**Introduction**

Cryptocurrency in the last decade has grown exponentially to an incomprehensible size. It is featured blatantly across news sites, publications, and has spread into the homes of enthusiasts and even ordinary people. Cryptocurrency, at its foundation, is a type of virtual currency that uses cryptography to secure transactions. The first and currently largest cryptocurrency used today is Bitcoin. Bitcoin was developed in 2009 by an unknown person or group of people and is still widely used despite being in development. Other notable cryptocurrencies include Ethereum, Litecoin, and Ripple. Today, many establishments ranging from convenience stores to package lockers accept cryptocurrencies as payment. Bitcoin ATMs have increased in popularity, oftentimes being stationed right next to ATMs of well-known international banks. Governments buy cryptocurrency to use as a fallback in the case of unstable economies. Cryptocurrency is used by gamblers, criminals, investors, video gamers, and is seen in many other larger circles. Cryptocurrency has evolved from being a niche hobby of the early 2010's and is slowly taking the world by storm. The key selling point of using this type of currency is that it is decentralized. Formally, the decentralization means that there is no regulating authority that manages the currency. This, therefore, allows for fully anonymous and instant transactions at low rates and minimal fees, as no physical banks are needed to verify transactions. Decentralization also forces all transactions to be public, and cryptocurrencies manage this on a platform called blockchain, circling back to the process in which cryptocurrency is created.

Anyone looking for a quick profit at the expense of a slightly raised electricity bill is drawn by the idea of "mining" cryptocurrency, but at what cost? Cryptomining is known as the process in which new units of cryptocurrencies (also known as crypto coins) are minted. Very powerful hardware and intensive software is put to work, solving complex mathematical problems called hashes. Every time someone sends another user any amount of Bitcoin, the transaction is signed, or verified, through these hashes. Typical banks verify transactions between two users using micro-deposits, often a series of a few cents, confirming the correct sender and recipient are being dealt with. Bitcoin, on the other hand, uses miners to decrypt these hashes, verifying the Bitcoin is legitimate and the recipient and sender are correct. Solving these hashes rewards cryptominers with their cryptocurrency. By mining, a user lends their computer's hardware and electricity and is paid, or "rewarded", in small units of cryptocurrency. This hardware is often seen in the form of enthusiast-grade graphics cards, central processors, and memory. The high demand and difficulty in producing hardware of this grade has inadvertently led to a worldwide global micro-transactor and silicon shortage. " For Taiwan Semiconductor Company (TSMC), the world’s largest semiconductor producer, 4% to 6% of its production capacity of leading nodes (7 nm and 5 nm) is used for Bitcoin mining" (Li 1). The implications of this shortage include disruptions of supply chains and high demand for mining hardware. More importantly, however, is the focus on the energy that mining generates.

Currently, there are many different forms of mining that go on. Individuals and enthusiasts are mining on their own hardware and power by contributing to mining pools consisting of hundreds of people. The combined computational power of all these lower-end computers contribute to solving a single hash. "There is no typical size of cryptocurrency mining operations, but a wide scale ranging from students who do not pay for their electricity ... to gamers who leverage their graphics cards whenever they are not playing ... all the way up to dedicated, large scale crypto-mining farms …" (Stoll et al. 1). There are also forms of unethical mining that takes place, such as computer malware or power stealing, that add on to the staggering effect of cryptomining. Cryptocurrency's mining difficulty increases as more and more miners join in on breaking down cryptocurrency hashes. To ensure that each block takes around ten minutes to mine, hashes have become more complex over time, requiring more power and time to solve. This results in a snowballing effect. More mining power is needed to receive the same amount of repayment, which ends up increasing the demand for cryptocurrency, which finally increases the demand and profit of mining. This has led to more miners being introduced to mining cryptocurrency, and an overall greater carbon footprint, which has implications of its own. Mining does generate a tangible financial value to the miners, which does help accelerate the economy. However, the fact that cryptocurrency quantities are limited means that eventually, the profit that miners get from mining new coins will approach zero. Bitcoin itself has a rule programmed that "after every 210,000 blocks are mined (approximately every 4 years), the block reward halves and will keep on halving until the block reward per block becomes 0 (approximately by year 2140)" ("Bitcoin Block Reward Halving Countdown"). In 2009, for example, one block contained 50 bitcoins. Today, it is only 6.25 bitcoins. The next halving is set to occur in early 2024, decreasing the reward to 3.125 coins per block. Though cryptocurrencies are decentralized, open-source, and fast and easy to use, it does not mean this system is without flaw. Cryptocurrency's biggest downfall is the threat it poses to the global ecosystem as well as its failure of sustainability. Thus, the question to be asked is how badly does cryptocurrency affect our global climate? Does the power consumption and waste generated by cryptocurrency outweigh its environmental impact? A hypothesis is that the difference in mining profits versus energy consumption is too low to warrant any sort of mining any further. Although the benefits of cryptocurrencies are numerous, cryptocurrency is not yet the perfect monetary solution due to the threat it poses to the global ecosystem, its failure of sustainability, and ultimately its effect on public health.

**The Threat of Bitcoin on Global Warming**

To create a more specific outlook on the effects of cryptocurrency on global climate, Bitcoin will primarily be considered. This is because Bitcoin is the largest and biggest offender of climate change, and many case studies examine only Bitcoin in detail as there is a wide array of public information available on it. As previously mentioned, to create new units of Bitcoin, computers use high amounts of energy to mine and procure coins. This process is known as a proof-of-work system (PoW) and is the opposite of its proof-of-stake (PoS) counterpart. In a PoW system, physical effort (in this case, computational power) is used to solve arbitrary mathematical puzzles to prevent anyone from cheating and finding workarounds in hopes of a reward. Only those who put in the effort (which is proved by the solving of the problems) can get rewarded. In this case, the reward is new units of the cryptocurrency itself. PoS, on the other hand, is a system that validates entries into a secure database and does not require any additional proof of effort. An example of this is Sweatcoin. "Sweatcoin [is] a free fitness app that awards points — “sweatcoins” — for walking or running outside. Accumulate 550 sweatcoins, [and] the app [would reward with a] Fitbit Flex wearable fitness tracker" (Singer 1). Users can also sell their Sweatcoin for cash, and Sweatcoin profits through its brand partners and advertisements. Due to the PoW approach of Bitcoin, one of Bitcoins largest flaws is its extremely high electricity usage. The implication of this energy usage is elevated carbon emissions being released into our atmosphere, also known as the greenhouse effect. The greenhouse effect is "the result of a process in which a planet’s atmosphere traps the sun radiation and warms the planet’s surface … Greenhouse effect occurs in the troposphere (the lower atmosphere layer), where life and weather occur … Carbon dioxide is responsible for 20% of the thermal absorption." (Cassia et al. 1). Currently, the greenhouse effect is a scientifically accepted theory that was established by John Tyndall in 1859 that explains why the Earth is warmer than it would be without an atmosphere. The greenhouse effect is known to be the cause for many environmental anomalies, such as the gradual melting of the ice caps, as well as rising sea levels worldwide. A data visualization figure sourced from a case study by Chock et al. estimates that Bitcoin alone will be responsible for a global temperature increase of 2 °C by early 2023. "In January of 2016, each [Bitcoin] mined required 1005 kWh of electricity; but by June 2018, each coin mined required 60,461 kWh" (Goodkind et al 1). Goodkind et al. also have estimates for per-coin economic damages and mortality rates. All this information was found by measuring the traces of pollutant gasses found by burning fossil fuels in the air for use in electricity consumption. The rates at which these gasses were found were then divided by the amount of electricity used to mine a single coin, resulting in the average emissions released to generate one coin. This important figure was the key in understanding the extent of the damages caused by Bitcoin, as the emission rates themselves could then be linked to many different causes of concern, such as rates of cancer, mortality, and global temperature increases. "The damages from a [Bitcoin] ... are estimated to be $3,551 ($1480 from mortality impacts, $2071 from climate impacts)"(Goodkind et al. 1). Around half of this figure comes from mortality impacts, and the other from climate change impacts. For reference, mortality impacts include a variety of topics including disease care, research, and death arrangements. This large figure raises the question of whether mining is worth the damages it causes.

**Global Warming's Implications on Public Health**

The way that carbon emissions actively affect the public is well known. As stated earlier, there is a mortality per-coin estimate which represents the damages caused to human populations created by one coin. These damages include but are not limited to lung diseases and cancer, birth defects, skin illnesses, and more. The severity of air pollution caused by particulates released by the burning of fossil fuels, " … is an important environmental risk factor for cardiopulmonary and lung cancer mortality" (Pope III, C. A., et al. 1). This paper uses attributes and evidence of short-term exposure studies but goes beyond to explore the long-term implications of these particulates affecting lung health. The severity of the air pollution is also what is mainly responsible for the morality half of the per-coin estimates calculated by Goodkind et al. The paper written by Pope III et al. heavily focuses on metropolitan areas, as the particulates per area in the atmosphere above these areas are the greatest. This specifically is due to many factors including industrialization and population footprints, but it can be assumed that metropolitan areas and cities have very high and dense populations and so have a greater energy need; this then leads to a higher concentration of power. Although the paper focuses on metropolitan areas, the case study conducted by Stoll, et al. highlights that most of the mining done by Americans, as an example, is done in metropolitan areas. "Based on Device Ips, we can confirm the U.S. concentration. We identify the location of ASIC [crypto miners] via the IoT-search engine Shodan … we can view the distribution on a national level" (Stoll et al. 12). Since mining pools are facilitated by public platforms and all Bitcoin transactions are recorded on a public ledger, it is easy for data scientists to know roughly where transactions are taking place, as well as the size of these transactions. Stoll et al. were able to pinpoint and monitor the internet locations of users on a peer-to-peer network and create a heatmap of where transactions are taking place. Of the 19% of mining that happened in America, roughly more than half of transactions were done in or near metropolitan areas. There is a cause for concern as a correlation can be made between power usage locations and public health issue rates in metropolitan areas. A certain percentage of mining can be said to cause these effects. Proof of this is found in the case study conducted by Goodkind et al. as it is seen that the emission rates of electricity generation were combined with the electricity usage per coin created. When introducing their case study methodology, they write, "We start by collecting data on emission rates per kWh of electricity generation by country … for pollutants commonly created by burning fossil fuels to produce energy" (Goodkind et al. 1). As stated, carbon dioxide emissions were taken into consideration when calculating the environmental half of the damages-per-coin estimate. Bitcoin's environmental negligence does not end here – Bitcoin is also responsible for large amounts of e-waste that has been slowly adding up to dangerous amounts. E-waste, or electronic waste, is a term used to describe waste of electronic products that have typically reached the end of their life cycle. E-waste includes old technology such as tube televisions, CD players, and VCR systems, but can also include hardware that is modern but dysfunctional, such as an overworked mining computer that no longer powers on. There are known to be three types of e-waste: major appliances (refrigerators, washing machines), small appliances (vacuum cleaners, blenders), and computer and telecommunication appliances (computers, phones). Of these, Bitcoin miners fall under the last category and are one of the most difficult to recycle due to the number of components and different materials used. As of May 2021, Bitcoin's annual e-waste generation added up to 30 metric kilotons, or just over 66 million pounds. Aside from filling landfills, e-waste " represents a growing threat to our environment and includes issues from toxic chemicals and heavy metals leaching into soils to air and water pollution caused by improper recycling" (De Vries, Alex, and Christian Stoll 1). This relates back to the entire idea that Bitcoin poses a major threat to public health worldwide, as landfills are used in every major country with proper infrastructure.

**Case Study Methodologies and Limitations**

Bitcoin is an extremely public platform, albeit anonymous. All Bitcoin transactions are facilitated under digital identities, and all transactions are made visible to everyone. Transactions are recorded on the blockchain, as mentioned previously, which is a ledger of all Bitcoin transactions ever made. A copy of this blockchain is stored by mining software to ensure that the Bitcoin sender (the miners) and recipients (the mining pool organizers) are dealing with the correct amount of money. Fortunately for data scientists, services such as Blockchain.com, CoinDesk, and BitInfoCharts can give accurate and detailed representations of the Bitcoin blockchain data, formatting it for readability and scalability. Databases like these are the raw sources of data scientists and case studies such as that of Stoll et al. These databases include the internet locations of mining pool servers as well as miners' own personal devices. Stoll et al. chose to use BTC.com and Slushpool to analyze internet locations and were able to find that American miners contribute heavily to European mining pools to evade mining pool prohibition. Additionally, they found that over 95% of mined blocks were done in America. This information was then used to calculate Bitcoin's carbon footprint based on total power and geographic area (Stoll, Christian, et al. 1). The implication of this American mining could possibly mean that other countries are not reporting well enough on their mining and electricity usage habits, but more importantly it shows how American industrialization has led miners to create adverse global conditions in favor of mining profits. The biggest limitation of these case studies is the lack of accurate data that can be used. Bitcoin's effect on our environment is still a relatively new issue to researchers, and so there is evidently a great deal of research and effort to be done on this topic. Furthermore, Bitcoin being the largest cryptocurrency means that most public information on cryptocurrency is found on Bitcoin. Information on air quality, however, is widely available and accurate and strengthens the case study analyses on Bitcoin's effect on carbon emissions and air quality. As an example, the case study conducted by Goodkind, Andrew L. et al. uses official air quality models developed by the Center for Air, Climate, and Energy Solutions which are reputable and as accurate as possible.

**Solutions to the Bitcoin Energy Crisis**

            One straightforward approach to end this issue is to take legal action against carbon polluting. "Governments should devise and pass policies which encourage the energy companies and people, in general, to use renewable energy instead of conventional energy" (Egiyi and Ofoegbu 21). Although it would be very beneficial in theory, it would be very difficult for governments to regulate this on a large, country-wide scale. Especially when dealing with regulating Bitcoin, there is no specific bank or organization that governments can turn to due to Bitcoin's decentralized nature. Therefore, governments would need to create task forces dedicated to stopping the mining and transferring of cryptocurrencies. This itself is difficult since it is impossible to know who exactly mining is, and who is trading. One possibility that organizations have used in the past to restrict mining is checking all outgoing network requests and blocking any that trail back to cryptocurrency servers. However, this is easily preventable using a virtual private network, which could mask the traffic and hide any websites that were visited. There is also the possibility of running a whitelist of only approved sites, but this would be difficult to moderate as new, safe websites are being added all the time, and safe websites could, once whitelisted, turn into cryptocurrency servers. There is also the chance that users could use internet services such as the dark web to conduct Bitcoin transfers, which ultimately is impossible to govern. Therefore, it is extremely unviable for governments to properly regulate cryptocurrencies in their economies. However, not all hope is lost for government regulation. Recently, cryptocurrency exchanges have been requiring KYC ID from users before letting them conduct transactions. KYC, or Know Your Customer (or sometimes Know Your Client) is a process of checking identifying documents when opening certain banking accounts. These IDs are also checked over time, to confirm the identity of any given user. Cryptocurrency exchanges gather the KYC IDs they require from users and share them with law enforcement agencies. "If law enforcement is lucky, they can identify a subject based on pictures obtained by video surveillance, IP addresses, or Know Your Customer (KYC) information" (Ben-Peretz 1). Currently, this process is only done to aid ongoing investigations on illegal usage of cryptocurrency, such as to purchase illicit goods or services on the dark web or black market. However, it is viable for KYC ID to also aid in targeting those with high power usages. The next and so far most viable solution of this issue, is turning to renewable energy sources and the idea of green energy. Green energy refers to sustainable, or renewable energy. These are energy sources that do not use limited resources (such as the burning of fossil fuels), and therefore do not change the energy needs or climates long-term. Sustainable energy sources include wind power and solar energy. Although most green energy sources are also renewable, not all renewable energy sources are green. According to Mustafa et al., there is a need for businesses and corporations to adopt renewable energy and energy saving measures. They go on to claim, "Individual investors might be interested in investing in cryptocurrency when they can observe that their contribution is used for social benefits, like generating renewable energy, or climate change, to give two examples." (Mustafa et al. 1). To do this would be in the interest and benefit of everyone’s health and safety worldwide, and so the short-term political and corporate greed of those that pollute the world is only short-lived. Additionally, this solution is already in effect today. There are many forms of alternate energy being used, e.g. windmill farms and dams, that help power up America. Bitcoin is perhaps only a short-term endeavor for most, the emissions it generates however cannot be recovered. The idea of carbon neutrality, or net-zero carbon dioxide emissions, is significant because it could single-handedly stop climate change in its tracks. More and more businesses and corporations are pledging carbon neutrality by a certain time, as a goal to end harmful carbon emissions and save the planet. As an example, Rutgers University has recently pledged a "strategic plan [to] achieve carbon neutrality before 2041 … and [help] achieve national net-zero greenhouse gas emissions no later than 2050" ("President's Task Force on Carbon Neutrality and Climate Resilience"). A similar approach could be done by Bitcoin and the Bitcoin Foundation, or other major proof-of-work cryptocurrencies to align with similar goals of these other corporations and fundamentally combat climate change. Another consideration of eliminating the global change of cryptocurrency is completely moving to a PoS system of operations. This would kill the carbon emissions of Bitcoin at the source; however, abandoning PoW and the efforts of mining would mean that Bitcoin would ultimately perish in comparison to larger PoW currencies. It is possible that Bitcoin could adapt to this type of system, though it is not very plausible. Instead of proving hashes are solved through the work used to solve them, Bitcoin would have to find a different method of verifying hashes. Eliminating mining altogether would be the best way to combat Bitcoin's climate change, although this is unfeasible when considering those already so invested in Bitcoin's operations. It would also require a great amount of persuasion and dedication for the Bitcoin foundation to change their operating scheme.

**Conclusion**

Bitcoin has been influential in paving the way for a unified currency. Its benefits include it being fully anonymous, public, open-source, and decentralized. However, Bitcoin has large drawbacks in the sense of public health and security, and it should be in the interest of miners and cryptocurrency developers to adapt to our changing global environment. Due to the increase in global temperatures, electronic waste, and the proof-of-work nature of Bitcoin, Bitcoin is an extremely unsustainable currency of cryptocurrency. To create a change against climate change, Bitcoin will have to be handled differently before its high demand leads to a large increase in temperature. As technology advances, users feel a lower consideration for the implications of their actions. This inconsideration has put our planet at risk, and without change, the future of our planet is dangerously unknown.

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