THE BITCOIN STANDARD RESEARCH BULLETIN

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Bitcoin Mining: Energy and Security

Contents

I - Bitcoin mining	3
II- Energy	5
III- Global energy availability	11
IV- Bitcoin's energy consumption and security	14
V- Does Bitcoin consume too much energy?	20
VI- How bitcoin transforms the global energy market	22

For those unfortunate enough to still be addicted to consuming mass media, seemingly not a day goes by without a hysterical news item about how much energy bitcoin consumes, and what a terrible travesty that is because the energy could be used for better purposes. This edition of The Bitcoin Standard Research Bulletin will focus on Bitcoin's energy usage.

How much energy is Bitcoin really consuming? Is it too much, and is this a problem? What are the dynamics that govern mining, and how does Bitcoin's difficulty adjustment affect the profitability of mining operations?

I - Bitcoin mining

A detailed explanation of the importance of mining to the Bitcoin network can be found in Chapter 8 of The Bitcoin Standard. The most relevant point for this discussion is that the energy expenditure is a key to the safety and security of the network, allowing it to maintain an honest record of transactions and a predetermined fixed credible monetary policy. Bitcoin allows anyone to validate (i.e. read) this shared ledger for themselves and, provided their computer can solve ***Proof of Work*** problems, will reward them with new coin production and transaction fees in exchange for committing (i.e. writing) transactions to its shared ledger. The nature of proof of work problems is that they require repetitive trial and error guesses by computers to solve, and the more computing power dedicated to these guesses, the faster a correct guess is made. As more machines come online to try to solve these problems, the speed by which they guess the answer increases, which increases the production of blocks, and thus increases the production of new coins. But bitcoin's algorithm has a difficulty adjustment every two weeks that adjusts how hard it is to solve these problems; this adjustment ensures that the time it takes to find a solution remains around ten minutes for the network as a whole. Regardless of how many more computers join the network to mine bitcoin, there is no increase in the supply of bitcoin, only an increase in the difficulty of mining it. This automatic adjustment is how bitcoin is uniquely different from all other monetary assets. If demand for any metal increases, the production of that metal will accelerate, and thus its supply will grow at a quicker rate than previously. But bitcoin mining is like a sports competition: there is only one trophy to be handed out, and even if more people compete, more trophies aren't made; winning the trophy just becomes harder. This effectively ensures that the cost invested in producing a bitcoin is roughly equal to the value of a bitcoin, which is what ensures bitcoin is hard money. If a miner could produce bitcoin cheaply, it would be so profitable that other miners would join, and the difficulty would rise, increasing the cost of production until the profit is eliminated, or preserved for only the miners with the lowest electricity cost.

I view the difficulty adjustment as the crucial ingredient missing from previous digital currency attempts that allowed bitcoin to succeed. It ensures that the cost of producing a bitcoin always trends close to its price, thus ensuring that bitcoin remains hard money. The difficulty adjustment is also what makes bitcoin escape the easy money trap I discuss in my book, and allows it to have the positive feedback loop of economic incentives which I believe is the only way to understand its quick rise in value.

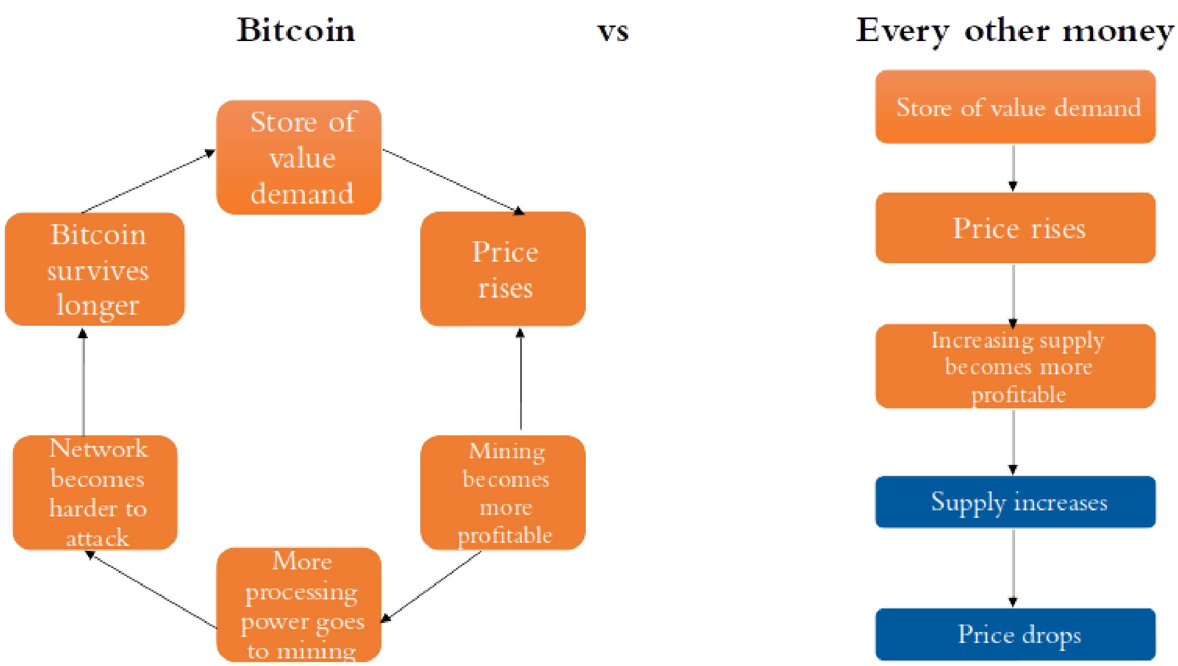

Figure 1: Bitcoin's monetary uniqueness

Another consequence of the difficulty adjustment relevant to today's topic is that it ensures that mining is only profitable for the miners who have electricity rates significantly cheaper than average. An upward adjustment of mining difficulty as mining activity increases erodes the profitability of all but the most competitive miners. If you're mining bitcoin profitably at an electricity cost that is widely available worldwide, then many people will purchase mining equipment and begin to mine to make that profit. But as their entry raises the computational capacity of the network and blocks are found faster, a sufficiently large difficulty increase restores the original block intervals; unfortunately for those now mining at the margin (i.e. the worldwide average electricity cost), they're no longer profitable. The only miners that can stay in the game are the ones with access to cheaper energy sources, which by definition are not easily attainable worldwide.

II- Energy

Remarkably, modern science is not very clear on what exactly energy is. The term defies clear definition, so much so that famous physicist Richard Feynman said "it is important to realize that in physics today, we have no knowledge of what energy is. We do not have a picture that energy comes in little blobs of a definite amount." The world's most popular thermodynamics textbook, by Yunus Cengel and Michael Boles has this to say on the subject: "Thermodynamics can be defined as the science of energy. Although everybody has a feeling of what energy is, it is difficult to give a precise definition for it. Energy can be viewed as the ability to cause changes."

A common definition usually heard is that energy is the ability to do work. Wikipedia has a more precise definition: "In physics, energy is the quantitative property that must be transferred to an object in order to perform work on, or to heat, the object."

I like to think of energy as an animating force that can move or heat objects, and access to energy is the ability to command this force to perform tasks valuable to humans. The importance of this ability cannot be overstated. The progress in the quality of human life can best be understood as the increase in the energy available to the human being to perform the tasks they want. Comparisons across the world today, and across time, can vividly illustrate the enormous value that access to energy entails. Our modern world is largely the product of the development of tech-

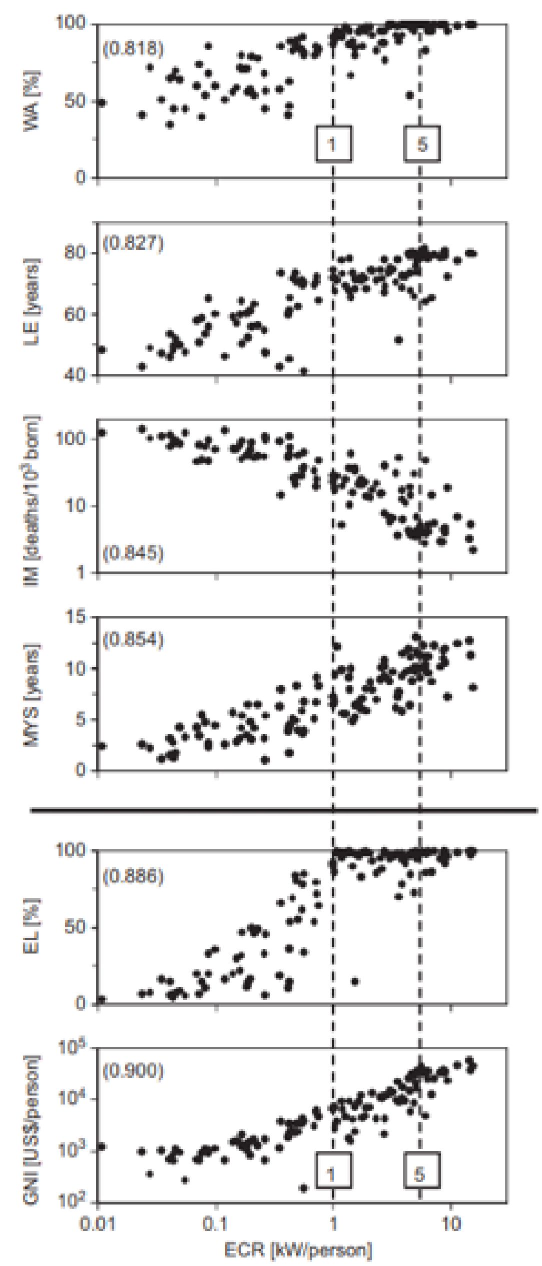

Fig. 1. Quality-of-life-related variables and energy consumption rate per capita *ECR*: Improved water access *WA*, life expectancy *LE*, infant mortality *IM*, mean years of schooling *MYS*, electrification level *EL*, and gross national income *GNI*. Correlation coefficient in parentheses (infant mortality and gross national income are considered in logarithmic scale). Note: Data for 118 countries with populations larger than four million in 2005 (data sources: Barro and Lee, 2010; DM, 2011; EIA, 2011; Elvidge et al., 2011; IEA, 2010; UN, 2011a, b; WB, 2011).

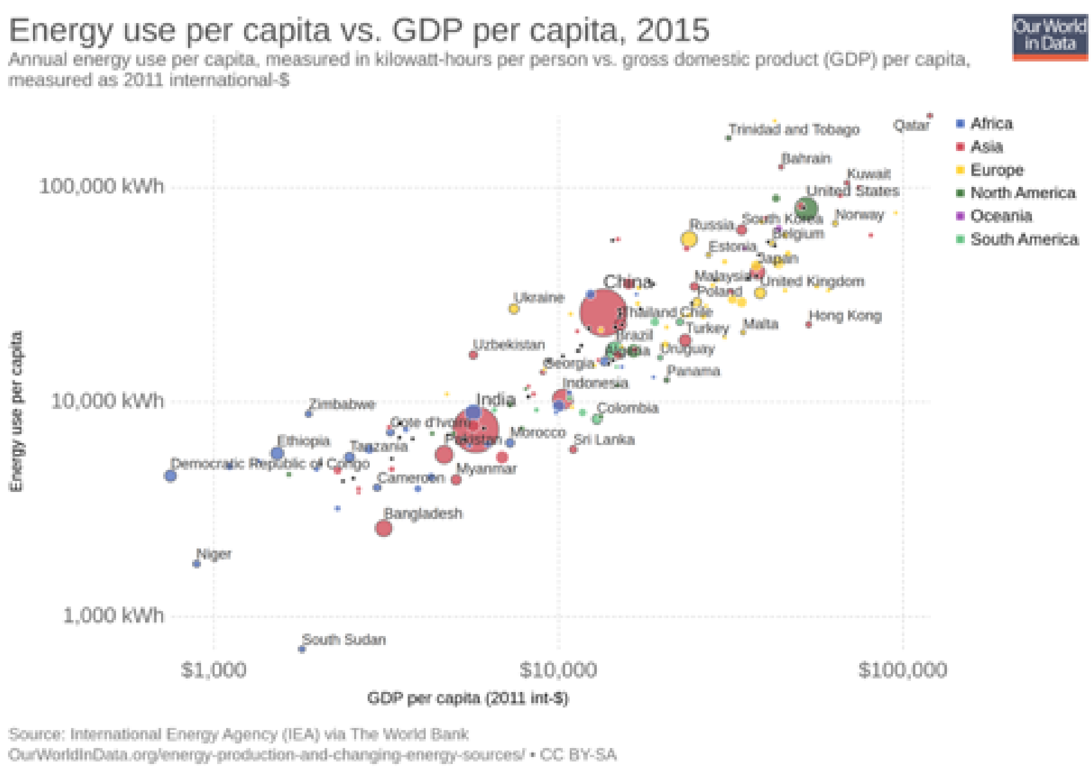

Figure 3

nologies that give us regular access to huge quantities of energy. Modern civilization and most its achievements and essentials would not be possible without levels of energy consumption that are complete outliers by historical standards.

The attached Figure 2, from the study 'Energy Consumption and Quality of Life' by Cesar Pasten and Juan Carlos Santamarina shows the correlation of energy consumption per capita with improved water access, life expectancy, infant mortality, mean years of schooling, electrification, and gross national income. As is apparent, the more a society is able to harness and consume energy, the more it is able to provide itself the basic needs of modern life.

Taking a closer look at GDP, the relationship is very clear and has been for a very long time: More energy consumption translates to more economic production, and consequently, better standards of living.

Figure 4 shows the relationship between energy consumption per capita and the share of the population living in extreme poverty. No country that eliminated extreme poverty consumes less than 10,000kWh/capita/year, and no country

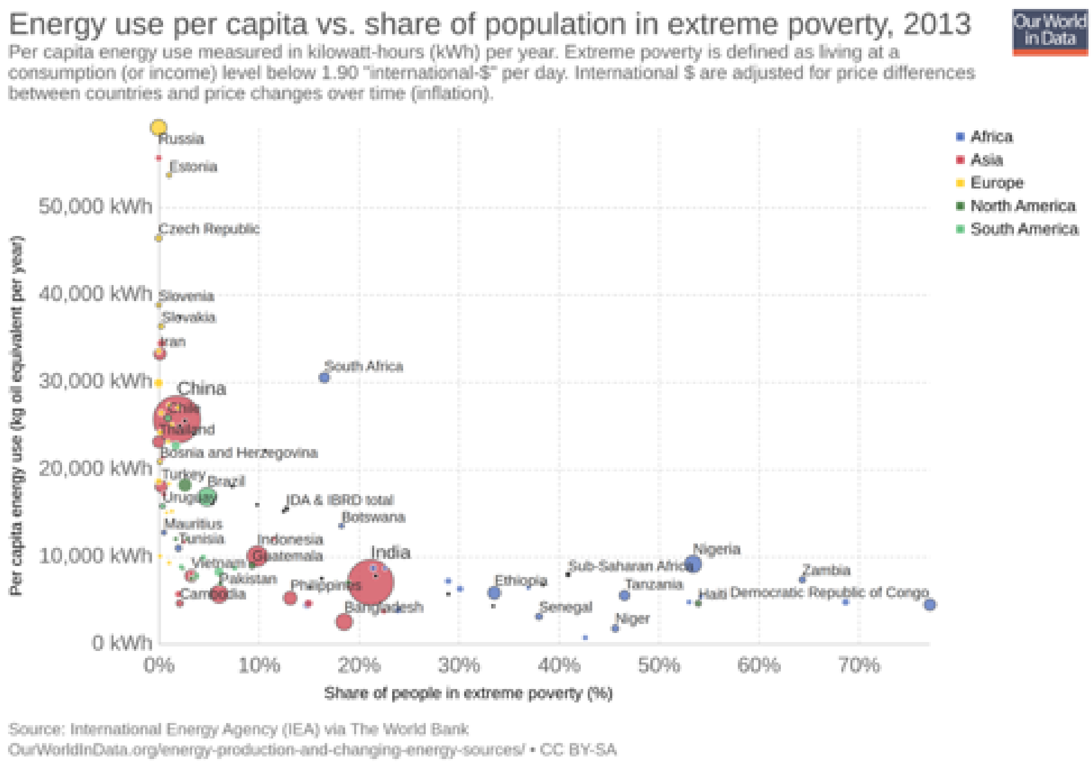

Figure 4

that has more than 20% of its population in extreme poverty consumes more than 10,000kWh/capita/year.

The progress of humanity has been driven by technological advancements that unlock the the energy latent in hydrocarbon fuels. The fact that most humans today live protected from most of nature's harms, can stay warm in the winter, and can travel faster than their running speed is due to the industrial revolution innovations that gave us various forms of engines to access the energy present in the three main hydrocarbon fuels: coal, oil, and gas. **As John Cross put it**:

"The history of economic development is the history of the amount of energy brought under human control. Economic historians have observed the close relationship between economic growth and energy consumption as we put more energy to work for us. American economist Deirdre McCloskey called the surge in energy use that began around 1800 "the Great Enrichment." The benefits to mankind have been enormous, extending life expectancy, increasing food output to sustain burgeoning populations, and lifting the standard of living for most people to levels not even royalty could aspire to just a few centuries ago.

The late Italian economic historian Carlo Cipolla attributed both the Agricultural Revolution thousands of years ago and the Industrial Revolution starting in the late 18th century to people harnessing energy power…

Fossil fuels played a negligible role in supplying energy until the Industrial Revolution. While everything on the planet is a possible source of energy, fossil fuels proved especially efficient and convenient in meeting the energy demands of industrialization. In Cipolla's words, the Industrial Revolution "can be regarded as the process whereby the large scale exploitation of new sources of energy by means of inanimate converters was set on foot." Coal was the first widespread source of inanimate energy, rising from 10 percent of Britain's energy supply in 1560 to 60 percent by 1750, in the process ending Britain's deforestation. This began a cumulative process, where a rising supply of energy stimulated more economic growth, which boosted education that led to the discovery of new sources of energy, notably other fossil fuels.

The first commercial use of fossil fuels was kerosene to generate light and end our perpetual plunge into darkness after sundown. (This stopped the widespread slaughter of whales, whose oil until then was the main source of indoor light.) The U.S. pioneered the exploitation of oil in the 19th century, a mantle it is reclaiming today thanks to innovative technologies to develop shale deposits. By 1860, the oil age had begun in earnest due to the development of drilling technology in Pennsylvania.

In his excellent book ***The Moral Case for Fossil Fuels***, Alex Epstein makes the compelling case for how hydrocarbon fuels are the root of modern prosperity. Life everywhere until the 16th century primarily relied on burning wood for the provision of energy. Compared to modern hydrocarbons, wood contains much less energy per unit of weight. As the utilization of coal started in the 16th century, and later was followed by oil and gas, the amount of energy available per person expanded enormously, and with it our quality of life. To visualize the true benefit of energy for our lives, Epstein invites you to imagine the energy you consume today in terms of the energy consumption of humans performing tasks for you. By that measure, he finds that the average American has 186,000 calories at his service daily, or the energy equivalent of 93 humans. Before modern fuels, such an amount of energy was rarely ever available for anyone. Only the richest kings could dream of having as much energy at their daily disposal, either in the form of combustible wood, or enslaved humans.

Another way to appreciate the importance of hydrocarbon fuels to our modern way of life is to realize how much more power it has afforded us. In physics, power is defined as the rate of

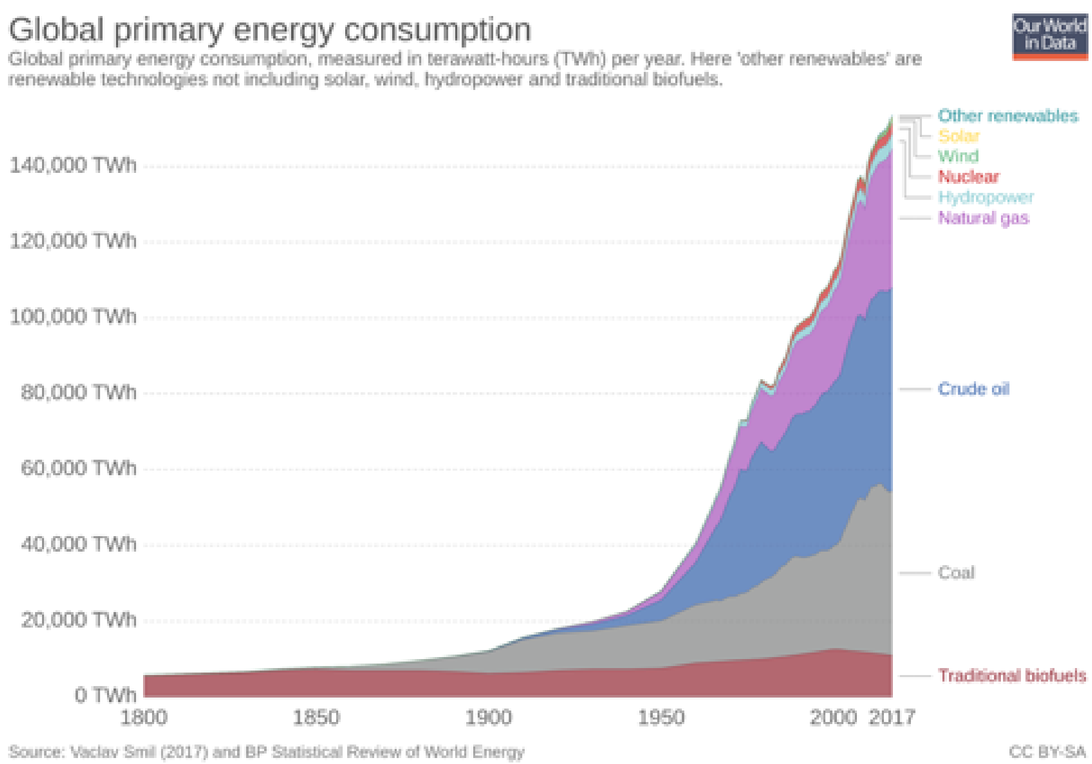

Figure 5

doing work over time, which is what matters for many jobs that call for high quantities of energy over short periods of time, such as moving heavy weights. For instance, energy is plentiful in sunlight and wind, but it's difficult to quickly harness it for generating enough power to move heavy loads. The introduction of hydrocarbon fuels has vastly increased humanity's potential for generating power, as can be seen from Figure 5 taken from Vaclav Smil's **World History and Energy**:

The amount of power that a modern day steam turbine produces is more than a million times the power that can be produced by a horse, which was the state of the art in power generation up until around 2,500 years ago. It is worth noting that the power from water turbines is almost up there with the power of steam turbines. Water turbines are placed at rivers and waterfalls and, combined with an electric generator, they convert running water's energy into electricity. Hydroelectric energy is responsible for around 16% of global electricity production.

As human ingenuity has advanced, the ways in which we've taken advantage of the naturally occurring energy in our planet have multiplied in both magnitude and efficiency. The result is that people every day from all around the world are climbing out of poverty is in no small part due to their ability to use more energy in their daily life.

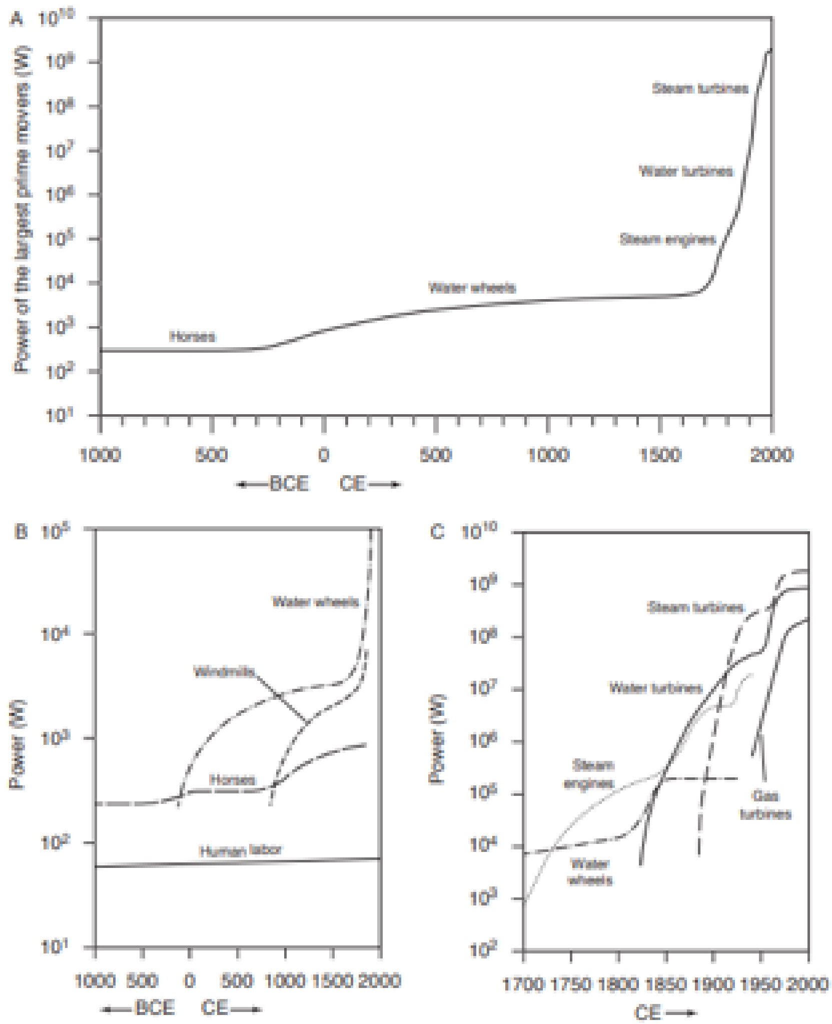

FIGURE 2 The maximum power of prime movers shown as the sequence of the highest capacity converters for the span of the past 3000 years (A) and shown in detail for the periods 1000 BCE to 1700 CE and 1700 CE to 2000 CE (B and C).

Figure 6

III- Global energy availability

One of the most common misconceptions about energy is that it is scarce or limited. In the popular imagination, the earth has a limited supply of energy that humans consume whenever they heat or move anything. This scarcity perspective views energy consumption as a bad thing because anything that consumes energy depletes our planet's finite supplies of energy. Reality is very different.

The total amount of energy resources available for humans to exploit is practically infinite, and beyond our ability to even quantify, let alone consume. The solar energy that hits the earth every day is hundreds of times larger than global energy consumption. The rivers of the world that run every hour of every day also contain more energy than global energy consumption, as do the winds that blow, and the hydrocarbon fuels that lie under the earth, not to mention the many nuclear fuels we have barely begun to utilize.

To begin with the most obvious of energy sources, the sun alone showers the earth with 3,850,000 exajoules of energy every year, that is more than 7,000 times the amount of energy humans consume every year. In fact, the amount of solar energy that falls on earth in one ***hour*** is more energy than the entire human race consumes in one year. The amount of wind energy alone blowing around the world is around four times the total energy consumed worldwide. Some estimates put the potential hydroelectric yearly power capacity at around 52 PWh, or a third of all the energy consumed in the world.

There are no accurate estimates of the amounts of hydrocarbon fuels that exist in the earth, but the closest estimate we have (proven oil reserves) is constantly increasing due to new discoveries, and at a pace greater than that of the increase in consumption of oil, as discussed in The Bitcoin Standard.

> The belief that resources are scarce and limited is a misunderstanding of the nature of scarcity, which is the key concept behind economics. The absolute quantity of every raw material present in earth is too large for us as human beings to even measure or comprehend, and in no way constitutes a real limit to what we as humans can produce of it. We have barely scratched the surface of the earth in search of the minerals we need, and the more we search, and the deeper we dig, the more resources we find. What constitutes the practical and realistic limit to the quantity of any resource is always the amount of human time that is directed toward producing it, as that is the only real scarce resource (until the creation of Bitcoin). In his masterful book, The Ultimate Resource, the late economist Julian Simon explains how the only limited resource, and in fact the only thing for which the term resource actually applies, is human time. Each human has a limited time on earth, and that is the only scarcity we deal with as individuals. As a society, our only scarcity is in the total amount of time available to members

of a society to produce different goods and services. More of any good can always be produced if human time goes toward it. The real cost of a good, then, is always its opportunity cost in terms of goods forgone to produce it.

In all human history, we have never run out of any single raw material or resource, and the price of virtually all resources is lower today than it was in past points in history, because our technological advancement allows us to produce them at a lower cost in terms of our time. Not only have we not run out of raw materials, the proven reserves that exist of each resource have only increased with time as our consumption has gone up. If resources are to be understood as being finite, then the existing stockpiles would decline with time as we consume more. But even as we are always consuming more, prices continue to drop, and the improvements in technology for finding and excavating resources allows us to find more and more. Oil, the vital bloodline of modern economies, is the best example as it has fairly reliable statistics. As Figure 20 shows, even as consumption and production continue to increase year on year, the proven reserves increase at an even faster rate. 1 According to data from BP's statistical review, annual oil production was 46% higher in 2015 than its level in 1980, while consumption was 55% higher. Oil reserves, on the other hand, have increased by 148%, around triple the increase in production and consumption.

There is no energy scarcity problem, because energy cannot run out as long as the sun rises, the rivers run, and the wind blows. Energy is constantly available for us as humans to utilize as we like. The only limit on how much energy is available to us is how much time humans dedicate toward channeling these energy sources from places where they're abundant to places where they're needed. All energy is ultimately free, but the costs lie in paying the supply chain of individuals and firms to transport this energy to where it's needed and in a usable form. It thus makes no sense to discuss energy itself as a scarce resource, which implies a fixed, god-given quantity for humans to consume passively. In its usable form, energy is a product that humans create by channeling the forces of nature to where they are needed. Like with every economic good other than bitcoin, there is no natural limit to the production of this good; the only limit lies in how much time humans dedicate to producing that good, which in turn is determined through the price mechanism sending signals to producers. When people want more energy they're willing to pay more for it, which incentivizes more of its production at the expense of producing other things. The more people desire it, the more of it can be produced. The scarcity of energy, like all types of pre-bitcoin scarcity, is relative scarcity, whose cause lies in the opportunity cost of securing resources.

The real scarcity of energy lies not in its absolute availability, but in its availability in the right times and places (e.g. high energy over short periods of time) when and where it is needed. Hydrocarbons have value because they're chemically stable, light, and easy to transport forms of energy, which lend themselves to usability for purposes that demand high power at any time and location in the world. Concentrated populations anywhere in the world can regularly access energy through the importation of relatively small volumes of hydrocarbons.

IV- Bitcoin's energy consumption and security

The amount of energy that Bitcoin consumes can theoretically be estimated from its hashrate, or direct output of the energy consumption of the machines that secure the network.Since there is a wide variety of equipment performing bitcoin mining and no central authority or registry to count the miners, there is no easy way of observing how many of each type of mining rig is produced, and how much energy they are collectively consuming.Various methodologies have been employed to estimate this, and I do not intend to delve into the measurement problems and debates around their accuracy. As I explain below, the exact current number is not important. Various estimates put the range of energy consumption between 1 and 10 GW. Translated over a year, this would be around 8.76 TWh/year to 87.6 TWh/year, or between 0.005% or 0.05% of total global energy consumption. In other words, Bitcoin is somewhere between five-thousandths of one percent and one-twentieth of one percent of total energy production, which of course is an enormous amount of energy. Bitcoin currently consumes as much as an average 350,000 to 3.5 million individual humans consume per year.

However, if Bitcoin continues to operate successfully for another ten years its energy consumption will likely be far greater than even the most exaggerated estimates of today, which makes quibbling about today's Gigawatts pointless. If the Bitcoin network attracts more store of value demand and the mining reward allocated out every ten minutes appreciates in value, more energy expenditure by miners will be justified to mine these coins. If, on the other hand, bitcoin were to collapse in value, the decline in the value of the reward would cause many miners to switch off their mining equipment, thus reducing the demand for electricity.

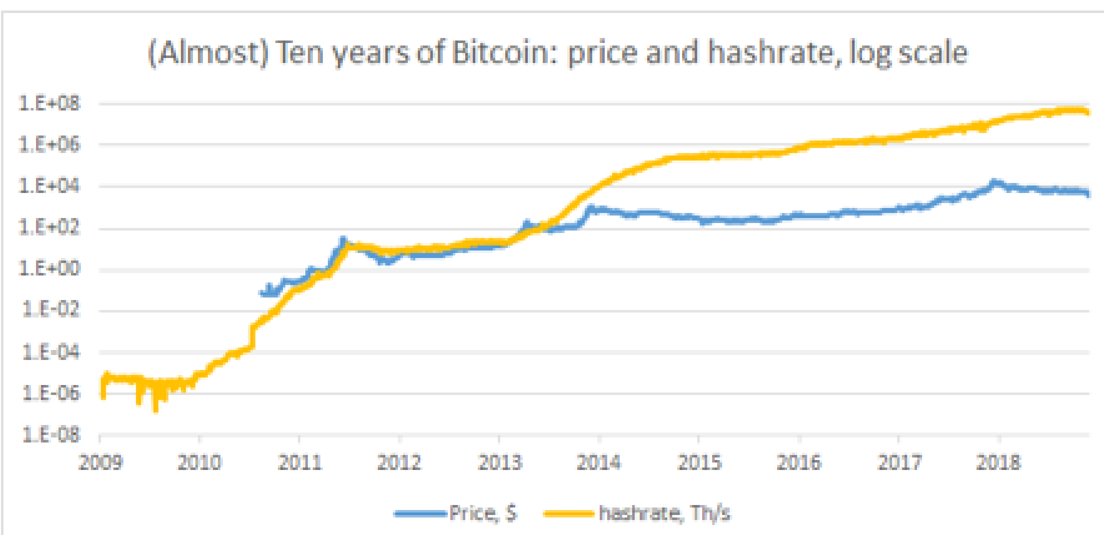

Figure 7

The current drop in the bitcoin price has brought about a relatively rare situation in the history of bitcoin: The bitcoin hashrate has been largely flat over a three-month period. This is useful in explaining the economic dynamics of mining and how it works. As the price of bitcoin was rising throughout the period of 2017, bitcoin miners worldwide were watching the value of the rewards they earn rise very quickly, while non-miners looked on with envy. In this environment miners would seek to expand operations, while outsiders enter the market, placing orders for miners being delivered. As the price continues to rise, the amount of mining hashpower on the network expands, which leads to the speed of finding blocks to increase. Bitcoin's difficulty adjusts roughly every two weeks, and will react to the rising hashpower trying to solve the bitcoin mining puzzles with raising the difficulty of the puzzle, thus making mining less profitable for miners. As the difficulty rises, the amount of processing power and electricity that needs to be expended to produce a bitcoin rises.

As the bitcoin price began to drop at the end of 2017, bitcoin's hashrate showed no signs of slowing down. This is to be expected, since new investment in new mining equipment takes time to be produced and deployed on the network, so 2018 was when most of the mining ordered by investors in 2017 was being deployed. As the hashrate went up by around five-fold over the course of 2018, and the bitcoin price lost about three quarters of its dollar value, the profitability of miners has been decimated. Reports emerged of miners in China even destroying their equipment, because it became too expensive to operate.

Anybody with familiarity with the mining business knows that over the last few months, only the mining businesses operating with the lowest electricity costs have managed to maintain profitability. Miners who invested in infrastructure connected to grids with prices above 10c/kWh, likely stopped being profitable months ago. At this point it is not clear whether even miners at 5c/kWh are profitable at current prices and difficulties. This became evident as the difficulty started to fall in October, meaning that many miners were shutting down their miners, which signified not only that the miner is not profitable, but that it cannot even cover its operating expense.

It is unclear where hashrate will go over the coming few weeks, and it will depend to a large extent on the price of bitcoin, as well as the magnitude of new miners coming out of mining hardware producers. So long as the hashrate is falling, we can deduce that the marginal miners, the ones left with the most expensive electricity costs, are turning off their equipment. The hashrate has largely stopped rising around the end of August and has been dropping since October.

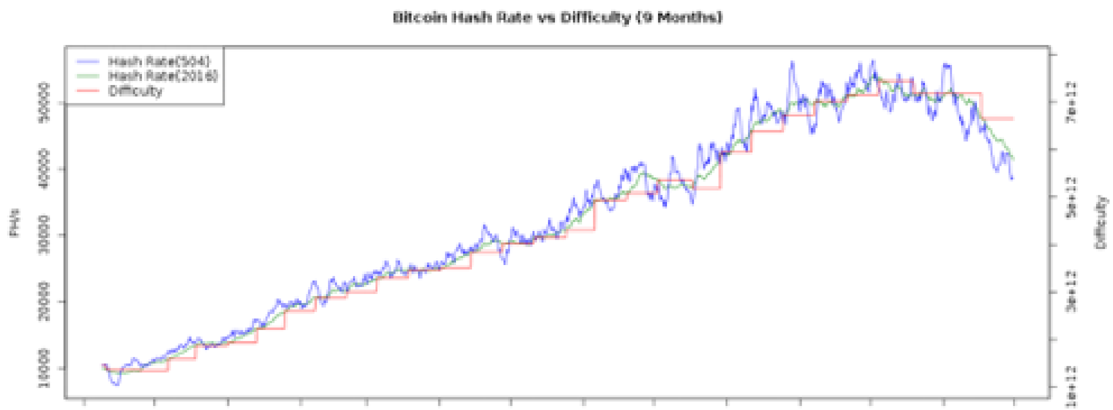

Figure 8

Figure 9

Over the next few days, bitcoin's mining difficulty is set to drop by another 13%, back to its levels in July. Whether this will be enough to stop the decline in hashrate remains to be seen. But for now, we have on our hand the first three-month decline in difficulty since July 2015. The only previous times this had happened was in January and February 2013, in January 2012, and in October 2011. Should the difficulty of mining drop another 10% in the next difficulty adjustment period, then it would be the first time since April 2012 that the Bitcoin difficulty is down over a six month period.

While it is definitely too early to start panicking, it must be noted that a drop in bitcoin's hashrate is a reduction in its security and the predictability of its supply. At a very basic level, the increase in the hashrate of bitcoin is what makes it very expensive to try to attack or disrupt the network with mining power. The higher the hashrate, the more expensive it is to solve a block's proof of work and receive its reward.

The cost of securing the bitcoin network cannot understood as a static or fixed amount of hashrate mining the network. The production of processing power worldwide is an ever-growing industry that continues to churn out more processing power at an ever-decreasing cost. A set amount of hashrate today might be too expensive to assemble to attack the network, but in a few years, this amount will become feasible to produce at a much lower cost.

Therefore, bitcoin's security does not just depend on having a high hashrate, but on having an ever-growing hashrate, so that a potential attacker is constantly having to update the arsenal they need to attack the system. More precisely, I view the security to be dependent on the hashpower rising, because that would signify that bitcoin continues to be a profitable use of processing power, which is incentivizing the producers of hashpower worldwide to dedicate more of their resources to produce miners for bitcoin. This means that a potential attacker would be fighting a losing war against market forces in a vain attempt to accumulate more than 50% of the hashrate behind the network.

The production of processing power is not a secret monopolistic guild which can simply be hired to produce hardware only for attacking bitcoin. There are many companies that produce processing power, many that could produce it, and the more money is to be made in this business, the more companies enter. Should an attacker attempt to buy the hashrate needed to attack bitcoin while the hashrate is rising, they cannot monopolize all hashrate production to attack bitcoin, as the rising incentive to mine the network will continue to attract people to invest in mining it honestly. Thus, as long as the hashrate is rising, any potential attacker faces an ever-drifting hashrate goal to amass, and I would not expect it possible to manage to secure more than half the network's hashrate for attacking it, because the more hashrate is taken away from securing the network, the more profitable securing it becomes, the more investment goes into it, the bigger the task facing an attacker.

If, on the other hand, bitcoin hashrate continues to drop or stagnate for a significant period of time, this would be an indication that little new hardware is being produced to enter into bitcoin mining. The longer this goes on, the less daunting the task of a potential attacker becomes. Without new processing power being demanded and rewarded by the bitcoin network, it is feasible for another bidder to outbid the network for hashing power and muster enough of it to attack the network, particularly when many of the miners are not profitable and have mining capacity unused which they could be persuaded to sell for very little.

Bearing in mind that Bitcoin hashpower increased by five multiples in the space of one year allows us to understand how this threat could unfold. An attacker with very large amount of resources could bid for a lot of machinery while bitcoin's price is stagnant or declining as miners are laying off their machinery. Within a few months they could amass enough hashrate to disrupt the network.

Having said that, just because the attack becomes more likely does not make it likely, easy, or perhaps even possible, at all. Contrary to what many believe, a miner with 51% of the hashrate cannot overturn consensus rules, change the monetary policy, or even confiscate any bitcoiner's coins. These consensus rules are determined by the nodes, and not the miners, and if the nodes were to reject a miner's changes, all the hashrate in the world cannot force the node to accept them. A miner might be able to censor transactions from being included, and potentially double-spend some transactions. The real danger lies in passing off enough invalid transactions to create confusion about the valid chain and cause the network to be split among differing forks with different transaction records, which would likely highly undermine investors' confidence in the network, causing them to sell, which would bring the price down, making honest mining less profitable, and further attacks more feasible. But such attacks are not just expensive to mount, they are more expensive to maintain, as nodes continue to refuse invalid blocks, and the miner needs to continue to solve the proof of work correctly to keep adding the invalid block to the nodes. In the worst case where such an attack succeeds an efficient line of defense is for bitcoiners to raise the number of confirmations they would require to accept a transaction, which would make it harder for users to not rely on transactions recorded on an invalid ledger.

In conclusion, a dropping difficulty does make bitcoin slightly less secure, but not by much. We would require many more months, possibly years, of stagnation or decline in hashrate to begin worrying about whether this compromises bitcoin's security. Even if it does, the kind of attack imagined requires an enormous amount of financial resources, as well as logistic capabilities to pull off, that it is highly unlikely to ever be pulled off. Even if it were, it is not clear it could succeed in anything more than temporary disruption of the network.

This brings me back to the conclusion of the section of my book that deals with how to kill bitcoin. These sophisticated technical attacks on bitcoin are interesting in the same way a Hollywood movie plot is interesting; not because they will likely happen. As I explain in my book, the real driver of bitcoin security is the economic incentive it offers for people to keep it alive, to code it, to mine it, and to hold it. As long as government restrictions over money and banking persist, demand for bitcoin will likely persist, and those who use it will likely continue to find a way to use it. Should governments really want to kill bitcoin, they need to attack that economic incentive for using it. In other words, they need to provide their citizens with a free market monetary system that can compete with bitcoin. Their best bet would be a return to the gold standard, but I would not encourage you to bet on this happening any time soon.

V- Does Bitcoin consume too much energy?

The current market value of all bitcoins in existence (around $80b) is around 0.1% of the total global broad money supply. Compared to narrow money ($28t), it is less than 0.3%. Is building a new form of electronic money for a thousandths of the global money supply worth expending 0.05% of the global energy production?

Whatever our individual answer to this question may be, the answer of the market is unequivocal. If people are willing to pay the miners the market price of bitcoin, then people value the services bitcoin offers them enough to justify the electric consumption. This is, after all, the only way that the market for energy functions. The fundamental starting principle of Austrian economics is the notion that value is subjective. There are no objective ways of determining value, and value can only exist in the mind of people, based on their subjective preferences and understanding of goods and services. For energy to be available for people at an affordable rate, there is simply no alternative to having a free market in its production and distribution. This ensures that the users of the energy get to pay its cost, and so will only pay for it if their subjective valuation of it exceeds the price. In places where markets for electricity are dysfunctional, with subsidies or government-enforced monopolies, such as Beirut, where I write these lines to constant power interruptions, electricity is neither cheap nor reliable. For that, there is simply no alternative to a free market.

To understand the growth of energy as a good, one must understand that it can only really function as a market good, because otherwise the potential to waste it enormous. The extent to which electricity has grown over the past century is extent to which humans have found productive uses for energy and paid for it, and for capital investment to provide it. At every step along the way, someone had discovered a way to utilize the awesome power of energy to create economic value that justified the cost of producing it. As people find more uses for energy, more energy is produced.

The electric washing machine came into the home to save humans enormous amounts of time washing. The car came into the streets of cities to relieve people from living surrounded with horse manure. The personal computer replaced the type writer, electric light replaced candles, central heating replaced chimneys, and all aspects of human life started to become revolutionized with the application of ubiquitous power at the press of a button. Every one of these innovations required more energy to operate than its predecessors, but people happily paid the cost because it was more valuable, and more productive. The modern world built by the industrial revolution is the product of countless small marginal innovations that have improved our life through increasing productivity with energy.

It is only natural for better technologies to consume more energy, and there is nothing different about bitcoin in this regard. As an apolitical global settlement network with its own automated algorithmic monetary policy, bitcoin is a more advanced technology for performing the functions of central banking than the current government monopolies. In the same way cars and airplanes consume more energy than bikes and horses, bitcoin's monetary system consumes more energy than the central banking system it replaces.

Many bitcoin defenders make the mistake of attempting to compare the amount of energy consumption taking place in the banking system to bitcoin's energy consumption, in an attempt to argue bitcoin consumes less energy. I do not find this comparison accurate, because as discussed in my book, I do not think bitcoin replaces banking, or the functions of banking. It rather replaces central banking, being a primitive and barbarian edifice, consume nowhere near as much energy as bitcoin in the same way outhouse cleaners consume less energy than a sewage system, or horses consume less energy than cars. That did not stop cars from displacing horses, and our quality of life has not suffered from all the extra energy we have "wasted" on cars instead of riding horses. The benefits incurred from this move are incalculable for us, primarily by not having to deal with horse manure as a permanent fixture of life. In a very similar way, the benefits of bitcoin lie in the horrors it would allow us to avoid by taking money production out of the hands of the state's violent Keynesian barbarians.

Should Bitcoin take from one governments the ability to finance one needless war, if it prevents one instance of hyperinflation such as Venezuela from happening, if it prevents one megalomaniac leader from being able to finance his genocide, bitcoin's energy consumption would be the best bargain humanity ever got. If it restores to humanity a sound monetary system outside of government control, and allows us to return to a store of value that appreciates over time, just how much would bitcoin worth?

When making a true cost benefit analysis of bitcoin, the true benefit is not in replacing banks' or central banks' energy consumption. It is rather in returning to a free market monetary standard, and the long-term orientation, individual liberty, restraints on government power, and sound economic system it provides. It is akin to a return to the economic institutions of the late nineteenth century, ***la belle epoque***, arguably the pinnacle of human civilization. In my mind, if bitcoin succeeds as a technological solution immune to control by government, no amount of electricity it consumes could possibly be too much. There are no better uses of electricity imaginable, to me at least.

VI- How bitcoin transforms the global energy market

1- Global liquid energy market

The most significant impact that bitcoin can have on the market for energy is that it is a technological solution that makes energy production far more fungible and liquid. Bitcoin mining is unique in being an energy-extensive and highly profitable use of energy that does not need to be located near human settlement to operate. As discussed above, the problem of energy is not in its scarcity, but in the ability to channel it to where it is most needed, and that is usually where humans live. Bitcoin mining does not have that problem. The implications of this are tremendous, and only just beginning to be understood.

First, areas blessed with cheap energy can now monetize this capacity by using it to mine bitcoin. Second, it makes monetizable isolated energy sources which are left untapped because they would require significant costs to be connected to electric grids near residential or industrial areas. Simple satellite internet connections are sufficient to connect a bitcoin miner in a very isolated location to the bitcoin network and allow it to monetize the energy source it is near. A relatively small investment can allow an investor to monetize the energy source and cover their capital costs, before then using the energy to built more residential, commercial, or industrial facilities that benefit from the low cost of energy.

Third, only the energy with low opportunity costs leading to very low electricity rates will be consistently profitable for mining, and will attract long-term capital investment and infrastructure. Wherever energy is in high demand by residential, commercial, or industrial facilities, using that energy to produce bitcoin will carry a significant opportunity cost, as there are people who would pay dearly for using that energy. Energy sources that are isolated, however, can be used for bitcoin mining but cannot be used for residential, commercial, or industrial uses, and so carries a very low, zero, or even negative opportunity cost. The first kind of energy will be profitable for mining during spikes in the price, such as what we saw in 2017, but this profitability will be quickly eliminated through rising difficulty, as we saw in 2018.

This is why Bitcoin mining will only be profitable at prices lower than the average global electricity rates. These rates would be expected to converge more and more over the coming future thanks to Bitcoin putting a bid under their prices, and thanks to Bitcoin investment in cheap energy allowing the accumulation of capital and the reduction in the cost of energy production.

2- Increased energy production

The essential property of capital goods is that they increase the marginal productivity of the producer who uses them. The fisherman who catches fish with a modern trawler has a much higher hourly productivity than the fisherman using a little boat and net, whose productivity is in turn higher than that of the fisherman on the coast holding a fishing rod, whose productivity is higher than anyone trying to catch fish with their own hands. As the stock of capital increases, the marginal productivity of the worker increases, and that is why countries that have higher capital stocks have higher income than poorer countries. The march of human progress and civilization is the march of capital being accumulated to produce more output per unit of effort expended by a human being, and the more capital is accumulated, the more productive humans are, and the lower the marginal cost of the good produced.

As mentioned above, energy on this globe is not a fixed stock which we slowly deplete, but rather an ever-renewing flow from which we only need to utilize a tiny fraction to thrive. As such, more capital investment in energy production will only lead to more capital dedicated to the utilization of these vast resources of energy, more energy production, and lower energy cost.

Applying this analysis to the question of bitcoin power consumption has startling implications. Contrary to your local news anchor bimbo's hysteria, bitcoin isn't "consuming" the world's energy, bitcoin is providing a powerful market incentive to energy producers worldwide to increase their energy production. By giving a large financial incentive to anyone able to mine at an electricity cost below that of the market, Bitcoin makes the development of cheap sources of electricity, anywhere in the world, very rewarding. This financial reward in turn leads to growing investment in capital infrastructure for cheap energy sources, which leads to increased energy production, and decreased cost.

This might sound too good to be true for some readers, as it seems that bitcoin will magically create resources to go toward investment in energy infrastructure. The mark of a good economist is to stop whenever someone is trying to sell you a feel-good story and ask "Where's the catch? What's the opportunity cost?" The resources do indeed have to come from somewhere, and that is government seniorage.

Remember here that Bitcoin only has any value because people choose to hold it. If bitcoin has a price, it is only because someone decided to go to bed tonight without selling their bitcoin at that price. Only demand for holding money gives money value. When demand for holding money declines, the value of the money declines too, while when the demand increases, the value increases. If bitcoin continues to grow, it would acquire more demand, which must come at the expense of something else people will be demanding less. In this case, the obvious alternative is government money. Bitcoin's growth will have to come at the expense of the demand that people have for government money worldwide, and thus, it would cause the value of government to decline, or to grow less than it otherwise would have. This will either lead to the destruction of the value of a highly inflationary national currency if people dump it for bitcoin, or at least limit governments' hands in inflating their currency, forcing them to be more careful with their monetary policy, as was discussed in the monetization scenarios of last month's research bulletin. Either way, in a world in which bitcoin is growing fast, government's ability to finance its operation through the stealth tax of inflation would be seriously compromised. Instead of inflation taking away from the wealth of the productive in order to finance needless wars, politicians, bureaucrats, their cronies and other unproductive parasites, bitcoin's seniorage would is being awarded in an open global competition to whoever can produce the cheapest electricity. Instead of seniorage rewarding parasitism, corruption, and warmongering, bitcoin's seniorage rewards smart engineering, creative technological solutions, and intelligent use of capital.

The problems of government control over money are discussed extensively in Chapter 8 of The Bitcoin Standard, and will not be repeated here. Suffice it to say that not only can Bitcoin potentially defund governments from the resources they need to grow more controlling and exploitative of their populations, it will also direct these resources toward developing energy production.

There's an old saying in economics that the cure for high prices is high prices. As the price of anything rises, the incentive for producing it increases, so its supply will increase as a response, thus bringing the price down. But the relationship is more complex than just an increase in supply as a response to an increase in demand. Once one understands the nature of capital production it becomes clearer how this relationship works. As the price of a good rises, producers earn increased returns on their sales, which allow them to invest in capital production, and as rising prices help cover the initial capital costs, the costs that remain are the marginal costs, bringing prices down and quantities up.

3- Hydroelectric power development

Bitcoin changes the economics of power sources by introducing an energy-extensive and highly profitable use of electricity that is largely location independent. Large numbers of miners can be installed near a water dam and they could operate without much need for human supervision. This could finance the building of infrastructure in areas that are not profitable to for human settlement currently. But after a dam and powerplant have been built and financed over 5 years of operating Bitcoin mining, the energy that is produced could finance further infrastructure development, bigger dams, and even residential and commercial areas. Bitcoin mining will provide the start-up capital needed to finance a large amount of hydroelectric power around the world.

Followers of mining over a long period of time will conclude that the only kind of mining that is profitable in the long-run is mining based on hydrolectric energy or excess flared methane. Hydrocarbon energy is simply too expensive as a source of energy for bitcoin mining. It can surely be profitable during times in which Bitcoin's price rises very quickly, but it cannot compete with energy sources like hydroelectric power which have a far lower opportunity cost. And that, fundamentally, is what hydroelectric power's advantage comes from. Hydrocarbons are much cheaper to transport than hydroelectric energy. They are thus in high demand everywhere humans settle. They can be used for cars, homes, cities or all kinds of other uses. They will always have a high opportunity cost, relatively, because there is always someone who could use them for something highly productive. Hydroelectric energy, on the other hand, usually has a very low opportunity cost, or even a negative opportunity cost, when one considers the dangers posed by flooding.

Bitcoin is already having a discernible impact in the world of energy production by allowing for the monetization of hydroelectric power in an unprecedented manner. Large amounts of hydroelectric power are generally located in areas of mass water movement, and thus are not ideal for human habitation. Societies likely develop in areas away from this, and thus most cities and urban areas rely on hydrocarbon energy, or nuclear for their energy supply. Hydroelectric power, while plentiful, requires very large infrastructure and capital investment to make available reliably for urban areas. Enormous amounts of excess energy are disposed in the seasons with extensive run-off, when there is no conceivable way of storing it.

A recent **report by Coinshares** observes data on bitcoin mining operations leads to an observation which cannot simply be explained by coincidence: the bulk of Chinese Bitcoin mining is located in provinces with significant solar, wind, and hydroelectric capacity. Outside of China, most large-scale mining operation are located in the "Pacific North West (Washington State, Oregon and British Columbia), Quebec, upstate New York, Northern Scandinavia (Norway and Sweden), Iceland and Georgia. The energy sectors of almost all of these regions except New York and Russia are dominated by renewables and there are publicly available figures showing the percentage of renewables penetration in each region [Figure 9]. Europe and North America also have the lowest hydropower utilisation factors in the world, with both regions using less than 40% of installed capacity."

The smartest mining operations are the ones that have figured this out. In particular, Bitfury's main product is the Block Box, a shipping container custom-fitted with bitcoin miners and an engine to run them. The Black Box can be located anywhere energy is plentiful and cheap, and just needs a simple internet connection to mine and produce bitcoin for its owner. Upstream Data, Inc. is a Canadian firm located in Alberta which relies on building a similar custom-fitted mining operation to be located at oil fields to benefit from the flaring of methane that is too cheap to be transported or used for anything else. While these operations have only been around for a few years, it will be one of the most interesting aspects of the development of bitcoin to observe what kind of developments these projects will lead to.

As Bitcoin mining continues to move to natural sources of hydroelectric power, investors in these sources will likely accumulate capital, and once the infrastructure for the generation of the energy has paid for itself, it can be used for alternative uses, and it can power the building of more facilities and infrastructure around the energy source. Bitcoin mining can thus finance the first step of exploitation of natural energy sources, and then finance the building of residential, commercial, or industrial developments that can benefit from that energy. The long run net result will be that more and more communities and cities will start locating around these natural energy sources. We will start seeing more and more of humanity clustered around natural energy sources.

Historically, cities and population centers have developed according to many considerations, primarily around seaports, trade routes, and natural resources. The cities of the twenty-first century were not built with the utilization of the energy sources of the twenty-first century in mind, and so cities generally exist far away from sources of energy that could power them. As Bitcoin finances the development of energy infrastructure, it will naturally lead to a world where more and more of the population lives near abundant energy sources with a low marginal cost for energy.

4- Ending energy subsidies

By creating a globally liquid and fungible energy market, bitcoin has created a unique situation in human history where energy sources can be utilized independently of their location. Bitcoin thus creates a profitable use of an energy source anywhere it exists in the world, and gives an incentive for anyone to use their energy to mine bitcoin if the cost of the energy is too low. This doesn't just apply for stranded energy sources, but also for subsidized and artificially-cheap electricity sources. Wherever anyone has access to subsidized energy, it would make sense for them to mine bitcoin, and thus monetize the subsidy given them. As this becomes more apparent, it will soon become untenable to have significant energy subsidies anywhere.

The amount of distortions that have happened in the energy market around the world over the past century cannot be overstated. As electricity's spread came along with the spread of the modern managerial state, there is barely a spot on earth in which the production and consumptioin of electricity is not treated as a matter of national importance on which public policy must pronounce. In most the world this has translated into subsidies for specific industries, interest groups, or energy uses. Such a subsidy, like all government subsidies, is highly destructive economically. It distorts consumption decisions, thus giving the subsidized an incentive to consume more than they need. It distorts production decisions, incentivizing producers to produce less. The most pronounced impact of such distortions are the power cuts that plague much of the world, a simple market shortage caused by the control of the price of energy. At the least, these subsidies will cause inefficient waste of resources.

Bitcoin is a black hole heading for anyone trying to keep electricity artificially cheap anywhere. Anybody trying to make some uses of electricity come at a lower price, because of political or whatever silly reasons, will find that people who get that cheap electricity will use it to mine bitcoin, until they bankrupt the people providing them subsidized electricity. Anybody subsidizing electricity today has a sword hanging over their neck. They need to either stop subsidizing electricity, or go bankrupt.

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