MBS Final Tesis Report - Raphaël Altieri PGE3C

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2 to 3 pages report on how the ideas of my Tesis are starting to build up.
Deadline 31st of January - Deposit via Ecampus and Email to David Roubaud.
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Overall Outline of the Master Thesis Final Report

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Introduction

In this work my focus is to talk about the following topic:
Does the bitcoin network allow the creation of a new and parallel energy market ?

As most of us know, Bitcoin is a decentralized digital currency that relies on a technology called blockchain to validate transactions and create new bitcoins. This process of creating new bitcoins is called mining, and it is the key feature that links the Bitcoin network and energy. The mining process is designed to be computationally intensive and requires a lot of energy to operate.

The first point to consider is the energy consumption of the Bitcoin network. The process of mining requires solving complex mathematical problems, which requires a significant amount of computational power. This computational power is provided by specialized computer hardware called ASICs, which consume a lot of electricity to operate. In fact, it is estimated that the energy consumption of the Bitcoin network is currently on par with that of small countries. This high energy consumption has led to concerns about the environmental impact of Bitcoin mining, as well as the cost of using the currency. As we will see forward, despite this valid criticism this is a feature ensuring the value of Bitcoin and in no way a weakness of the Bitcoin Network.

Nevertheless, we can already state the following argument: 1 Unit of Energy = 1 Bitcoin.

Another point to consider is that:

The mining algorithm uses a protocol of proof of work in the Bitcoin network. In other words this means that in order to validate transactions and create new bitcoins, the Bitcoin network uses a consensus mechanism called *proof of work*. As stated above, this mechanism requires miners to solve complex mathematical problems in order to validate transactions and create new bitcoins. This process of solving mathematical problems is computationally intensive, which is why it requires a lot of energy.

By some analysts *Proof of work* is considered to be superior to *proof of stake*, which is another consensus mechanism that is used in some other blockchain networks. The main advantage of proof of work is that it is a more secure and a decentralized mechanism compared to proof of stake.

In *proof of stake*, the validation of transactions is based on the number of coins a miner holds. This can lead to centralization of the network as the rich miners with more coins can validate more transactions. In contrast, proof of work is based on computational power, which allows for a more decentralized network as any miner can participate with sufficient computational power.
The link between the Bitcoin network and Energy is an important one to consider when discussing the currency.

The use of *proof of work* consensus mechanism in the Bitcoin network ensures a more secure and decentralized network, making it superior to *proof of stake*. Nevertheless, I will not discuss which protocol is better in this Thesis.**In this study we will focus mainly on observing the ramifications of the Bitcoin Network.**

As we’ve been able to discuss above, because of the way the Bitcoin Network was created the link between the Bitcoin network and Energy is unbreakable and leads to an important implicit characteristic to consider when discussing the currency:

1 Unit of Energy = 1 Bitcoin.
Can we quantify that energy ? Or in other words...
Does the bitcoin network allow the creation of a new and parallel energy market ?

1 .Literature Review and Research Question Presentation (15 to 25 pages)

Bitcoin, as described by Nakamoto (2008), is a decentralized digital currency that uses cryptographic techniques to enable peer-to-peer transactions. Nakamoto's seminal paper on Bitcoin proposed a solution to the problem of double-spending, which had long been a challenge in creating a digital currency. Bitcoin's design is such that it relies on a distributed network of nodes to validate and record transactions in a public ledger called the blockchain. This ensures that transactions are secure and irreversible once they have been added to the blockchain. As Nakamoto (2008) noted, "Nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone" (p. 3). This means that the Bitcoin network can continue to function even if some nodes go offline or are compromised.

Antonopoulos (2014) built on Nakamoto's work by providing a more comprehensive overview of Bitcoin and its underlying technology. In his book Mastering Bitcoin: Unlocking Digital Cryptocurrencies, Antonopoulos delved into the technical details of how Bitcoin transactions are validated and how the blockchain works. He also explored the broader implications of Bitcoin and other cryptocurrencies, such as their potential to disrupt traditional financial systems and enable new forms of peer-to-peer exchange. According to Antonopoulos (2014), "Bitcoin is a protocol that allows for decentralized, trustless, peer-to-peer exchange without the need for intermediaries" (p. xxv). This makes it an attractive option for individuals and businesses seeking greater control over their financial transactions. However, Antonopoulos also acknowledged that Bitcoin's decentralized nature makes it vulnerable to certain risks, such as the potential for network attacks and regulatory crackdowns. Despite these challenges, Bitcoin has continued to grow in popularity and has inspired the development of numerous other cryptocurrencies and blockchain-based applications.

The wide-area synchronous grid is an interconnected network of electric power systems that operate on the same frequency and phase angle, covering large geographic areas such as continents or entire countries. The synchronization of the grid allows for the efficient transmission of electricity over long distances, but it also poses technical and operational challenges. For example, the grid must maintain a balance between electricity supply and demand in real-time, and disturbances such as power outages or voltage fluctuations can quickly spread across the entire network. Additionally, different regions of the world face specific challenges, such as the high demand for electricity in Asia or the intermittent nature of renewable energy sources in Europe.

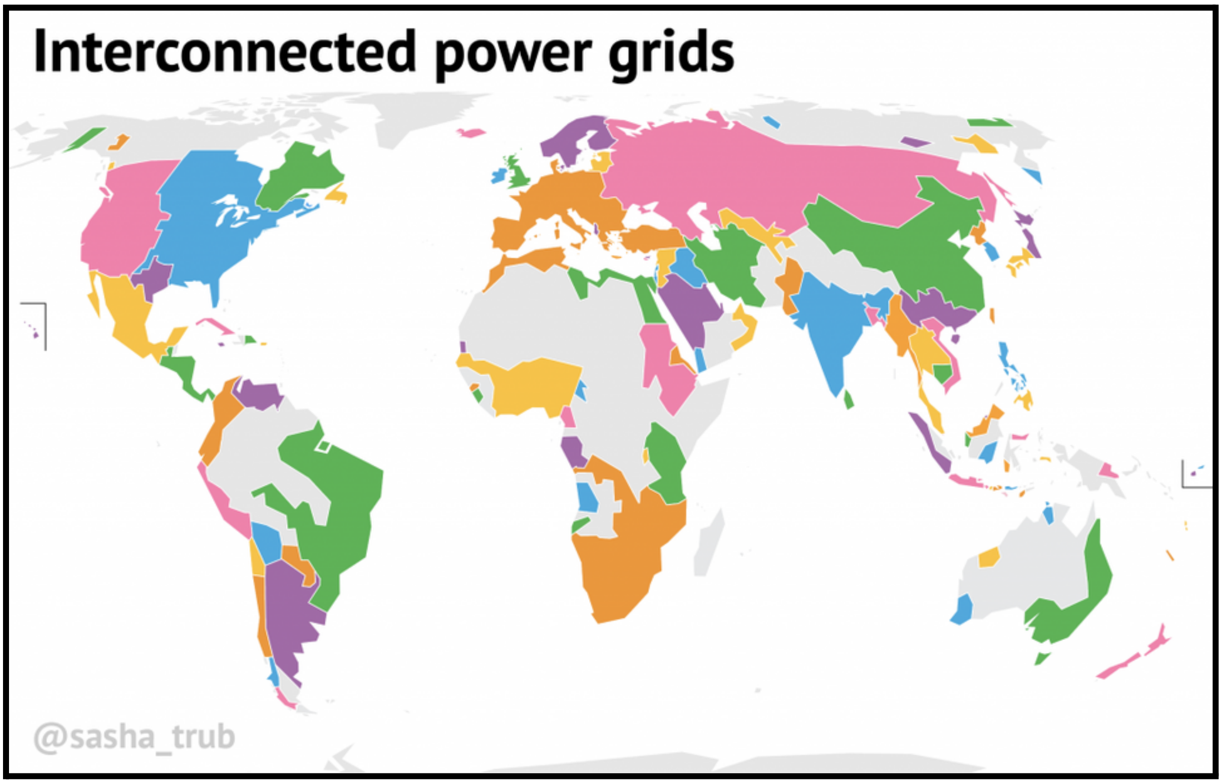
Indeed, around the world there is a multitude of wide area synchronous grids, or in other worlds a multitude of *unified power grids* that are able to get electricity from one point to another.

One of the technical challenges of unifying the grid is the need to maintain a consistent electrical frequency and voltage across the network. Even small deviations can disrupt the synchronization of the grid and cause power outages. To overcome this challenge, researchers have proposed various solutions, such as using advanced control systems and monitoring technologies, implementing voltage regulation techniques, and developing power electronics devices that can convert electricity between different frequencies and voltages.

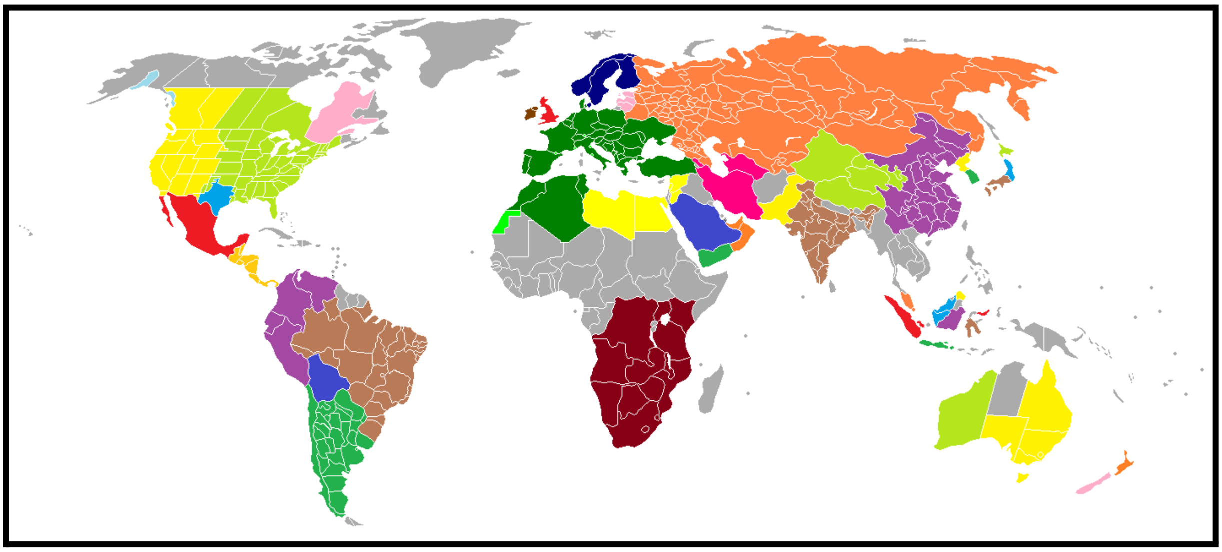
However, these solutions can be complex and expensive to implement on a large scale, and there is still a need for further research and development. Maybe in the future when superconductive materials are more easy to use in our electric networks this grid will tend to unify.

Until that moment arrives the reality is the following:

- Several fragmented, often politically guided, energy-inefficient power grids exist.



https://sashamaps.net/docs/maps/interconnected-power-grids



https://en.wikipedia.org/wiki/Wide_area_synchronous_grid

Indeed, with that said a few more details are worth mentioning:

As was said before, there are multiple reasons why the wide-area synchronous grid around the world is not unified. One reason is that different countries and regions have different regulations, policies, and infrastructure for electricity generation and transmission. This can make it difficult to connect different grids and to share electricity between them. Additionally, different regions may have different energy mixes, with some places relying heavily on renewable energy sources and others relying on fossil fuels. This can also make it difficult to share electricity between different regions.

Another reason is that different regions have different electrical frequencies. For example, in North America, the standard frequency is 60 Hz, while in Europe it is 50 Hz. This means that if electricity is transmitted between regions with different frequencies, it can cause technical problems and damage to equipment.

Additionally, there are political and economic barriers that make it difficult to unify the wide-area synchronous grid. For example, some countries may be unwilling to share their electricity with other countries, or may be unwilling to give up control of their electricity transmission infrastructure. To address these challenges, researchers have proposed the creation of regional energy markets and international collaborations, such as the European Union's Internal Energy Market and the North American Energy Integration, which aim to promote cross-border energy trade and cooperation.

Despite these challenges, there are solutions to unify the wide-area synchronous grid in the future. One solution is to increase the use of high-voltage direct current (HVDC) transmission lines, which can transmit electricity over long distances with minimal loss and can connect different electrical frequencies.

Another solution is to create regional energy markets, where electricity can be bought and sold between different countries and regions. This would allow for greater flexibility and efficiency in the electricity market, and would make it easier to share electricity between different regions.

Additionally, advanced technologies such as smart grids and distributed energy resources (DERs) can help to unify the wide-area synchronous grid. Smart grids use digital technology to make the grid more efficient and reliable, and DERs such as solar panels and wind turbines can be connected to the grid to provide clean, renewable energy.

International collaboration and cooperation is essential in order to unify the wide-area synchronous grid. Countries and regions must work together to develop common standards and regulations for electricity transmission and generation, and to coordinate their efforts to build the infrastructure needed to connect different grids.

In conclusion, unifying the wide-area synchronous grid around the world is challenging due to a variety of factors, including different regulations, policies, and infrastructure for electricity generation and transmission, different energy mixes, and political and economic barriers. However, solutions such as the use of high-voltage direct current (HVDC) transmission lines, regional energy markets, advanced technologies, and international collaboration and cooperation can help to unify the wide-area synchronous grid in the future.

Now you might wonder, what has all of this to do with Bitcoin.

The main reason for this Thesis is that I think that the link between Bitcoin mining and Energy could potentially help to solve the problem of unifying the wide-area synchronous grids.

As previously stated Bitcoin mining, the process of validating transactions on the Bitcoin network, requires a significant amount of energy. However, this energy consumption could be harnessed to help unify diverse wide-area synchronous grids. We could indeed imagine a system where the use of excess energy could be transformed into energy that is digitally stored: Bitcoin.

For example, if excess energy (at peak-producing hours) from renewable sources, such as wind or solar power, is used to mine Bitcoin, this would help to balance the grid by absorbing excess energy that would otherwise be wasted. Additionally, the use of renewable energy for Bitcoin mining would help to reduce the overall carbon footprint of the network. The potential use of excess energy from renewable sources to mine Bitcoin has been proposed as a way to balance the grid and reduce carbon emissions. Bitcoin mining requires a significant amount of energy, which can be supplied by renewable energy sources during periods of excess generation. This can help to reduce curtailment of renewable energy, which occurs when production exceeds demand and the excess energy is wasted. Some countries have already implemented programs to incentivize the use of excess renewable energy for Bitcoin mining, such as the Greenidge Generation plant in New York, which uses hydropower to mine Bitcoin during times of low demand.

This approach can provide additional revenue streams for renewable energy producers and help to reduce greenhouse gas emissions from traditional fossil fuel-based power plants. However, there are also concerns about the environmental impact of Bitcoin mining and the potential for it to consume too much energy if it becomes too popular.
This would lead anyways to the creation of a new energy market. Where for example on a sunny day, Spain can monetise their excess of Energy (that would otherwise be wasted) by mining Bitcoin with free energy.

Here's an example of Australia's price of the MegaWatt where thanks to more renewable energy added to the energy mix year after year, now at some hours of the day the *duck curve* got more extreme and makes that energy prices at some hours of the day do actually pay you.

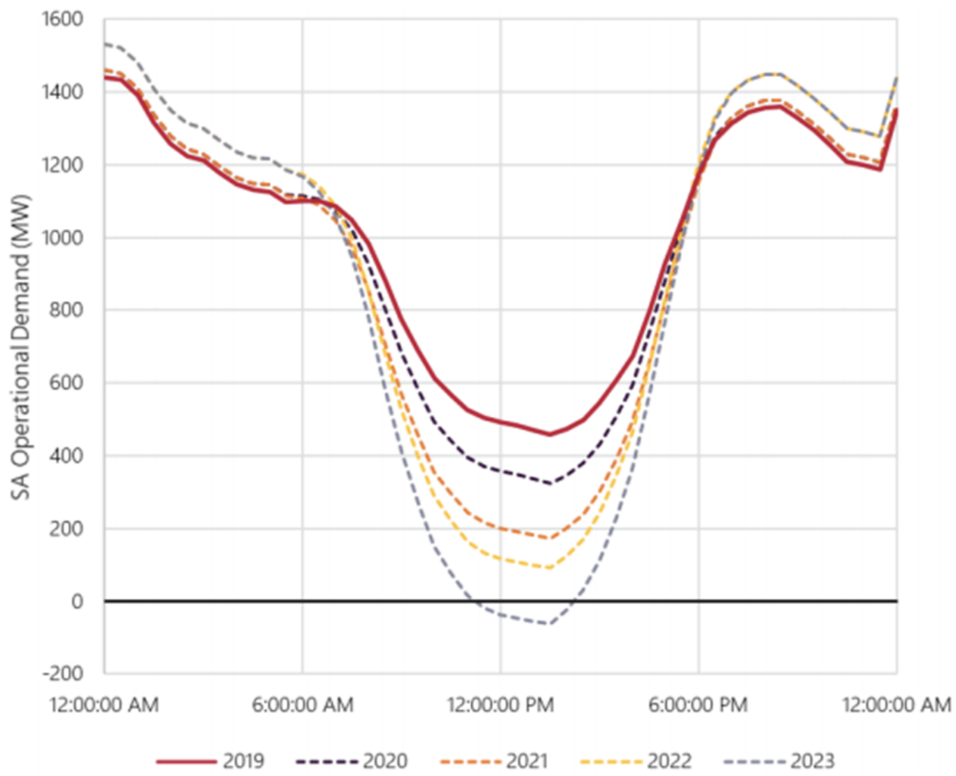


Figure 2: Effect on South Australian operational demand from increasing distributed PV generation (AEMO: Minimum operational demand thresholds in South Australia May 2020)

https://flowpower.com.au/negative-electricity-pricing/

The way that the Bitcoin network could bypass some barriers that actually exist and by doing so help to unify the wide-area synchronous grids is through the use of blockchain technology.

As stated before, blockchain is the technology that underlies Bitcoin, and it can be used to create decentralized and transparent energy markets. These markets could allow for the buying and selling of electricity between different regions and countries, which would help to unify the wide-area synchronous grid by arbitraging price differences in a solid and liquid BTC/USD market open the 24 hours of day and the 365 days of the year.

Moreover, a blockchain-based platform could be used to track and verify the generation and transmission of electricity from renewable energy sources. This would help to increase transparency and trust in the energy market, and would make it easier to share electricity between different regions.

Additionally, blockchain-based energy trading platforms could allow for peer-to-peer (P2P) energy trading, where individuals and small businesses can buy and sell excess energy with each other, without the need for intermediaries. This could help to increase the efficiency of the energy market and make it easier to share electricity between different regions and even inside of the already existing networks.

The link between the Bitcoin network and energy markets, therefore obvious, has the potential to help unify the wide-area synchronous grid by using excess energy from renewable sources to mine Bitcoin, and by using blockchain technology to create decentralized and transparent energy markets. These solutions could help to balance the grid and increase the efficiency of the energy market, and would make it easier to share electricity between different regions.

2. Research Methodology

2.1 Research Design

We decided to focus on a purely quantitative approach to analyze in relevant scenarios the implication of Bitcoin mining.

Research Design 1 (Quantitative):

To engage readers and provide a comprehensive understanding of the relationship between energy production and Bitcoin mining activities, we will conduct an in-depth quantitative analysis. This analysis will assess the efficiency of Bitcoin mining operations in various energy pricing environments and explore the potential of the Bitcoin network to convert excess (and often renewable energy) into economic value. The quantitative research design will be divided into several stages:

1. Data Collection: In this stage, we will gather historical data on Bitcoin mining hardware, energy prices, and renewable energy production from various sources, such as the International Energy Agency, National Renewable Energy Laboratory, Glassnode, and industry reports. This data will serve as the foundation for our quantitative analysis.

2. Hashrate Efficiency Frontier: Calculate the "Hashrate efficiency frontier," which represents the maximum number of hashes (computer calculations) achievable per watt of energy consumed. This metric will provide insights into the energy efficiency of different mining hardware and help us understand the evolution of mining technology over time. We will also examine how the efficiency frontier has shifted over the years in response to technological advancements and market forces.

3. Ground-floor-energy-price Estimation: Estimate the ground-floor-energy-price of one Bitcoin at various moments, which represents the minimum energy cost required to mine a single Bitcoin. This will help us understand the economic feasibility of Bitcoin mining in different regions with varying energy prices and renewable energy sources. We will analyze how the ground-floor-energy-price has changed over time and identify trends that may affect future mining operations.

4. Regional Analysis: Investigate the geographical distribution of Bitcoin mining operations and their relationship with renewable energy production. We will analyze the energy mix of different regions and determine the proportion of renewable energy sources used in Bitcoin mining. This will enable us to assess the potential for further integration of renewable energy into the Bitcoin mining process and identify regions where this potential is highest.

5. Scenario Analysis: Develop and analyze different scenarios for the future of Bitcoin mining and renewable energy. These scenarios will take into account factors such as technological advancements, changes in energy prices, and shifts in regulatory environments. By

examining the possible future trajectories of Bitcoin mining and renewable energy production, we can explore the potential synergies between these sectors and identify opportunities for mutual growth and development.

6. Statistical Analysis: Employ advanced statistical techniques, such as regression analysis and time-series forecasting, to identify patterns and correlations between renewable energy production, energy prices, and Bitcoin mining activities. This will enable us to quantify the impact of various factors on the relationship between renewable energy and Bitcoin mining and make informed predictions about the future of this relationship.

7. By conducting a comprehensive quantitative analysis of these aspects, we will gain valuable insights into the relationship between renewable energy and Bitcoin mining. This research design will enable us to explore the potential of the Bitcoin network to convert excess (and often renewable energy) into economic value and contribute to the growth of the renewable energy sector, providing a solid foundation for further research and discussion.

Research Design 2 (Quantitative):

This research design will delve into the unique case of El Salvador, where Bitcoin has been adopted as legal tender, and the country is leveraging geothermal energy from volcanoes to mine Bitcoin. **The study will provide a macroeconomic perspective on the implications of this decision and its potential effects on the country's energy market and economy, taking into account the synergy between the Bitcoin network and the energy market.** The quantitative research design will be divided into several stages:

1. Data Collection: Gather relevant data on El Salvador's economy, energy market, and Bitcoin mining activities. This will include data on GDP growth, inflation, foreign investment, energy prices, infrastructure development, and renewable energy share in the country's energy mix. Sources for this data will include governmental publications, industry reports, and financial market data.

2. Volcano Bonds Analysis: Analyze the structure and issuance of El Salvador's Volcano Bonds, a financial instrument designed to fund the country's Bitcoin mining operations using geothermal energy. Assess the potential risks and rewards associated with these bonds for investors, considering the efficiency and environmental impact of geothermal energy for Bitcoin mining. Evaluate the bonds' potential to attract international investors and facilitate the development of the country's geothermal energy sector.

3. Macroeconomic Impact Assessment: Examine the macroeconomic impact of El Salvador's decision to adopt Bitcoin as legal tender, focusing on indicators such as GDP growth, inflation, and foreign investment. Investigate whether this decision has influenced the development of a parallel energy market, characterized by decentralized, transparent energy

trading enabled by blockchain technology. Conduct a comparative analysis with other countries that have not adopted cryptocurrencies as legal tender to identify possible causal links between these decisions and macroeconomic outcomes.

4. Energy Market Effects: Investigate the potential effects of Bitcoin mining using geothermal energy on the country's energy market, including the impact on energy prices, infrastructure development, and the overall share of renewable energy in El Salvador's energy mix. Assess the role of Bitcoin mining in fostering cross-border electricity trading and the growth of peer-to-peer energy trading platforms in the country.

5. El Salvador as a Model: Analyze the potential for El Salvador to become a model for other countries seeking to integrate Bitcoin mining and renewable energy sources, and evaluate whether the country's experience can provide insights into the broader potential for synergy between the Bitcoin network and the energy market. Identify the key factors contributing to the success or failure of this approach and assess the replicability of this model in other countries with similar conditions.

6. Statistical Analysis: Employ advanced statistical techniques, such as regression analysis, to identify patterns and correlations between the adoption of Bitcoin as legal tender, the use of renewable energy sources in Bitcoin mining, and macroeconomic indicators in El Salvador. This will enable us to quantify the impact of these factors on the country's economy and energy market and make informed predictions about the future of this relationship.

By conducting a thorough quantitative analysis of El Salvador's unique case, we will be able to evaluate the potential benefits and challenges associated with integrating Bitcoin mining and blockchain technology in the energy market, particularly in the context of renewable energy sources. This research design will provide valuable insights into the real-world implications of innovative approaches to cryptocurrency mining and energy market integration while considering the potential creation of a new and parallel energy market.

2.2 Data Collection

To ensure the reliability and accuracy of our research, we will gather data from a diverse range of sources. These sources will include, but are not limited to, international organizations, national agencies, research papers from universities and other research institutions, industry reports, and news articles. By using multiple sources, we can cross-verify the data and strengthen the validity of our findings. In this section, we will discuss the various sources and the rationale behind their selection.

a) International organizations: Data from organizations such as the International Energy Agency (IEA) and the World Bank will provide comprehensive information on global energy trends, renewable energy production, and energy prices. These organizations have a wealth of experience in collecting and analyzing data and often serve as primary sources of information for researchers, policymakers, and industry professionals.

b) National agencies: Data from national agencies like the National Renewable Energy Laboratory (NREL) in the United States or the Energy Information Administration (EIA) will offer specific insights into regional and country-level energy markets and renewable energy trends. These agencies often have access to unique datasets that are not readily available through other sources, providing valuable information for comparative analysis.

c) Research papers from universities and research institutions: Academic research papers are critical for understanding the latest findings, methodologies, and theoretical frameworks related to the energy market, cryptocurrency, and the intersection of these fields. Accessing these papers through academic databases like JSTOR, SSRN, or ResearchGate will ensure that we are using up-to-date and peer-reviewed information.

d) Industry reports: Reports from industry leaders, consultancies, and think tanks such as McKinsey, Deloitte, and the World Economic Forum will provide valuable insights into the practical implications of our research topic. These reports often contain data on market trends, technological advancements, and real-world case studies, which can complement our quantitative analysis.

e) News articles: News articles from reputable sources like The Economist, The Wall Street Journal, or Bloomberg can provide real-time information on the latest developments in the energy and cryptocurrency sectors. These articles can also offer insights into the perspectives of industry experts, policymakers, and other stakeholders, which can be useful for understanding the broader context of our research.

In addition to the sources mentioned above, we will also explore other data sources, such as cryptocurrency data platforms (e.g., Glassnode, Coinmetrics), energy market data providers (e.g., Enerdata, Platts), and governmental publications (e.g., white papers, policy documents). By gathering data from a wide variety of sources, we can ensure that our research is comprehensive, accurate, and up-to-date.

To manage and organize the collected data, we will use tools such as Microsoft Excel, Google Sheets, or specialized data management software like NVivo. These tools will enable us to store, filter, and analyze the data efficiently and effectively.

In summary, our data collection process will involve a systematic and comprehensive approach to gathering information from a diverse range of sources. By cross-verifying the data and employing various data management tools, we will ensure that our research findings are reliable and robust, providing valuable insights into the relationship between renewable energy and Bitcoin mining.

The data sources that will be used will likely come from organizations like the International Energy Agency (IEA) or the National Renewable Energy Laboratory (NREL), and research papers from universities or other research institutions. Additionally, industry reports and news articles from reputable sources can provide valuable insights into current trends and developments in the energy and cryptocurrency sectors.

2.3 Data Measurement and Analysis

2.3.1 Research Design 1 (Quantitative):

a) Hashrate efficiency frontier calculation: Collect data on various Bitcoin mining hardware, including their energy consumption, processing power (hashrate), and mining efficiency. Use these data to calculate the hashrate efficiency frontier, representing the maximum number of hashes achievable per watt of energy consumed. Analyze the trends in mining hardware development over time, and investigate the impact of technological advancements on energy efficiency. Compare the efficiency of different mining hardware types, such as ASICs, GPUs, and FPGAs, to identify the most energy-efficient solutions for Bitcoin mining operations.

b) Ground-floor-energy-price estimation: Gather historical data on energy prices in different regions and countries, as well as information on the average energy consumption of Bitcoin mining operations. Using these data, estimate the ground-floor-energy-price of one Bitcoin at various moments in time, considering different energy pricing environments and renewable energy sources. Investigate the factors affecting the ground-floor-energy-price and its implications for the profitability of Bitcoin mining. Analyze the role of electricity subsidies, taxes, and regulations in shaping the energy cost landscape for mining operations.

c) Bitcoin network and energy market relationship: Collect data on the Bitcoin network's hashrate, price, and energy consumption, along with data on renewable energy production, excess energy generation, and energy prices. Analyze the relationship between these variables and explore the potential opportunities for integrating the Bitcoin network into the energy market. Examine the impact of fluctuating energy prices on Bitcoin mining profitability and the migration of mining operations to regions with lower energy costs. Investigate the role of Bitcoin mining in promoting the development of renewable energy infrastructure and its potential to act as a stabilizing force for energy grids.

d) Grid integration and demand response: Study the potential of Bitcoin mining operations to participate in demand response programs and their ability to provide grid services, such as frequency regulation and voltage support. Analyze the technical and regulatory challenges associated with integrating Bitcoin mining facilities into the grid and evaluate the potential benefits for grid operators, such as increased flexibility and reduced curtailment of renewable energy sources.

e) Impact of renewable energy on Bitcoin's carbon footprint: Assess the effect of increasing renewable energy adoption on the carbon footprint of the Bitcoin network. Investigate the potential for decarbonizing the Bitcoin network by shifting mining operations towards regions with a higher share of renewable energy sources in their energy mix.

f) Statistical analysis: Perform statistical analyses to identify trends and correlations between the hashrate efficiency frontier, ground-floor-energy-price, energy prices, and renewable energy adoption. Use regression models, time series analysis, and machine learning techniques to study the evolution of these variables over time and make predictions about future developments. Evaluate the robustness of the models by performing sensitivity analyses and testing alternative model specifications.

By further expanding the scope of the research design and incorporating additional elements into the quantitative section, the data measurement and analysis section becomes even more comprehensive and robust.

2.3.2 Research Design 2 (Quantitative):

a) Volcano Bonds analysis: Collect data on El Salvador's Volcano Bonds, including their structure, issuance, and financial performance. Analyze the potential risks and rewards associated with these bonds for investors, considering the efficiency and environmental impact of geothermal energy for Bitcoin mining. Investigate the role of government policies, regulatory frameworks, and market conditions in shaping the attractiveness of these bonds for investors. Assess the potential for similar financial instruments to be developed in other countries with abundant renewable energy resources.

b) Macroeconomic impact assessment: Gather macroeconomic data for El Salvador, including GDP growth, inflation, and foreign investment, before and after the adoption of Bitcoin as legal tender. Use econometric models to estimate the causal impact of this decision on the country's economy. Analyze the effect of Bitcoin adoption on various sectors of the economy, such as tourism, remittances, and technology development. Assess the potential long-term implications of widespread Bitcoin usage on monetary policy and financial stability.

c) Energy market analysis: Collect data on El Salvador's energy market, including energy prices, infrastructure development, and renewable energy mix. Investigate the potential effects of Bitcoin mining using geothermal energy on the country's energy market and assess the role of Bitcoin mining in fostering cross-border electricity trading and peer-to-peer energy trading platforms. Study the challenges and opportunities associated with the large-scale integration of geothermal energy into the grid and the potential impact on energy prices and grid stability.

d) Regulatory environment: Analyze the legal and regulatory landscape surrounding Bitcoin mining and renewable energy development in El Salvador. Identify potential barriers to the implementation of innovative energy projects and assess the effectiveness of existing policies in promoting the growth of the renewable energy sector and the integration of Bitcoin mining.

e) Comparative analysis: Analyze the potential for El Salvador to become a model for other countries seeking to integrate Bitcoin mining and renewable energy sources. Compare El Salvador's experience with other countries that have implemented similar initiatives, evaluating the broader potential for synergy between the Bitcoin network and the energy market. Identify the key factors that contribute to the success or failure of such initiatives and develop a framework for evaluating the feasibility of similar projects in different countries and contexts.

f) International cooperation: Examine the potential for regional and international cooperation in promoting the integration of Bitcoin mining and renewable energy sources. Assess the role of multilateral organizations, development banks, and private investors in supporting the growth of the renewable energy sector and the adoption of innovative energy solutions.

g) Future prospects: Investigate the future growth potential of the renewable energy sector and the Bitcoin network, considering the advancements in technology, market dynamics, and policy developments. Identify potential emerging trends, challenges, and opportunities for further integration of Bitcoin mining and renewable energy sources.

h) Statistical analysis: Perform statistical analyses to identify trends and correlations between the variables studied in El Salvador's case, using regression models, time series analysis, and other relevant quantitative methods to assess the relationships between Bitcoin mining, renewable energy, and the energy market. Conduct scenario analyses and develop forecasts for the evolution of the energy market and Bitcoin mining activities under various assumptions about technological progress, policy changes, and market developments.

By further expanding the scope of Research Design 2 and incorporating additional elements into the quantitative section, the data measurement and analysis section becomes even more comprehensive and robust.

3. Results and Analysis

3.1 Presentation of Results (Research Design 1)

As the Bitcoin Network matured over the years the methods used to generate new hashes got more sophisticated. This meant that the amount of hashes you could get from one same unit of energy became higher. In other words, the energy efficiency output (here below denominated in MH/J) was higher. This lead the to the overall increase in the hashrate of the network.

In the early days of Bitcoin, mining was done on personal computers using CPUs (central processing units). However, CPUs are general-purpose hardware and not specifically designed for Bitcoin mining, hence they were not very energy efficient.

Over time, Bitcoin miners moved to using GPUs (graphics processing units), which are more efficient than CPUs for the type of computations required for Bitcoin mining. GPUs are designed to handle many tasks simultaneously, which makes them well-suited for the repetitive calculations required in mining.

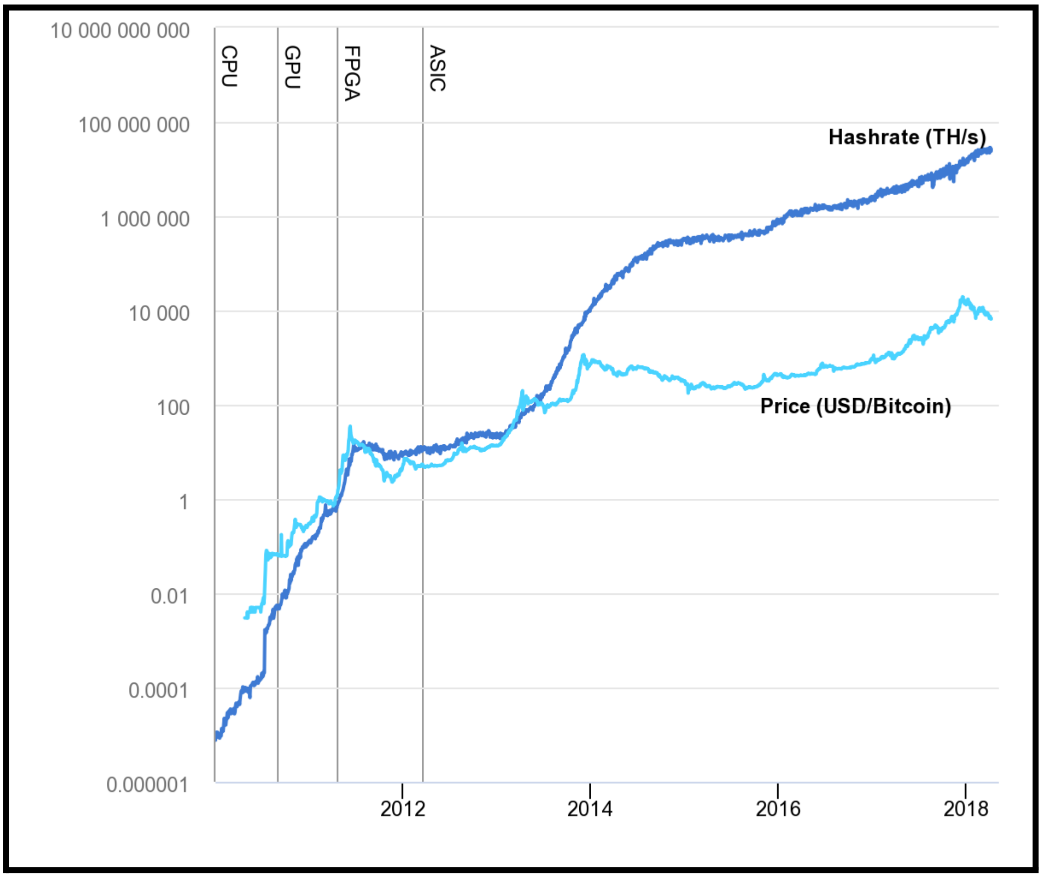
After GPUs, miners started using FPGAs (field-programmable gate arrays), which are even more energy efficient. Unlike CPUs and GPUs, FPGAs can be programmed to perform specific tasks, in this case, Bitcoin mining, which makes them more efficient.

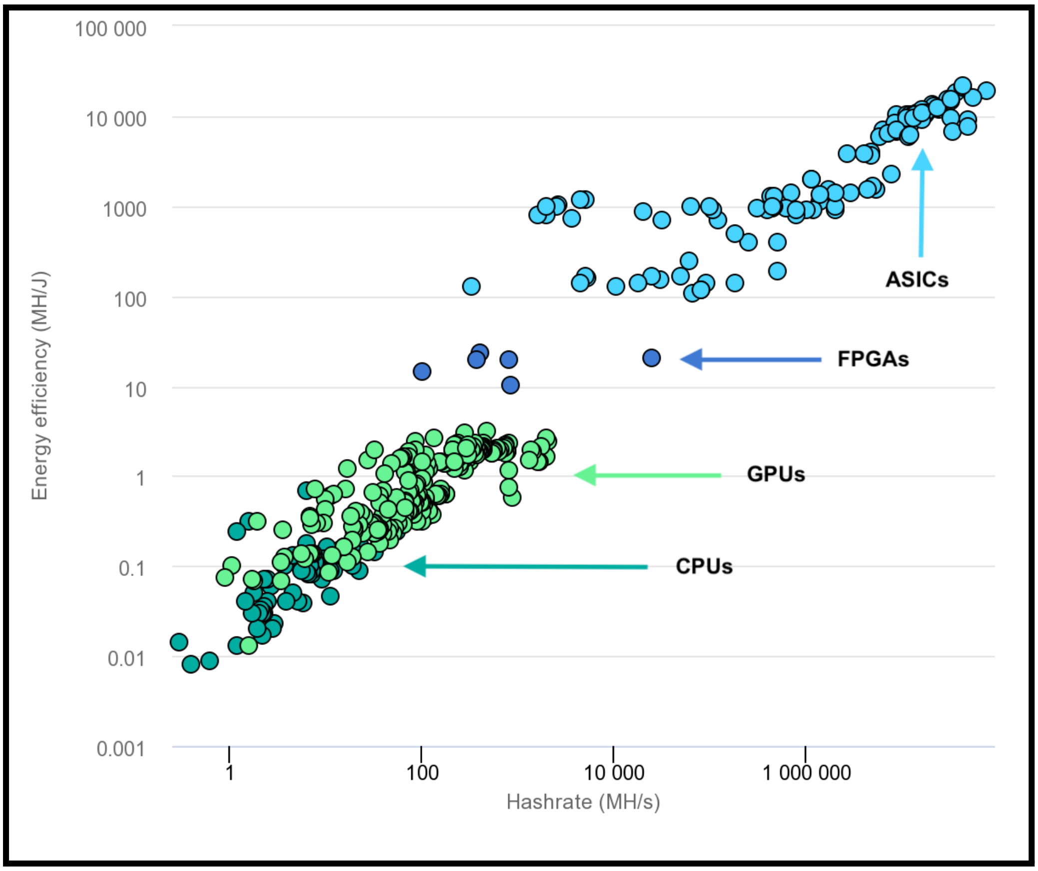
Then came ASICs (application-specific integrated circuits), the current standard for Bitcoin mining. ASICs are custom-built for Bitcoin mining, making them the most energy efficient option available. They can perform the necessary calculations for Bitcoin mining and nothing else, leading to a significant increase in the number of hashes generated per unit of energy.

As the energy efficiency of Bitcoin mining hardware has increased, so too has the overall network hash rate. This is because the same amount of energy can now generate more hashes, leading to a higher chance of solving the mathematical puzzle required to add a new block to the Bitcoin blockchain.

Still, on average, a new block is added to the Bitcoin blockchain every 10 minutes, regardless of how much hashing power is being used by the network. That's because an increased hash rate of the network also leads to an increase in the difficulty of the mathematical puzzle that needs to be solved to mine new Bitcoins.

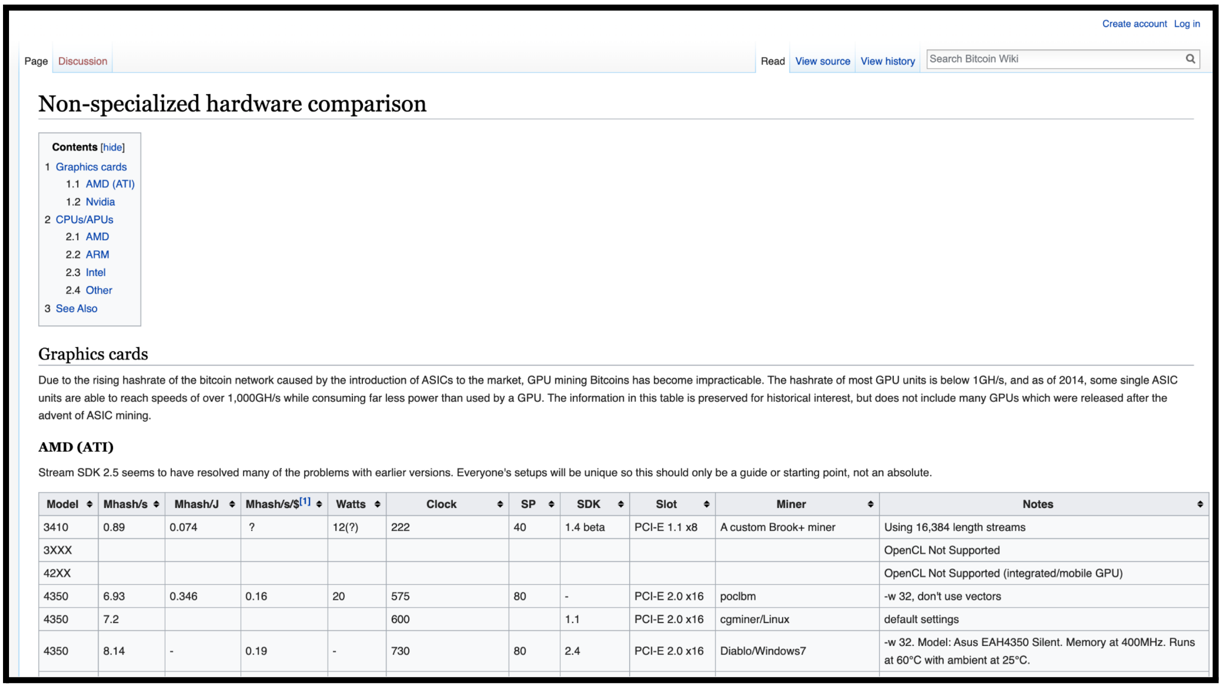
We will not explain in more detail the nature of the difficulty adjustment mechanism, nor the nature of the mathematical puzzle (solved through hashes) of the Bitcoin Network to keep the analysis more concise on the implication part of these mechanisms.





https://www.iea.org/commentaries/bitcoin-energy-use-mined-the-gap

The "Non-specialized hardware comparison" page on the Bitcoin.it wiki provides a useful historical perspective on Bitcoin mining before the widespread adoption of ASICs. It lists various types of CPUs and GPUs, along with their performance in terms of hashes per second, energy efficiency (in terms of hashes per watt), and more. This gives a good idea of how Bitcoin mining efficiency evolved as miners moved from CPUs to GPUs and later to FPGAs before finally settling on ASICs.



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Non-specialized hardware comparison

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Graphics cards

Due to the rising hashrate of the bitcoin network caused by the introduction of ASICs to the market, GPU mining Bitcoins has become impracticable. The hashrate of most GPU units is below 1GH/s, and as of 2014, some single ASIC units are able to reach speeds of over 1,000GH/s while consuming far less power than used by a GPU. The information in this table is preserved for historical interest, but does not include many GPUs which were released after the advent of ASIC mining.

AMD (ATI)

Stream SDK 2.5 seems to have resolved many of the problems with earlier versions. Everyone's setups will be unique so this should only be a guide or starting point, not an absolute.

Model	Mhash/s	Mhash/J	Mhash/s/$[1]	Watts	Clock	SP	SDK	Slot	Miner	Notes
3410	0.89	0.074	?	12(?)	222	40	1.4 beta	PCI-E 1.1 x8	A custom Brook+ miner	Using 16,384 length streams
3XXX										OpenCL Not Supported
42XX										OpenCL Not Supported (integrated/mobile GPU)
4350	6.93	0.346	0.16	20	575	80	-	PCI-E 2.0 x16	poclbm	-w 32, don't use vectors
4350	7.2				600		1.1	PCI-E 2.0 x16	cgminer/Linux	default settings
4350	8.14	-	0.19	-	730	80	2.4	PCI-E 2.0 x16	Diablo/Windows7	-w 32. Model: Asus EAH4350 Silent. Memory at 400MHz. Runs at 60°C with ambient at 25°C.

https://en.bitcoin.it/wiki/Non-specialized_hardware_comparison

While these older types of hardware can still be used for mining Bitcoin, they are not competitive with ASICs in terms of energy efficiency or computational power. Today, Bitcoin mining is almost entirely done with ASICs, because the difficulty of the mathematical puzzles that need to be solved to mine Bitcoins has increased so much that other types of hardware are no longer cost-effective.

We will take some key "Non-specialized hardwares" that marked the early days of bitcoin mining history. They will help us to calculate the hashrate efficiency frontier calculation (HEFC):

They will consist of:

- The CPU that was most probably running on Hal Finney computer
- The most likely more widespread used CPU in the early days of Bitcoin
- The most likely more powerful used CPU in the early days of Bitcoin
- The most likely more powerful used GPU in the early days of Bitcoin
- The most likely more powerful used FPGAs in the early days of Bitcoin

We will add those results to:

- One widespread used ASIC in 2013
- One widespread used ASIC in 2017
- One widespread used ASIC in 2021

By doing so we will have a total of 8 different points.

Indeed, we will proceed to collect data on various Bitcoin mining hardware, including their energy consumption, processing power (hashrate), and mining efficiency. Use these data to calculate the hashrate efficiency frontier, representing the maximum number of hashes achievable per watt of energy consumed.

The CPU that was most probably running on Hal Finney's computer: Hal Finney was the first person to receive a Bitcoin transaction from Satoshi Nakamoto. If we assume that he was using a high-end CPU for the time when Bitcoin was launched in 2009, that might have been something like the Intel Core 2 Duo, which was a common high-performance CPU at the time.

The most likely more widespread used CPU in the early days of Bitcoin: This would likely have been a lower-end CPU, possibly also from the Intel Core 2 line or perhaps an earlier model.

The most likely more powerful used CPU in the early days of Bitcoin: This would have been a high-end CPU for the time, such as the Intel Core i7, which was introduced in 2008.

The most likely more powerful used GPU in the early days of Bitcoin: Early GPU miners might have used something like the Nvidia GeForce 9800 GTX+, which was a high-performance GPU for the time.

The most likely more powerful used FPGAs in the early days of Bitcoin: FPGAs were not as commonly used as CPUs and GPUs, but some miners did use them. One example might be the Xilinx Spartan-6, which was a popular FPGA at the time.

One widely used ASIC in 2013: By 2013, several companies had started producing ASICs specifically for Bitcoin mining. One example might be the Avalon1, which was one of the first widely used Bitcoin mining ASICs.

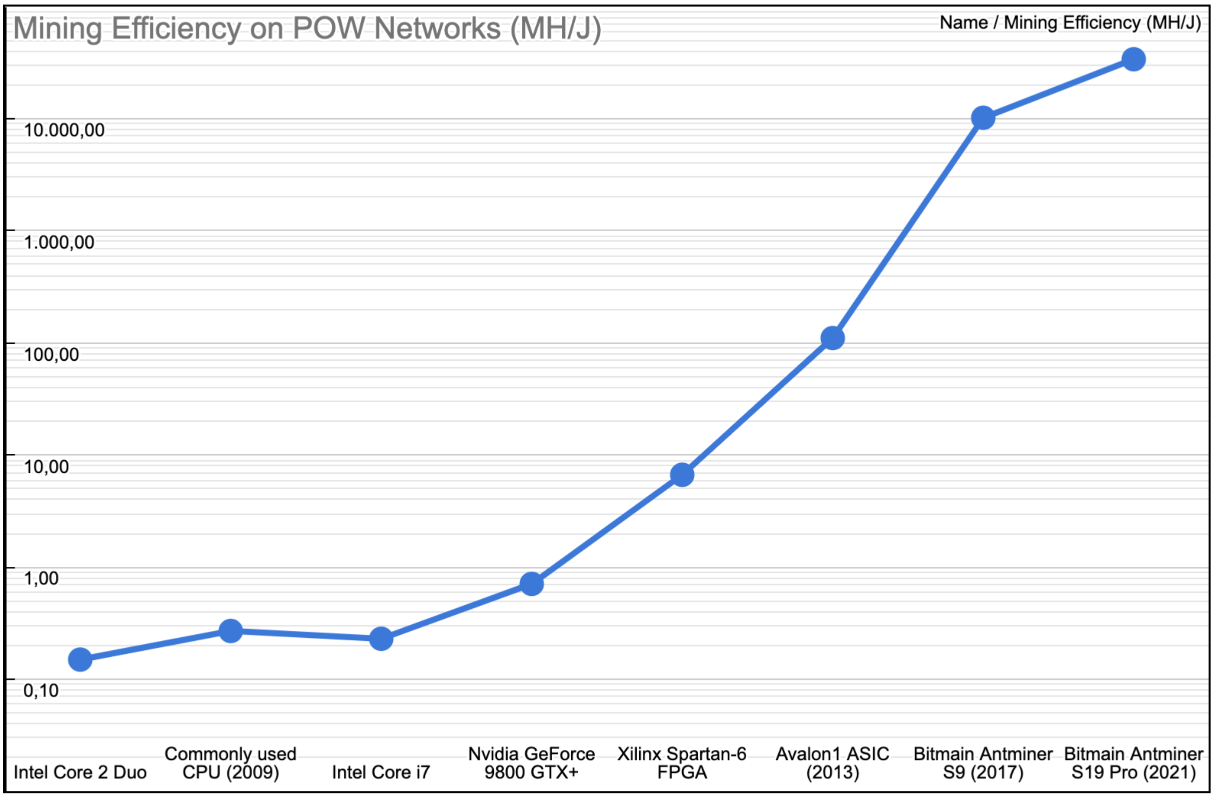
One widely used ASIC in 2017: By this time, ASIC technology had improved significantly. An example of a widely used ASIC in 2017 might be the Bitmain Antminer S9.

One widespread used ASIC in 2021: As of my knowledge cutoff in 2021, one of the most efficient and widely used ASICs was the Bitmain Antminer S19 Pro.

To construct your hashrate efficiency frontier, you would need to gather data on the hashrate (in hashes per second) and power consumption (in watts) of each of these devices, then calculate the efficiency in hashes per watt. The resulting data points can be plotted on a graph, with power consumption on the x-axis and hashrate on the y-axis, to visualize the frontier.

Name	Energy Consumption (W)	Processing Power (Hashrate; GH/s)	Mining Efficiency (MH/J)
Intel Core 2 Duo	65	0.01	0.15
Commonly used CPU (2009)	75	0.02	0.27
Intel Core i7	130	0.03	0.23
Nvidia GeForce 9800 GTX+	140	0.1	0.71
Xilinx Spartan-6 FPGA	15	0.1	6.67
Avalon1 ASIC (2013)	600	66.3	110.5
Bitmain Antminer S9 (2017)	1375	14	10,181.82
Bitmain Antminer S19 Pro (2021)	3250	110	33,846.15

The data above has been retrieved from several sources including the two mentioned above.



We observe that there's really a "before and after" ASIC-era when it comes to mining efficiency. This coincides with the 2013 to 2015 when the hashrate exploded.

ASICs began to enter the Bitcoin mining scene around 2013, and their impact on the network's overall hashrate was profound. Because they could generate more hashes per second for each unit of energy consumed, ASICs greatly increased the total computing power of the Bitcoin network. This led to a rapid increase in the network's hashrate, reflecting the rapid total amount increase of the hashrate.

As a side note this shift to ASICs not only made Bitcoin mining more efficient but also more centralized, as the cost and technical expertise required to operate ASICs are much higher than for other types of hardware. It also made Bitcoin mining a business model on its own. The emergence of mining pools, where miners combine their computational resources to increase their chances of mining a new block also happened during that era.

Satoshi Nakamoto, the pseudonymous creator of Bitcoin, did not explicitly predict the rise of mining pools in the original Bitcoin whitepaper. This development was a response to the practical realities of mining as the difficulty increased.

We now have the Mining Efficiency (MH/J) of 8 rigs but for simplification purposes we will suppose that as of 14th of May 2023 all the rigs participating in the mining of Bitcoin are Bitmain Antminer S19 Pro.

Knowing that the price of Bitcoin in US dollars is volatile and that the one of energy prices in US dollars is more stable, can we create a simple model that predicts when mining starts becoming profitable for us ?

Let's say Bitcoin is at 30k. We only have one unknown variable now:

The block reward was 6.25 Bitcoins.

Assuming you are using the Bitmain Antminer S19 Pro, which as per the previous example has an estimated mining efficiency of 33,846.15 MH/J and a power consumption of 3250W.

The amount of Bitcoin mined per day:

The Antminer S19 Pro has a hash rate of 110 TH/s or 110,000 GH/s.

Since the total hashrate of the Bitcoin network is variable, for simplicity let's assume it's 150,000,000,000 GH/s.

Your share of the total network hashrate is therefore (110,000 / 150,000,000,000) = 7.33e-7

The network mines an average of 144 blocks per day (24 hours * 60 minutes / 10 minutes per block), so your expected share of the daily block rewards is 144 blocks/day * 6.25 BTC/block * 7.33e-7 = 0.00065805 BTC/day

Now, calculate the revenue per day:

At a Bitcoin price of $30,000, your daily revenue would be 0.00065805 BTC/day * $30,000/BTC = $19.74/day

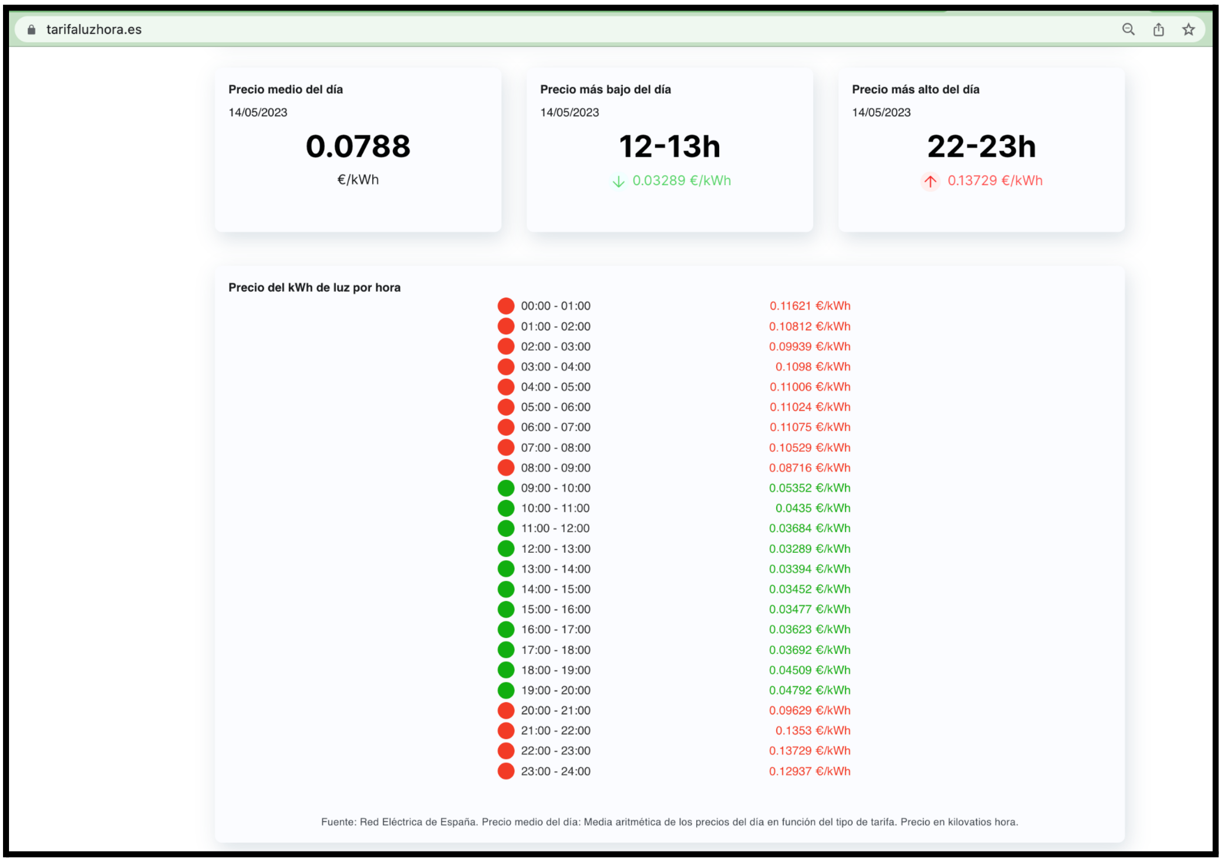
Finally, subtract the electricity cost from the revenue to get the profit:

$19.74/day - $(electricity cost)/day = $profit/day

So, with these assumptions, mining would be profitable at a Bitcoin price of $30,000. If the price is lower, the profit decreases; if the price is higher, the profit increases. Similarly, if the electricity cost is higher, the profit decreases; if the electricity cost is lower, the profit increases.

This is a simplified model and doesn't account for other potential costs, such as the initial cost of the mining hardware, maintenance costs, potential downtime, changes in the Bitcoin network's difficulty level, and changes in the total network hashrate.

For example purposes let's take for example the energy prices of the Iberian Peninsula of May the 14th 2023 according to https://tarifaluzhora.es/



tarifaluzhora.es

Precio medio del día	Precio más bajo del día	Precio más alto del día
14/05/2023	14/05/2023	14/05/2023
0.0788 €/kWh	12-13h 0.03289 €/kWh	22-23h 0.13729 €/kWh

Precio del kWh de luz por hora

00:00 - 01:00	0.11621 €/kWh
01:00 - 02:00	0.10812 €/kWh
02:00 - 03:00	0.09939 €/kWh
03:00 - 04:00	0.1098 €/kWh
04:00 - 05:00	0.11006 €/kWh
05:00 - 06:00	0.11024 €/kWh
06:00 - 07:00	0.11075 €/kWh
07:00 - 08:00	0.10529 €/kWh
08:00 - 09:00	0.08716 €/kWh
09:00 - 10:00	0.05352 €/kWh
10:00 - 11:00	0.0435 €/kWh
11:00 - 12:00	0.03684 €/kWh
12:00 - 13:00	0.03289 €/kWh
13:00 - 14:00	0.03394 €/kWh
14:00 - 15:00	0.03452 €/kWh
15:00 - 16:00	0.03477 €/kWh
16:00 - 17:00	0.03623 €/kWh
17:00 - 18:00	0.03692 €/kWh
18:00 - 19:00	0.04509 €/kWh
19:00 - 20:00	0.04792 €/kWh
20:00 - 21:00	0.09629 €/kWh
21:00 - 22:00	0.1353 €/kWh
22:00 - 23:00	0.13729 €/kWh
23:00 - 24:00	0.12937 €/kWh

Fuente: Red Eléctrica de España. Precio medio del día: Media aritmética de los precios del día en función del tipo de tarifa. Precio en kilovatios hora.

Let’s sum it up on a spreadsheet:

EURUSD = 1,09

kWh prices in the Iberian Peninsula in an hourly basis as of 14/05/2023			
00:00 - 01:00	0.11621	0,11621	€/kWh
01:00 - 02:00	0.10812	0,10812	€/kWh
02:00 - 03:00	0.09939	0,09939	€/kWh
03:00 - 04:00	0.1098	0,1098	€/kWh
04:00 - 05:00	0.11006	0,11006	€/kWh
05:00 - 06:00	0.11024	0,11024	€/kWh
06:00 - 07:00	0.11075	0,11075	€/kWh
07:00 - 08:00	0.10529	0,10529	€/kWh
08:00 - 09:00	0.08716	0,08716	€/kWh
09:00 - 10:00	0.05352	0,05352	€/kWh
10:00 - 11:00	0.0435	0,0435	€/kWh
11:00 - 12:00	0.03684	0,03684	€/kWh
12:00 - 13:00	0.03289	0,03289	€/kWh
13:00 - 14:00	0.03394	0,03394	€/kWh
14:00 - 15:00	0.03452	0,03452	€/kWh
15:00 - 16:00	0.03477	0,03477	€/kWh
16:00 - 17:00	0.03623	0,03623	€/kWh
17:00 - 18:00	0.03692	0,03692	€/kWh
18:00 - 19:00	0.04509	0,04509	€/kWh
19:00 - 20:00	0.04792	0,04792	€/kWh
20:00 - 21:00	0.09629	0,09629	€/kWh
21:00 - 22:00	0.1353	0,1353	€/kWh
22:00 - 23:00	0.13729	0,13729	€/kWh
23:00 - 24:00	0.12937	0,12937	€/kWh

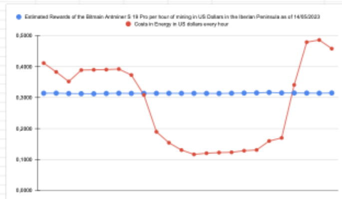
0:00	0,11621	€/kWh
1:00	0,10812	€/kWh
2:00	0,09939	€/kWh
3:00	0,1098	€/kWh
4:00	0,11006	€/kWh
5:00	0,11024	€/kWh
6:00	0,11075	€/kWh
7:00	0,10529	€/kWh
8:00	0,08716	€/kWh
9:00	0,05352	€/kWh
10:00	0,0435	€/kWh
11:00	0,03684	€/kWh
12:00	0,03289	€/kWh
13:00	0,03394	€/kWh
14:00	0,03452	€/kWh
15:00	0,03477	€/kWh
16:00	0,03623	€/kWh
17:00	0,03692	€/kWh
18:00	0,04509	€/kWh
19:00	0,04792	€/kWh
20:00	0,09629	€/kWh
21:00	0,1353	€/kWh
22:00	0,13729	€/kWh
23:00	0,12937	€/kWh

kWh prices in the Iberian Peninsula in an hourly basis as of 14/05/2023		
0h00	0,1266689	$/kWh
1h00	0,1178508	$/kWh
2h00	0,1083351	$/kWh
3h00	0,119682	$/kWh
4h00	0,1199654	$/kWh
5h00	0,1201616	$/kWh
6h00	0,1207175	$/kWh
7h00	0,1147661	$/kWh
8h00	0,0950044	$/kWh
9h00	0,0583368	$/kWh
10h00	0,047415	$/kWh
11h00	0,0401556	$/kWh
12h00	0,0358501	$/kWh
13h00	0,0369946	$/kWh
14h00	0,0376268	$/kWh
15h00	0,0378993	$/kWh
16h00	0,0394907	$/kWh
17h00	0,0402428	$/kWh
18h00	0,0491481	$/kWh
19h00	0,0522328	$/kWh
20h00	0,1049561	$/kWh
21h00	0,147477	$/kWh
22h00	0,1496461	$/kWh
23h00	0,1410133	$/kWh

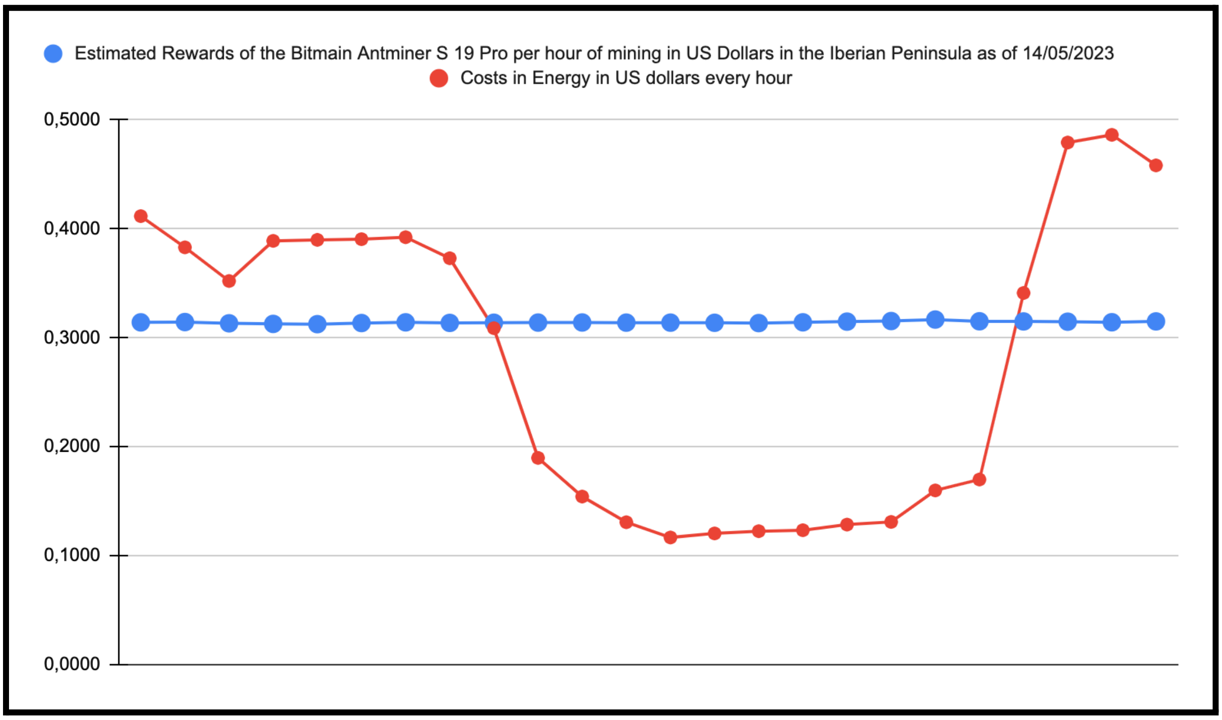
Estimation of mining income in USD from an Bitmain Antminer S19 Pro when mining Bitcoin (supposing you swap directly without fees from Bitcoin to USD) - Bitstamp, hourly open								
Hour	Price		Hashrate of the Bitcoin Network as of the 14/05/2023	Bitmain Antminer S19 Pro when mining Bitcoin	Share of the total network hashrate	Total Block Rewards in one hour on the Bitcoin Network as of 15/04/2023: 6,25Bitcoin*6	Estimated Rewards of the Bitmain Antminer S 19 Pro per hour of mining in Bitcoin	**Estimated Rewards of the Bitmain Antminer S 19 Pro per hour of mining in US Dollars**
00:00 - 01:00	26881	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3141
01:00 - 02:00	26905	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3144
02:00 - 03:00	26805	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3132
03:00 - 04:00	26759	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3127
04:00 - 05:00	26739	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3125
05:00 - 06:00	26826	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3135
06:00 - 07:00	26883	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3141
07:00 - 08:00	26837	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3136
08:00 - 09:00	26850	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3138
09:00 - 10:00	26863	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3139
10:00 - 11:00	26871	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3140
11:00 - 12:00	26859	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3139
12:00 - 13:00	26858	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3139
13:00 - 14:00	26846	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3137
14:00 - 15:00	26822	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3134
15:00 - 16:00	26885	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3142
16:00 - 17:00	26937	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3148
17:00 - 18:00	26983	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3153
18:00 - 19:00	27100	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3167
19:00 - 20:00	26994	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3151
20:00 - 21:00	26952	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3149
21:00 - 22:00	26932	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3147
22:00 - 23:00	26890	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3142
23:00 - 24:00	26955	USD/BTC	353.000.000 TH/s	110 TH/s	0,000000311614730	37,5	0,000011686	0,3150

Estimation of the cost in US Dollars of the Energy consumption of the Bitmain Antminer S 19 in the Iberian Peninsula as of 14/05/2023							
Hour	Price		kWh prices in the Iberian Peninsula in US dollars on an hourly basis as of 14/05/2023		Bitmain Antminer S 19 Consumption		Costs in Energy in US dollars every hour
00h00 - 01h00	29300,29	USD/BTC	0,1266689	$/kWh	3,25	kWh	0,4117
01h00 - 02h00	29326,45	USD/BTC	0,1178508	$/kWh	3,25	kWh	0,3830
02h00 - 03h00	29217,45	USD/BTC	0,1083351	$/kWh	3,25	kWh	0,3521
03h00 - 04h00	29167,31	USD/BTC	0,119682	$/kWh	3,25	kWh	0,3890
04h00 - 05h00	29145,51	USD/BTC	0,1199654	$/kWh	3,25	kWh	0,3899
05h00 - 06h00	29240,34	USD/BTC	0,1201616	$/kWh	3,25	kWh	0,3905
06h00 - 07h00	29302,47	USD/BTC	0,1207175	$/kWh	3,25	kWh	0,3923
07h00 - 08h00	29252,33	USD/BTC	0,1147661	$/kWh	3,25	kWh	0,3730
08h00 - 09h00	29266,5	USD/BTC	0,0950044	$/kWh	3,25	kWh	0,3088
09h00 - 10h00	29280,67	USD/BTC	0,0583368	$/kWh	3,25	kWh	0,1896
10h00 - 11h00	29289,39	USD/BTC	0,047415	$/kWh	3,25	kWh	0,1541
11h00 - 12h00	29276,31	USD/BTC	0,0401556	$/kWh	3,25	kWh	0,1305
12h00 - 13h00	29275,22	USD/BTC	0,0358501	$/kWh	3,25	kWh	0,1165
13h00 - 14h00	29262,14	USD/BTC	0,0369946	$/kWh	3,25	kWh	0,1202
14h00 - 15h00	29235,98	USD/BTC	0,0376268	$/kWh	3,25	kWh	0,1223
15h00 - 16h00	29304,65	USD/BTC	0,0378993	$/kWh	3,25	kWh	0,1232
16h00 - 17h00	29361,33	USD/BTC	0,0394907	$/kWh	3,25	kWh	0,1283
17h00 - 18h00	29411,47	USD/BTC	0,0402428	$/kWh	3,25	kWh	0,1308
18h00 - 19h00	29539	USD/BTC	0,0491481	$/kWh	3,25	kWh	0,1597
19h00 - 20h00	29390,76	USD/BTC	0,0522328	$/kWh	3,25	kWh	0,1698
20h00 - 21h00	29377,68	USD/BTC	0,1049561	$/kWh	3,25	kWh	0,3411
21h00 - 22h00	29355,88	USD/BTC	0,147477	$/kWh	3,25	kWh	0,4793
22h00 - 23h00	29310,1	USD/BTC	0,1496461	$/kWh	3,25	kWh	0,4863
23h00 - 24h00	29300,95	USD/BTC	0,1410133	$/kWh	3,25	kWh	0,4583

Profitable ?	
Estimated Rewards of the Bitmain Antminer S 19 Pro per hour of mining in US Dollars - Costs in Energy in US dollars every hour	**Profitable ?**
-0,0976	No
-0,0686	No
-0,0389	No
-0,0763	No
-0,0774	No
-0,0770	No
-0,0782	No
-0,0594	No
0,0050	Yes
0,1243	Yes
0,1599	Yes
0,1834	Yes
0,1973	Yes
0,1935	Yes
0,1911	Yes
0,1910	Yes
0,1864	Yes
0,1845	Yes
0,1569	Yes
0,1453	Yes
-0,0262	No
-0,1646	No
-0,1721	No
-0,1433	No



This are the results that we obtain on a graph:



Regional Analysis

3.1.2 Presentation of Results (Research Design 2)

The Gross Domestic Product (GDP) is a measure of a country's total economic output. For El Salvador, as for many countries, GDP has fluctuated over time due to a variety of economic, political, and social factors.

Up to 2021, El Salvador's economy has experienced moderate but steady growth over the past decades. Although there have been periods of faster and slower growth, the overall trend has been positive.

In 2019, El Salvador's GDP was $29.57 billion, with a real GDP growth of around 2.1%. However, El Salvador's economy, like the global economy, was severely affected by the COVID-19 pandemic in 2020. The World Bank estimated that El Salvador's GDP contracted by 8.6% in 2020 due to the pandemic.

The service sector has been a major driver of economic growth in El Salvador, accounting for about 60% of GDP. Remittances from Salvadorans living abroad have also played a crucial role in the economy, representing around 20% of GDP.

Here is a rough estimate of El Salvador's GDP growth from 2010 to 2021, according to World Bank data and other sources:

- 2010: $24.78 billion (Growth: 1.4%)
- 2011: $25.56 billion (Growth: 3.1%)
- 2012: $25.92 billion (Growth: 1.4%)
- 2013: $26.04 billion (Growth: 0.5%)
- 2014: $26.80 billion (Growth: 2.9%)
- 2015: $27.39 billion (Growth: 2.2%)
- 2016: $27.87 billion (Growth: 1.7%)
- 2017: $28.37 billion (Growth: 1.8%)
- 2018: $28.97 billion (Growth: 2.1%)
- 2019: $29.57 billion (Growth: 2.1%)
- 2020: $27.04 billion (Contraction: -8.6% due to COVID-19)
- 2021: $28.74 billion (Growth: 10.3%)

https://datos.bancomundial.org/indicator/NY.GDP.PCAP.KD.ZG?end=2021&locations=SV&start=2010&type=shaded&view=chart

However, El Salvador has also grappled with a series of economic challenges. These include high levels of poverty and inequality, low investment in infrastructure, corruption and crime, and a high level of public debt. In addition, the economy is heavily dollarized, meaning that El Salvador has limited capacity to implement independent monetary policies.

In response to the crisis, the government of El Salvador has implemented a number of measures, the most controversial of which is the adoption of Bitcoin as an official currency. While not a direct response to COVID-19, the government's adoption of Bitcoin in 2021 can be seen as part of a broader strategy to attract investments, facilitate remittances, and stimulate the economy in a post-pandemic context.

This made El Salvador the first country in the world to adopt Bitcoin as an official currency in September 2021. This has led to the government of Nayib Bukele focusing on specific points with the adoption of Bitcoin in this country. In this way, the Congress of El Salvador approved the Bitcoin Law in June 2021. According to this law, Bitcoin is legal tender in the country alongside the US dollar. This means that all businesses must accept Bitcoin as a form of payment if offered, unless they do not have the technology to do so.

Another proposal within the Bitcoin law launched by the government of Nayib Bukele was the Chivo Wallet where all Salvadorans are entitled to receive $30 in Bitcoin upon registering on the Chivo wallet.

One of the important points is the mining of Bitcoin with geothermal energy. El Salvador proposes plans to mine Bitcoin using geothermal energy from its volcanoes, in an attempt to make Bitcoin mining a more eco-friendly activity.

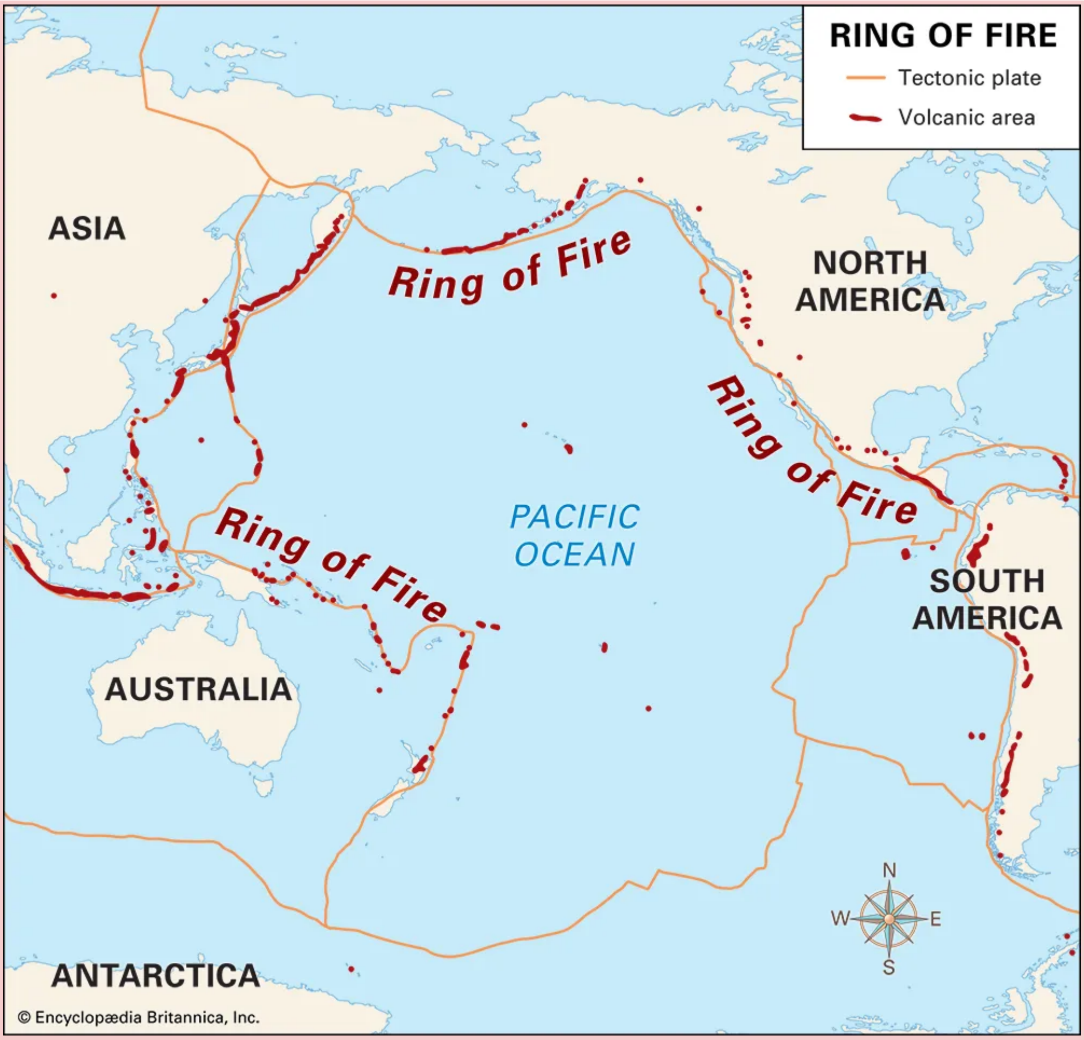
As part of El Salvador's initiative to adopt Bitcoin as legal currency, President Nayib Bukele announced plans to use the country's geothermal energy to mine Bitcoin. This proposal arose in response to concerns about the environmental impact of Bitcoin mining, which requires a significant amount of energy and often relies on non-renewable energy sources.

Geothermal energy, on the other hand, is a renewable energy source that harnesses the natural heat from the Earth's interior. In El Salvador, which is a volcanic country with abundant geothermal activity, this form of energy already represents a significant part of the energy matrix.

Bukele's plan is to use this geothermal energy to power Bitcoin mining operations. According to Bukele, mining Bitcoin with geothermal energy would not only be more environmentally friendly, but could also provide a new source of income for the country.

The fact that El Salvador is taking the initiative to generate geothermal energy to boost a new market and improve Bitcoin mining opens up a very large economic window with positive expectations. The use of geothermal energy for electricity generation, and specifically for Bitcoin mining, could have multiple implications for the energy market and El Salvador's economy.

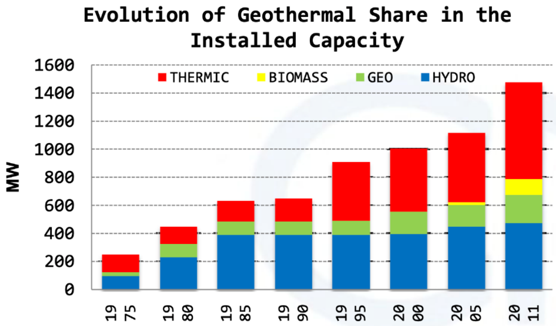
Given that El Salvador is located in the "Pacific Ring of Fire," a zone with high volcanic and seismic activity. This geographical feature provides the country with considerable potential for generating geothermal energy, also known as volcano energy, a renewable and sustainable energy source that uses the heat from the Earth's interior to generate electricity. This type of energy has several advantages over conventional energy sources. Unlike other renewable energy sources such as solar or wind, geothermal energy is available 24 hours a day, 7 days a week, regardless of weather or seasonal conditions, and produces very few greenhouse gas emissions, making it a clean energy option

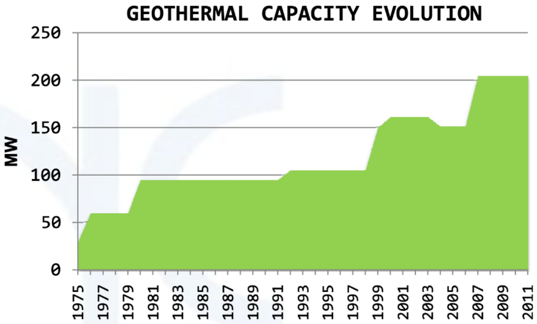


https://kids.britannica.com/students/article/Ring-of-Fire/603130

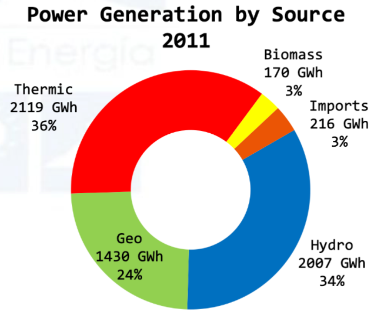
El Salvador is already one of the world leaders in geothermal energy production. According to World Bank data, around 20% of the country's electricity is already generated from geothermal sources, largely driven by LaGeo, a state-owned company responsible for the exploration and exploitation of the country's geothermal resources. LaGeo operates several geothermal power plants in El Salvador, including the Ahuachapán and Berlin plants, which together have a capacity of around 204 megawatts.

Current Status

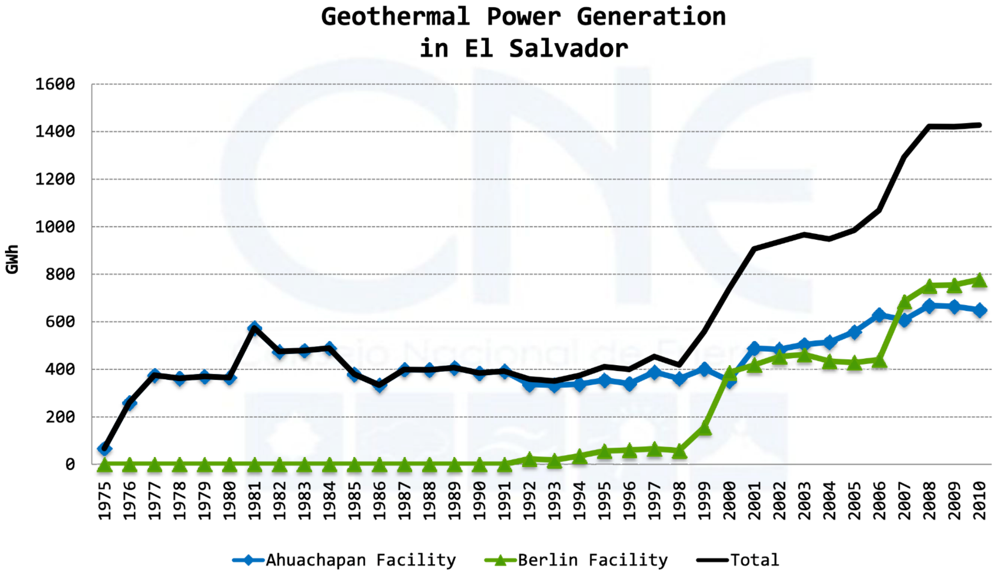




Evolution of Geothermal Share in the Installed Capacity								
	1975	1980	1985	1990	1995	2000	2005	2011
% Hydro	38.6	51.4	61.4	59.7	42.7	39.2	40.1	32.0
% Geo	12.0	21.1	15.0	14.6	11.6	16.0	13.5	13.8
% Biomass	0.0	0.0	0.0	0.0	0.0	0.0	2.2	7.4
% Thermic	49.4	27.5	23.6	25.7	45.7	44.8	44.2	46.8



Current Status



Current Status

COUNTRY	INSTALLED CAPACITY (MW)	RANK
USA	3,093	1
PHILIPPINES	1,904	2
INDONESIA	1,197	3
MEXICO	958	4
ITALY	843	5
NEW ZEALAND	628	6
ICELAND	575	7
JAPAN	536	8
El SALVADOR	204	9
KENYA	167	10
COSTA RICA	166	11
NICARAGUA	88	12
RUSSIA	82	13
TURKEY	82	14
GUINEA	56	15
GUATEMALA	52	16
PORTUGAL	29	17
CHINA	24	18
FRANCE	16	19
ETHIOPIA	7.3	20
GERMANY	6.6	21
AUSTRIA	1.4	22
AUSTRALIA	1.1	23
THAILAND	0.3	24

It represents **25.5%** of the national electricity generation

COUNTRY	POWER GENERATION (GWh)	RANK
USA	16,603	1
PHILIPPINES	10,311	2
INDONESIA	9,600	3
MEXICO	7,047	4
ITALY	5,520	5
ICELAND	4,597	6
NEW ZEALAND	4,055	7
JAPAN	3,064	8
KENYA	1,430	9
El SALVADOR	1,422	10
COSTA RICA	1,131	11
TURKEY	490	12
GUINEA	450	13
RUSSIA	441	14
NICARAGUA	310	15
GUATEMALA	289	16
PORTUGAL	175	17
CHINA	150	18
FRANCE	95	19
GERMANY	50	20
ETHIOPIA	10	21
AUSTRIA	3.8	22
THAILAND	2.0	23
AUSTRALIA	0.5	24

Source:"Geothermal Power Generation in the World". Ruggero Bertani. Enel Green Power

https://www.mofa.go.jp/region/latin/fealac/pdfs/2-2_el_salvador.pdf

By using geothermal energy for Bitcoin mining, El Salvador could further increase its reliance on this renewable energy source. This would help diversify its energy matrix and reduce its dependence on imported and non-renewable energy sources.

In this sense, El Salvador has the opportunity to make Bitcoin mining more sustainable by using geothermal energy to power mining operations. As I mentioned earlier, geothermal energy is a renewable energy source that uses heat from the Earth's interior to generate electricity. It emits no greenhouse gasses and is constantly available, unlike other renewable energy sources such as solar or wind, which depend on weather conditions.

If done correctly, Bitcoin mining with geothermal energy could have a significantly smaller impact on the environment compared to mining that uses electricity generated from fossil fuels. This could make El Salvador an attractive place for Bitcoin mining operations and could help position the country as a leader in sustainable cryptocurrency mining.

Up to this point, mentioning the proposals of President Nayib Bukele since the officialization of bitcoin as legal currency in El Salvador and his plan for the use of geothermal energy, we can say that, the issuance of "Volcano Bonds" on the Bitcoin blockchain is an example of how traditional financial assets are moving towards the blockchain. In simple terms, tokenizing an asset means representing the value of a real asset on a blockchain through a digital token. This digital token is essentially a smart contract that represents ownership of an asset or a right to an asset.

Decentralized finance, or DeFi, has been a pioneer in this movement. In the DeFi space, smart contracts on blockchains like Ethereum are used to replicate and enhance traditional financial products such as loans, insurance, exchanges, and yes, bonds.

The issuance of bonds on the blockchain has several potential advantages over traditional bond issuance. On one hand, issuance on the blockchain can be more efficient and transparent. Smart contracts can automate many of the administrative tasks associated with bond issuance, such as distributing interest payments to bondholders. Furthermore, all transactions on the blockchain are public and auditable, which can increase transparency and trust in the process.

On the other hand, bond issuance on the blockchain can also be more accessible. Traditional bonds often have a high entry price, making them inaccessible to many individual investors. But by tokenizing a bond, it can be divided into smaller units, allowing more people to invest.

In the case of El Salvador, the idea is to issue "Volcano Bonds" on the Bitcoin blockchain to finance Bitcoin mining infrastructure powered by geothermal energy. These bonds could attract investors from around the world who are interested in Bitcoin and sustainable investments. And since the bonds would be linked to Bitcoin production, they could also offer potentially high returns.

3.2 Analysis of Results

By further expanding the scope of Research Des

4. Theoretical and practical applications (or discussion)

4.1 Theoretical application

By further expanding the scope of Research Des

4.2 Practical application

By further expanding the scope of Research Des

Conclusion

References

Appendices