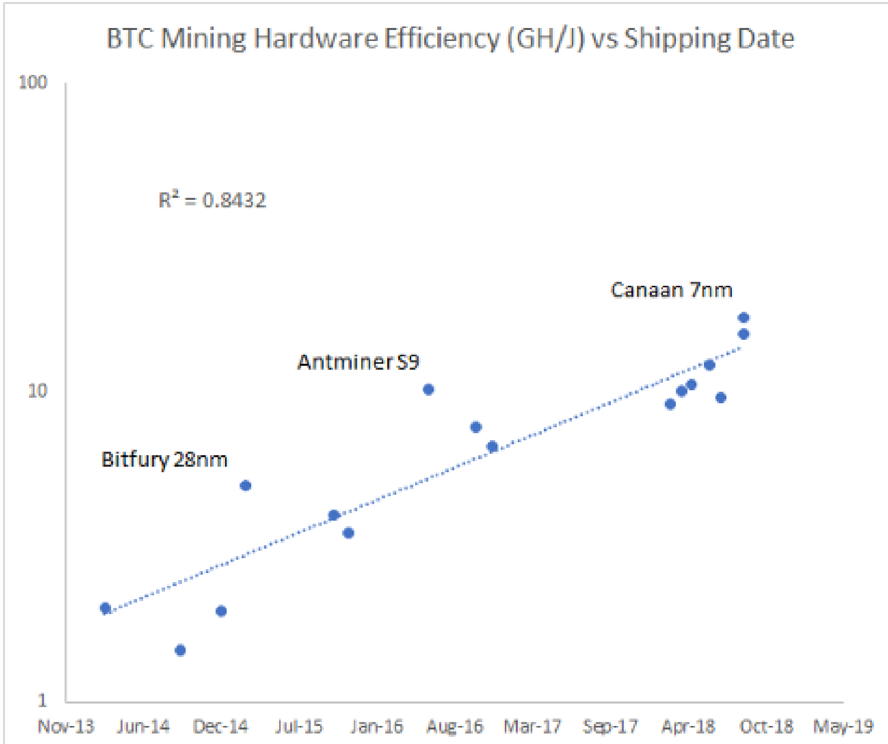
Mining hardware — efficiency gains

The mining industry has matured significantly since its humble beginnings. What was once a 'fun hobby' is now a booming multi-billion dollar industry. There has been significant capital deployed in the development of Bitcoin mining hardware. What started on CPUs, to GPUs, is now dominated by special purpose built hardware — ASIC chips.

ASICs improve the security of the network by forcing attackers to deploy significant capital to attack the network. General purpose chips such as GPUs and CPUs can be borrowed from other businesses and services (such as data centers) whereas, special purpose chips such as ASICs must be bought in the market.

ASICs have also improved the security of the network through improvements in the overall compute power dedicated. This was achieved through increasing efficiency, measured a GH/J (gigahashes relative to joules of energy used). Bitcoin miners are rewarded for increasing their marginal revenues (by increasing their relative hashpower) and decreasing their marginal costs (by using more efficient hardware). There is a direct incentive mechanism, in the form of mining rewards, to build chips that create more compute power per unit of energy dissipated. There is a long-standing trend in computing hardware known as Koomey's Law[15], which asserts that the number of computations per joule of energy dissipated doubles approximately every 1.5 years. We performed an analysis of Bitcoin mining hardware efficiency since ASIC chips were introduced and noticed an accelerated trend:

[15] https://en.wikipedia.org/wiki/Koomey%27s_law



Source: Node Blockchain Research[16]

Since ASICs were first introduced in March 2014, efficiency has improved by 872%. This means efficiency has been doubling every year, outpacing Koomey's Law. Intuitively, this makes sense as there is a direct incentive to innovate. Every incremental increase in efficiency directly impacts your bottom line as a miner. Whereas, in the general computing ecosystem there are only indirect incentives to innovate (such as longer battery life for mobile devices).

ASICs – more than mining

By design, Bitcoin ASICs can only be used for one purpose. That said, we believe the manufacturers can transfer the knowledge, facilities and capital gained through the development of these chips into other ASIC applications, such as AI (specifically within machine learning).

Google recently launched an ASIC chip that accelerates its internal machine learning algorithms and empowers others to use the same via Google Cloud for their own AI applications[17]. As AI applications transform every industry from healthcare to agriculture, the demand for computing power will continue to rise. Nvidia reported that over 20% of its revenue now comes from AI chip demand and this stream

[16] Calculated using reported data from manufacturers and as of date available for commercial purchase (Bitmain, Bitfury, Canaan, GMO, Halong and Pangolinminer).

[17] https://www.forbes.com/sites/moorinsights/2017/05/22/google-cloud-tpu-strategic-implications-for-google-nvidia-and-the-machine-learning-industry/#2679e8773af7

has shown a 524% growth over the last four years for the company[18]. The global AI chip market is expected to reach $91.2B by 2025, increasing at a 45.4% compounded annual growth rate[19].

Bitcoin ASIC producers may have the right mix of ingredients to take advantage of this growing market. Their years of experience provide them with best practices and innovations to redeploy into AI specific ASICs. Furthermore, those that succeeded during the mining boom have built up a vast pool of valuable talent, strong supply chain relationships and efficiencies through both vertical integration and operational economies of scale through their capital expenditure. Most are also well financed (the chip market is highly capital intensive) through cash flow from operations and significant investor interest.

In fact, Bitmain, which is the largest producer of Bitcoin ASICs has already developed and launched an AI focused ASIC. Their internal projections indicate that AI applications will generate 40% of their revenues in the next five years. In the last five years, since developing the first mass-produced and sold ASIC chip, the company has captured 8 percent of the domestic chip design market in China. It took Huawei HiSilicon (the incumbent) 14 years to achieve 17 percent[20]. Bitmain is expected to go public this year with over 500 employees in their R&D department alone and $1.1B of reported profits in the first quarter of 2018[21]. Although it still may be too early to determine if their product will actually be successful or if the AI chip market will transition in any meaningful way to ASICs; we believe there is potential for Bitcoin mining hardware manufacturers to have an impact in this industry.

Optimizing PUE (power usage effectiveness) in data centers

PUE is a ratio to define how efficiently a data center uses energy. Specifically, PUE measures the ratio between how much energy is used by the computing equipment in contrast to cooling and other overhead. A study published in 2017 that analyzed average PUE for traditional data centers in Europe shows a range of 1.6–1.8[22]. Bitcoin mining data centers on the other hand, have reported PUE as low as 1.03–1.33[23]. This goes back to our comments on the direct incentives in mining. Bitcoin mining data centers aggressively optimize their energy usage to maximize their bottom line by reducing their costs. It is through this that they have developed several best practices to optimize their data center PUE.

Traditional data centers reportedly use roughly 416 TWh/yr of electricity, which equates to 2.22% of worldwide electricity (133x more than Bitcoin mining today)[24]. Using the data above, they operate at a PUE which is 44% less efficient than Bitcoin mining server. At their average PUE ratio, roughly 41% of their electricity is not being directly utilized in the computing processes they are built to perform. If traditional data centers are able to improve their PUE by even an insignificant 2% through any best practices developed by Bitcoin mining centers, they would save an estimated 37.72 TWh/yr, which is greater than the entire electricity consumption of Bitcoin mining as of July 2018.

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[18] https://qz.com/1202851/artificial-intelligence-revenue-soars-for-nvidia-nvda/
[19] https://www.alliedmarketresearch.com/artificial-intelligence-chip-market
[20] https://www.coindesk.com/crypto-unicorn-bitmain-weighs-18-billion-ipo-one-of-worlds-largest/
[21] https://drive.google.com/file/d/11IweEa_80ol4EjPmoRdIYTiBqYd_-y2T/view?ref=tokendaily
[22] http://www.mdpi.com/1996-1073/10/10/1470/pdf
[23] http://blog.zorinaq.com/morgan-stanley-bitcoin-research-reports/#fn:sourceGW
[24] https://www.forbes.com/sites/forbestechcouncil/2017/12/15/why-energy-is-a-big-and-rapidly-growing-problem-for-data-centers/#4777ef185a30

Data Centers Worldwide	Estimate
Power Consumption (MW)	416,000
Energy Consumption (TWh/yr)	3,648
Percentage of world's energy consumption	2.2205%
Percentage of world's electricity consumption	16.5698%
Average PUE	1.7
Non IT Facility Energy (TWh/yr)	1,496
Energy savings - 2% Improvement (TWh/yr)	37.36

Source: Node Blockchain Research[25]

At their current growth rates, analysts predict that data centers will be one of the biggest energy consumers on the planet[26]. If software is eating the world, it's going to need energy to do it. Now, one could argue that Youtube's data centers that host millions of cat videos are a waste of energy, or that Facebook's servers translating your likes into hyper-targeted ads is a waste of energy. To state this however, is a misunderstanding of the subjective nature of value. As Saifedean Ammous points out in his book, The Bitcoin Standard (pp.218-219):

"Electricity is generated worldwide in large quantities to satisfy the needs of consumers. The only judgment about whether this electricity has gone to waste or not lies with the consumer who pays for it. People who are willing to pay the cost of the operation of the Bitcoin network for their transactions are effectively financing this electricity consumption, which means the electricity is being produced to satisfy consumer needs and has not been wasted."

Based on this, can we really make the argument that data centers are a 'useful' use of energy while Bitcoin mining is a waste of energy? Economically, the result is the same, both are paying to use produced electricity. The important difference between the two is that unlike traditional data centers, Bitcoin data centers are directly and aggressively incentivized to continually improve the efficiency of their energy usage. As the cost curve continues to shift for miners from up-front capital to ongoing operating costs, there will be increased pressure to improve their usage of power. We expect this will push them to further innovate on data center efficiency technology and practices.

Energy reallocation

The world is increasingly connected. Although physical borders still exist, most have been eliminated within the digital realm. However, physical limitations mean energy markets are largely a very fragmented place. Countries such as Canada produce more electricity than they consume, resulting in a surplus. Luckily for Canada, their southern neighbours in the US consume more electricity than they produce, allowing a solution for the country to sell some of the excess electricity generated. This only works due to the proximity of the two nations and the electrical infrastructure setup between their borders.

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[25] Power consumption estimates drawn from https://yearbook.enerdata.net/.

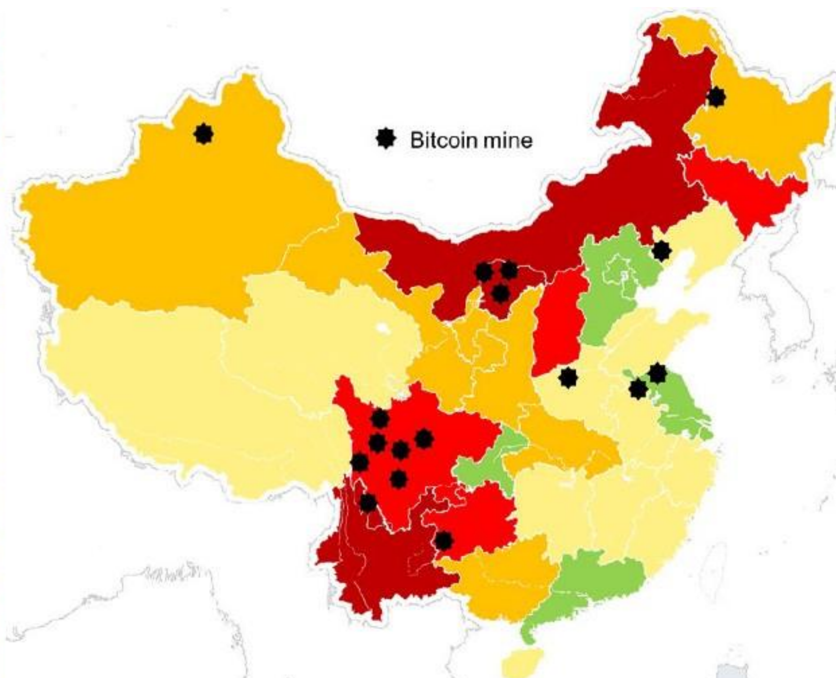
[26] https://www.forbes.com/forbes/welcome/?toURL=https://www.forbes.com/sites/forbestechcouncil/2017/12/15/why-energy-is-a-big-and-rapidly-growing-problem-for-data-centers/&refURL=&referrer=#4777ef185a30

In the case of fossil fuel power plants, this oversupply dynamic can be managed by actively throttling production. However, in the case of renewable sources (such as solar, wind, hydro and nuclear) this is more difficult to do. Storage of electricity (such as in the form of batteries) is not yet economically practical at scale and it often results in significant losses to and from the storage medium. As a result, in some cases the excess energy is simply shunted directly into the ground and wasted.

Bitcoin has no physical limitations as a digital currency. Mining can occur anywhere in the globe. Naturally, it should flow to areas of electricity oversupply first. These areas should have the cheapest sources of electricity for miners, which is in line with the economic incentive to optimize their marginal cost to produce.

Today, there is a significant amount of mining activity in China. This is partly due to proximity to hardware manufactures of ASICs, but also due to the vast amount of electricity produced in China (the world's largest). China is currently in an economic surplus of electricity and 26% of its production is from renewable sources[27]. A major source of electricity in China is derived from hydro, in fact, it is the 2nd largest hydropower producer in the world[28]. Hydropower is effective for Bitcoin mining as the marginal cost of generation is essentially zero and it is a stable source of electricity. A study performed by the BitMEX research group revealed that the majority of Chinese Bitcoin mining operations are in areas of relative oversupply.

Province	2016	Color
Inner Mongolia	3.77	
Yunnan	3.15	
Guizhou	2.87	
Shanxi	2.34	
Jilin	2.28	
Sichuan	2.19	
Gansu	1.94	
Ningxia	1.93	
Heilongjiang	1.83	
Xinjiang	1.82	
Guangxi	1.71	
Shaanxi	1.59	
Hubei	1.54	
Qinghai	1.46	
Liaoning	1.44	
Anhui	1.42	
Hainan	1.40	
Hunan	1.31	
Tibet	1.30	
Shandong	1.29	
Jiangxi	1.28	
Fujian	1.26	
Henan	1.18	
Zhejiang	1.13	
Chongqing	0.96	
Jiangsu	0.90	
Guangdong	0.88	
Hebei	0.84	
Tianjin	0.80	
Shanghai	0.66	
Beijing	0.47	



Source: BitMEX research group

Their research indicates that these are largely rural areas with hydro plants situated nearby and were previously home to Aluminium production plants. Due to the lack of electricity infrastructure within these areas, excess electricity generated from these areas is difficult to transport to the cities. In many cases, massive hydro plants built to transfer electricity to the rest of the country are inefficiently utilized.

[27] https://yearbook.enerdata.net/

[28] https://blog.bitmex.com/mining-incentives-part-2-why-is-china-dominant-in-bitcoin-mining/

Lauri Myllyvirta, a Beijing-based campaigner with Greenpeace noted that excess power at these stations was often wasted as state-run grid operators often failed to prioritize renewable energy over coal. In 2016, the Yunnan region alone wasted a staggering 32 billion kWh of hydropower, about equal to the annual consumption of Bitcoin mining today[29]. Local miner Eric Mu explained how a local hydropower station in Sichuan that was struggling to pay its employees turned it around due to their mining business[30]:

"[The power station] couldn't obtain the quota enabling them [to] sell power to [the] national grid, which prefers the state-owned power stations over those that are privately-owned. Also, the county-level grid could only consume a small percentage of the power the station generated. When we approached them with a solution, it was clear a win-win arrangement could be formed."

In theory, electricity is a homogenous good. It has equal utility whether produced in Italy or Canada, yet each unit costs almost 6x more in Italy than it does in China[31]. This inefficiency arises due to both physical limitations (storage and transportation is difficult) and in some cases political inefficiency. The example above illustrates how Bitcoin mining arbitrages political inefficiency in the electricity market in China. We believe this example can be expanded to the rest of the world's electricity market. Miners (similar to traders) will arbitrage price differences due to inefficiencies between regions globally. As miners move in and take advantage of areas of oversupply, the electricity price stabilizes to react for this increase in demand. Through this, we posit that Proof-of-Work mining introduces an opportunity to improve the overall efficiency of electricity markets globally.

Renewable energy

As discussed above, Bitcoin miners will seek the cheapest electricity possible for their operations. Some have argued that this results in an increased reliance on fossil fuel sources by miners. The relentless competition and economic incentive design results in an environment where miners will not make their decisions based on negative environmental externalities, but on profit motive alone. It is difficult to determine the percentage of mining performed using fossil fuels relative to renewable energy today due to the lack of data. That said, we believe that in the long-run, Bitcoin miners will increasingly seek renewable sources as opposed to fossil fuel energy sources.

We are at an inflection point with respect to the cost of renewable energy. Marginal costs to produce renewable energy continue to decline relative to the marginal costs to produce energy via fossil fuels[32]. In the long-run, this dynamic is expected to continue moving our reliance away from fossil fuel based energy. Hydro and nuclear are ideal sources for Bitcoin mining due to their stable nature as streams of energy (as opposed to solar and wind, both of which can be sporadic). We believe that strategically it is beneficial in the long-run for Bitcoin miners to target areas that generate electricity using renewable energy due to declining marginal cost relative to fossil fuel generated electricity. The incentive system in Proof-of-Work mining suggests that it is in their best interest to do so.

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[29] https://qz.com/1172632/chinas-dominance-in-bitcoin-mining-under-threat-as-regulators-hit-where-it-hurts-electricity/
[30] https://www.coindesk.com/my-life-inside-a-remote-chinese-bitcoin-mine/
[31] https://en.wikipedia.org/wiki/Electricity_pricing
[32] https://ase.tufts.edu/gdae/education_materials/modules/RenewableEnergyEcon.pdf

Type	Fixed costs	Marginal costs
Coal	Medium	Medium
Natural gas	Low	Low to high
Nuclear	High	Low
Hydroelectric	Medium	Zero
Solar	High	Zero
Wind	Medium	Zero
Oil	Low	High

Source: RStreet[33]

Bill Tai, who is a board director at Bitfury (one of the largest miners in the world), has long been an advocate for the use of green energy in mining. In fact, he has noted in a recent interview that Bitfury exclusively utilizes green energy for all of its mining operations due to the economic factors noted above[34].

Miners will first take advantage of arbitrage opportunities available in global energy markets by targeting areas of energy surplus such as China, Canada, Norway & Iceland[35]. Once these areas of oversupply have been tapped out, it will be interesting to see if long-term players will begin to make capital investments in renewable energy sources to further lower marginal costs for their operations. From a business perspective, this may be an attractive opportunity for miners as it would also reduce their dependency on fluctuating and unreliable energy costs from 3rd party sources and reduce risk of regulatory action against their mining farms.

Energy Innovation – putting waste to work

Another more recent trend in the mining space is putting what would otherwise be 'wasted' energy to work. Large oil wells in the US and Canada are being primarily exploited for petroleum with natural gas produced in the process as a by-product. Where it is economically viable, this by-product is captured and used to generate electricity, produce chemicals, or stored and transported for sale. However, there are significant economic costs and infrastructure required to do so; such as equipment, pipelines and personnel. Often times it turns out that at the current price of natural gas ($2.85/MMBTu)[36] companies would incur a loss trying to convert or sell this by-product. This is even more difficult in places such as offshore oil platforms or remote oil fields located far from the required infrastructure.

In these instances, the only way to safely remove the produced natural gas (as waste) is by burning it off into the air, a process known as flaring. It is estimated that 150 billion cubic meters of natural gas is 'wasted' each year through flaring which generates a staggering 400 million tons of carbon dioxide[37]. Venting the excess gas into the atmosphere has an even worse environmental impact as it is a more potent greenhouse gas than carbon dioxide.

An entrepreneur in Alberta, Steven Barbour, saw an opportunity to capitalize on what would otherwise be a wasted natural source of energy. His company, Upstream Data, has developed what can be

[33] https://www.rstreet.org/2016/08/10/economic-characteristics-of-electricity/
[34] https://www.spreaker.com/user/10197011/erik-bill-tai-derek-hsu
[35] https://yearbook.enerdata.net/
[36] Rate captured as FX:NGAS as of 8/28/18
[37] https://news.mit.edu/2017/new-way-harness-wasted-methane-1017

described as a portable Bitcoin mining unit which converts the natural gas into electricity and then utilizes it to operate mining rigs within a plug-and-play container. This process converts what would have otherwise been 'wasted' energy into Bitcoin.

Similarly, a joint operation between PRTI and Standard American Mining converted waste to energy in order to mine cryptocurrency[38]. PRTI uses a proprietary process to turn whole car tires into energy. In the US alone, 246M waste tires are created every year. These wasted tires are then either burned (150M a year) producing massive amounts of toxins and greenhouse gasses, buried (32M a year) where they never decompose and cost municipalities millions to do so, or ground down to be recycled using energy that could have been redeployed elsewhere[39]. By recycling these tires and converting them into energy, a new cheap source is available for mining.

We believe these are just two early examples of innovation within the energy space fueled by the incentive provided through Bitcoin mining. Once the energy arbitrage opportunity has been leveled, competitive miners will seek new ways to decrease their operating costs. In this cut-throat environment, they will look to innovate in the way they use energy to gain an edge over their competition.

Conclusion

It's become popular today to dismiss Bitcoin's Proof-of-Work as wasteful and bad for the environment. You can make Bitcoin's electricity usage seem relatively large – 'Bitcoin uses more electricity than a country!'. You can also make it look relatively small – 'Bitcoin uses less electricity than Christmas lights worldwide'. It's important as well to review the electricity usage against the closest comparable, global data centers, which today consume over 2% of worldwide electricity (a measure that is 133x larger than Bitcoin's usage). Why is it claimed that Bitcoin's electricity usage is wasteful yet these other uses are largely considered 'fair'?.

Those critical of Bitcoin's increasing energy usage will often compare and calculate 'Bitcoin's energy usage per transaction'. We note that it is inappropriate to calculate 'per transaction' metrics with regards to Bitcoin's current energy usage and hashrate. This calculation incorrectly assumes that the current hashrate only secures the active transactions occurring on the network. Bitcoin's security model (a blockchain) by design results in the hashrate securing all transactions that ever occurred on the ledger (dating back to 2010), it is actually increasing in efficiency as time passes.

We wrote this paper with the intention to illustrate the other side of the story in what we believe to be the positive externalities of Proof-of-Work mining. The discovery is that economic incentives are powerful. This industry provides one of the first mechanisms in which there is a reward to participants for efficiently utilizing energy. Our analysis captures a few early signs of the positive impact provided by the Bitcoin mining industry. As more competitors continue to enter this space and the ecosystem continues to grow, we expect the trends identified above to accelerate. This will result in Bitcoin's innovative Proof-of-Work mining system improving the efficiency and allocation of our energy usage worldwide.

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[38] https://blog.usejournal.com/the-worlds-first-waste-to-energy-crypto-mine-2638a6728efa

[39] http://www.prtitech.com/

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