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ORIGINAL ARTICLE

The feasibility study of the production of Bitcoin with geothermal energy: Case study

M. A. Ehyaei[1] | **F. Esmaeilion**[2] | **Moein Shamoushaki**[3] | **H. Afshari**[4] | **Biplab Das**[5]

[1]Department of Mechanical Engineering, Pardis Branch, Islamic Azad University, Pardis New City, Iran
[2]Department of Mechanical Engineering, K.N. Toosi University of Technology, Tehran, Iran
[3]Department of Industrial Engineering, University of Florence, Florence, Italy
[4]Food Science & Engineering Department, Faculty of Civil & Earth Resources Engineering, Islamic Azad University Central Tehran Branch, Tehran, Iran
[5]Department of Mechanical Engineering, National Institute of Technology Silchar, Assam, India

Correspondence
M. A. Ehyaei, Department of Mechanical Engineering, Pardis Branch, Islamic Azad University, Pardis New City, Iran.
Email: aliehyaei@yahoo.com

H. Afshari, Food Science & Engineering Department, Faculty of Civil & Earth Resources Engineering, Islamic Azad University Central Tehran Branch, Tehran, Iran.
Email: afshari1@gmail.com

Abstract
In this paper, a multigeneration cycle of electricity, cooling, and Bitcoin whose energy source is geothermal, has been subjected to energy, exergy, and economic analyses. The cycle under consideration includes the steam cycle (upstream cycle), the carbon dioxide cycle (downstream cycle), and the liquid–gas line to absorb the heat dissipated by the carbon dioxide cycle. In this cycle, the steam cycle condenser acts as the carbon dioxide cycle evaporator. Part of the electricity generated by this cycle is used to generate Bitcoins. Energy and exergy efficiencies at baseline (excluding Bitcoin production) are 45.8% and 38.1%, respectively. In this cycle, if more power is spent on producing Bitcoin as a product, the energy and exergy efficiencies of the cycle are reduced. Because Bitcoin itself is not valuable in terms of energy and exergy. Considering the average price of Bitcoin during the years 2015–2022 and if 100% of the electricity generated by the system is spent on Bitcoin production, the payback period in 2018, 2021, and 2022 when the price of Bitcoin is equal to $13,412.4, $21,398.8, and $47,743.0, respectively, are less than the baseline. Therefore, the production of Bitcoin with a variety of renewable energies can be considered as a solution. Of course, it should be noted that large changes in the price of Bitcoin can affect the issue of economic benefit.

KEYWORDS
bitcoin, electricity, exergy, geothermal

1 | INTRODUCTION

The tendency for cryptocurrencies has been growing in recent years by increasing their value in the worldwide market. Also, day by day, more companies and businesses accept payment methods by cryptocurrencies, leading to more attention to investing in them. Nevertheless, there is a massive challenge in mining these cryptocurrencies: the remarkable electricity consumption of relevant equipment.[1–4] The process of validating Bitcoin blocks demands a substantial quantity of electricity, contributing to heightened greenhouse gas emissions. Consequently, prominent nations like China, Iran, Russia, Turkey, and Vietnam are prohibiting Bitcoin mining to avert grid imbalances, power outages, and environmental concerns.[5] Many researchers are thinking about the environmental impacts and carbon footprints of cryptocurrency mining. Besides, these days, mining cryptocurrencies consumes a considerable amount of produced electricity in the world.[6–8] Certainly, utilizing electricity generated from fossil fuels for Bitcoin production presents several challenges. This energy could serve more crucial purposes, and its application for Bitcoin production exacerbates environmental pollution. However, in light of the imminent role of digital currencies in trade, this aspect cannot be overlooked. Consequently, employing renewable energy resources for the production of Bitcoin and other digital currencies emerges as a potential solution.[4,9]

Providing decarbonized energy for different sectors of society is one of the most challenging issues researchers are trying to tackle. Nowadays, with a fast-growing technology trend, the energy demand has increased in many countries. For example, the energy demand in 2017 showed a vast increase compared with 1950 (around 5.5 times).[10] On the other hand, the significant fluctuation in fossil fuel prices affected the energy market and industry predictions. Besides, the fossil fuels application has had negative impacts on controlling the global warming rising trend. These factors prove that the transition from pollutant fuels to renewable resources is inevitable. In this case, the introduction of novel energy resources in different sectors can provide vital influences.[11,12] To elaborate on this issue, different sectors such as transportation, industrial, residential, entertainment, financial, and so forth have severe dependency on energy sources for sustainable performance. By taking the environmental issues, charges for fuel, availability, and sustainability into consideration, renewable energy can provide promising salvation for the aforementioned applications. Solar, wind, and geothermal energy are the most practical and renowned types of renewable energy. While the operation of solar and wind energies can be greatly erratic and suffer from a lack of consistency, geothermal energy can present a promising approach for the required sustainable operation. This can affect different aspects of the operational parameters both technical and economic features. This energy has been considered a clean resource as it is weather-independent.[13] Besides, geothermal-based power cycles have excellent potential to provide energy for different applications such as heating and cooling in addition to electricity production.[14] In addition, using the remaining heat of geothermal fluid before reinjection could decrease the thermal loss.

2 | LITERATURE SURVEY

While numerous studies have concentrated on energy consumption and associated demands linked to Bitcoin mining, fewer have focused on examining practical solutions for alternative and more sustainable energy supply. Stoll et al.[15] predicted that the energy consumption of the Bitcoin mining process by November 2018 is around 45.8 TWh and its yearly carbon footprint is in the range of 22–22.9 Mt CO_2. Another issue would be the fluctuation of the grid network. In some cases, it can affect the stability of the electricity transmission network. Another issue would be stealing the electricity to mine cryptocurrencies. Küfeoğlu and Özkuran[16] addressed the computational power requirements involved in the proof-of-work process, neglecting to assess the overall energy intensity associated with mining activities. They determined the peak energy demand period by analyzing the installed Bitcoin mining equipment in certain European countries. Several researchers have investigated the implementation of renewable energy to supply the necessary electricity for Bitcoin mining as a potential solution.

Govender[17] examined and elucidated the phenomenon of cryptocurrency mining utilizing renewable energy by exploring innovative business models. The findings indicated that the utilization of renewable energy for cryptocurrency mining is an expanding business sector motivated by the goal of maximizing profits through the utilization of the most cost-effective renewable energy sources. Malfuzi et al.[18] conducted a thermodynamic and economic modeling of a solid oxide fuel cell system, powered by either natural gas or biogas as a renewable energy source, which is employed not only to fulfill the necessary power for Bitcoin mining but also to meet the electricity demand. Bastian-Pinto et al.[19] created a numerical application using the real options approach to assess the financial consequences of investing in a Bitcoin facility for a wind energy producer. They mentioned it can enable the producer to strategically adjust outputs based on the future price differentials between electricity and Bitcoins. Kumar[20] reviewed the feasibility of utilizing geothermal energy for the purpose of Bitcoin mining. He concluded that geothermal energy stands out as a highly cost-effective and environmentally friendly choice among various alternative energy sources for Bitcoin miners engaged in mining activities.

Corbet et al.[21] investigated the impact of Bitcoin prices on energy markets and utility companies. Their findings reveal a consistent and substantial impact of cryptocurrency energy consumption on the performance of specific companies in the energy sector, distinguished by jurisdiction. This underscores the need for additional evaluation of the environmental implications associated with the growth of cryptocurrencies. Gundaboina et al.[22] discussed the outcomes of overclocking and undervolting in terms of power consumption and hash rate during the mining of Dogecoin, utilizing solar energy as the renewable power source. They mentioned the prospective direction of crypto mining using renewable energy and its linked hardware configuration, aiming to diminish electronic waste and enhance sustainable development. Niaz et al.[5] performed a technoeconomic evaluation across 50 states and a federal district in the United States, examining the viability of Bitcoin mining through the integration of carbon capture and renewable energy. They assessed the carbon footprint for each state from both economic and environmental standpoints to ascertain their competitive advantages.

Yüksel et al.[23] investigated the Bitcoin mining using nuclear energy. It was suggested that opting for nuclear energy in Bitcoin mining would be advantageous. They reported that it eliminates the release of carbon gases into the atmosphere, leading to a substantial reduction in environmental pollution. Kang et al.[24] researched monitoring the electricity stealing for mining purposes according to the available data. They assessed the system voltage, electricity consumption of users, and its effect on electricity loss in the network. They reported that renewable energy applications for cryptocurrency mining could reduce environmental impacts and network problems. Velický[25] addressed the obstacles associated with the shift to renewable energy, examined the characteristics of the Bitcoin network, and explored the involvement of Bitcoin mining operations in the global production and consumption of energy. Vega-Marcos et al.[26] proposed the development of a wind power plant to generate energy for Bitcoin mining in Spain. They suggested that if a wind power facility simultaneously invests in cryptocurrency mining while generating electrical energy for the grid, it has the flexibility to choose when to participate in the electricity market pool or focus on mining activities. However, based on the literature review, it is evident that there is a notable deficiency in the assessment of renewable energy-based systems for the purpose of cryptocurrency mining.

In our research, we have examined a power system that relies on geothermal energy, integrated with additional units to enhance electricity generation efficiency. Drawing on studies conducted by other researchers, geothermal energy has demonstrated notable potential for offering low-carbon energy and substantial flexibility for integration with other cycles. Subsequently, researchers have been focusing on modeling and analyzing geothermal-based power cycles as a multiproduction system to supply low-carbon energy for diverse applications. In addition, geothermal fluid, before reinjection, retains a significant amount of residual heat that can be utilized in other units to enhance the efficiency of the overall system. Wang et al.[27] evaluated a geothermal-based system linking with a transcritical CO_2 cycle according to the liquefied natural gas (LNG) cold energy application. Their assessment showed that rising exergy efficiency leads to growth in bigger areas of heat exchangers per network. Ahmadi et al.[28] carried out the thermodynamic evaluation of a geothermal-based cycle coupled with transcritical CO_2 to generate power. They applied optimization tools, three decision-making approaches, sensitivity assessment, and error testing to reach the best solution. They finally compared their results with other obtained ones based on previous studies.

Li et al.[29] assessed a transcritical CO_2 cycle utilizing geothermal energy from energetic and economic views. An energy and parametric study of a geothermal system integrated with an ejector-assisted transcritical CO_2 cycle has been performed by Zare and Rostamnejad Takleh.[30] They compared this system with studies done by other researchers. They also investigated the design variables' influence on the composed unit's thermodynamic behavior. Ehyaei et al.[31] modeled a geothermal cycle integrated with cooling, sodium hypochlorite, and reverse osmosis (RO) units. Energetic assessment results showed that the presented cycle can generate 1.751 electricity and 1.04 cooling capacity. Also, the investment return is predicted at 2.7 years. A combined geothermal system linked with LNG, Proton Exchange Membrane, and Organic Rankine Cycle (ORC) units has been evaluated from thermodynamic and exergoeconomic aspects by Mehdikhani et al.[32] The thermal efficiency of their designed cycle has increased by 3.18% compared to previous similar studies. A geothermal cycle with district heating and total reinjection of noncondensable gases has been evaluated from energetic and economical, and environmental points of view by Shamoushaki et al.[33] They assessed this system in subcritical and supercritical cases, and the Levelized Cost of Energy for subcritical is obtained at 5.52 c€/kWh and at supercritical at 6.96 c€/kWh.

Habibollahzade et al.[34] researched the difference in heat recovery of a geothermal system using a CO_2 cycle (in both transcritical and supercritical cases) and an ORC energetically and economically. Their results illustrated that the transcritical CO_2 system produces more power than others. Li et al.[35] researched a geothermal cycle combined with a thermal storage unit from thermodynamic and economic aspects. They optimized their proposed system, and at the optimum point, thermal efficiency and unit cost of production were calculated at 23.35% and 17.07 $/GJ, respectively. Afshari et al.[36] examined an integrated geothermal system connected to a CO_2 cycle, an RO system, an electrodialysis unit, a lithium bromide absorption chiller, and a liquefaction unit for natural gas. The objective was to generate electricity, cooling, desalinated water, sodium hydroxide, and hydrogen.

Beyond the inherent capabilities and advantages of an integrated geothermal power cycle, incorporating additional components such as a CO_2 cycle and LNG tank can further enhance the overall benefits of the system. The combination facilitates the utilization of cold energy derived from LNG, thereby augmenting the overall efficiency of the power generation process. This coupling allows for the recovery of both CO_2 and LNG cold energy, optimizing the utilization of resources within the power generation system. The inclusion of a CO_2 cycle has the potential to contribute to carbon capture and storage, potentially lessening the environmental impact of the power plant by mitigating CO_2 emissions. The synergistic interaction among the geothermal system, CO_2 cycle, and LNG tank unit can result in enhanced performance parameters, including thermal efficiency and exergy efficiency, when compared with conventional alternatives. This integrated system may also yield economic advantages by optimizing resource utilization and boosting the overall efficiency of the power plant, potentially leading to reduced operational costs. These benefits have motivated researchers to incorporate these integrations with other systems. A new definition of the ORC system has been designed by Choi et al.[37] to harness the cold energy from LNG for power generation. They analyzed and optimized this system from energy, economic, and environmental views.

The assessment showed that their novel system had more efficient performance than previous conventional ones. An ORC cycle to apply LNG cold energy has been analyzed and optimized by Sun et al.[38] Their assessments showed that a decline in LNG inlet temperature has an effective role in lessening the cycle irreversibilities. Xia et al.[39] designed a novel CO_2 cycle recovering LNG cold energy working via ambient temperature. Their analysis illustrated that thermal efficiency was obtained at 6.75% and network at 108.7 kW. The evaluations showed that a lower ambient mass flow rate had less influence on the cycle operation. Cao et al.[40] assessed a biomass-based cycle linked with a CO_2 cycle, LNG tank, electrodialysis, and multieffect distillation. Thermal and exergy efficiencies are obtained at 75.1% and 88.4%, respectively. Gawusu et al.[41] a careful consideration of blockchain and its relevance in applying renewable energy to provide decarbonized electricity. Their assessment proves that many researchers in recent years have concentrated on integrating blockchain technology with renewable resources considering the challenges and possible solutions.

This study aims to address several research gaps that have received little or no attention thus far. From the examination of existing literature, there is a limited number of studies that have explored the power generation for cryptocurrencies specifically with a focus on renewable energy sources. In addition, reviewing the existing research literature, it can be inferred that there is a notable absence of articles investigating the utilization of geothermal energy specifically for Bitcoin production. While numerous studies have explored the application of geothermal energy for various purposes such as electricity generation, hydrogen production, and heating and cooling systems, there is a distinct lack of research elucidating the use of geothermal energy in the production of digital currencies for added benefits. Moreover, this study introduces a new configuration based on geothermal energy designed for the efficient generation of multiple products. This configuration is capable of generating the necessary electricity for Bitcoin mining, in addition to conventional power and cooling outputs. The findings of this study have the potential to guide policymakers, investors, and stakeholders in recognizing this system as a promising solution for commercialization. This can contribute to reducing the volatility and dependence of Bitcoin mining sites on fossil-based fuel power production and grid networks. This proves especially advantageous in areas with unreliable or insufficient grid infrastructure, providing miners with increased authority over their energy provision and diminishing susceptibility to power interruptions. Furthermore, policymakers must navigate a delicate balance between fostering innovation and economic development linked to cryptocurrency technologies and the pressing need to shift towards more sustainable and cleaner energy sources which the results of this research would be an effective solution.

A notable policy-level challenge linked to Bitcoin mining relying on fossil-based power production is its environmental impact and carbon footprint. Mining operations for Bitcoin, especially those powered by fossil fuels, contribute to heightened greenhouse gas emissions, intensifying apprehensions regarding climate change and environmental sustainability. Given the growing importance of digital currencies and their market growth, especially in recent years, the lack of this research is observed. As the focus on environmental issues intensifies, authorities might enforce more rigorous standards on energy-intensive sectors, like, Bitcoin mining. The adoption of renewable energy can position mining operations to adhere to current and forthcoming regulations, preventing potential legal and financial consequences. The scope of this study is aligned with all these aspects. This article proposes a new geothermal arrangement cycle to analyze its energy, exergy, and economics. The products of this proposed system are electricity and cooling. Some of the electricity generated is used to generate Bitcoins. Then, based on the percentage of electricity that is spent on Bitcoin production and changes in Bitcoin prices during the years 2015–2021, sensitivity analysis is performed. The contributions of this paper are as follows:

- A case study of a power generation system with a geothermal energy resource to generate electricity and Bitcoin.
- Investigating the energy, exergy, and economic effects of Bitcoin production on the electricity production system.

3 | SYSTEM DESCRIPTION

The designed system is intended to produce electric power from geothermal resources. The part of electricity is used by Bitcoin miners. Figure 1 demonstrates the configuration of the designed system consisting geothermal cycle, CO_2 cycle, and LNG line. This system has the proper potential for electric energy production. The system operation can be divided into two parts: (1) geothermal cycle and (2) CO_2—LNG cycle. In the geothermal cycle, hot water is extracted from the production well (1), and after pressure regulation in the expansion valve; the obtained fluid is divided into vapor and liquid phases. High-grade energy vapor is expanded in the turbine for electrical energy production (3) while the liquid phase is sent to the second expansion valve to be modified for the combination process in the mixing chamber (4). In the mixing chamber, the obtained

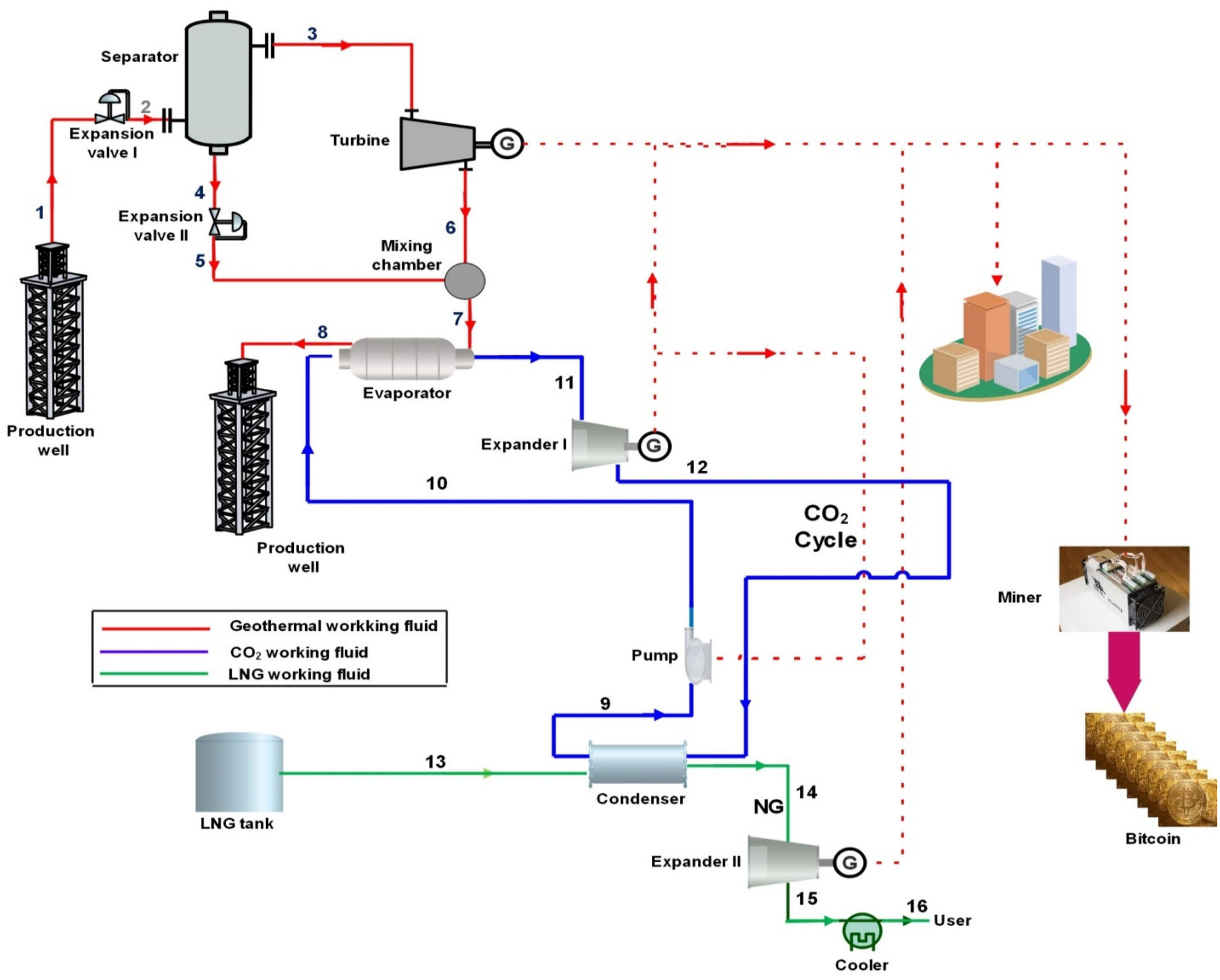

FIGURE 1 Configuration of the proposed system for Bitcoin production. LNG, liquefied natural gas.

streams from the turbine outlet and expansion valve II are combined to be employed as an energy source for the CO_2 cycle in the evaporator (7). By losing the energy content, the low-grade fluid is returned to the production well (8).

Through the CO_2 cycle, CO_2 is heated by the geothermal working fluid in the evaporator (10). High pressure and temperature fluid are sent to the expander I for auxiliary power production (11). In the next stage (12), the working fluid is cooled down by the LNG stream in the condenser (9). After that, the designed pump increases the working fluid's pressure (10).

In the LNG stream, after increasing the associated temperature in the condenser (13), LNG turns to its vapor phase as NG (natural gas) and expands in the expander II (14). At that point, the working fluid is used for cooling purposes in the cooler unit (15). The obtained fluid from the cooler is sent for specific applications. One important concept belongs to the produced electric power. A specific share is sent for household applications while the remaining part is delivered to the Bitcoin miners for Bitcoin production.

4 | MATHEMATICAL MODELING

In the first stage, several initial considerations are established to simplify the modeling process[31,42–44]:

- All included processes are steady-state.
- The associated polytropic efficiency of the involved expanders, pumps, and turbine is equal to 85%.
- All heat exchangers have an effectiveness equal to 85%. Also, their type is shell and tube.
- The working fluid of the geothermal cycle is hydrothermal type. The considered environmental conditions are 15°C temperature and 1 bar for pressure.
- Related values to the potential and kinetic energies are ignored.
- Presented connections and pipelines do not have any type of pressure loss.

In a standard and simple method, balances equations of the mass and energy rates are presented as[43,45]

$$\sum_{\text{in}} \dot{m} = \sum_{\text{out}} \dot{m}, \tag{1}$$

$$\dot{Q} - \dot{W} = \sum_{\text{P}} \dot{m}(h_{\text{f}} + (h - h_0)) - \sum_{\text{R}} \dot{m}(h_{\text{f}} + (h - h_0)). \tag{2}$$

While $\dot{Q}$ and $\dot{W}$ signify the rates of heat transfer and shaft work (kW), each, $\dot{m}$ stands for the mass flow rate (kg/s), and h represents specific enthalpy (kJ/kg). Presented subscripts for the product, formation, reactant, and ambient condition are shown by P, f, R, and 0, respectively.

Table 1 tabulates the related equations for each component based on Equations (1) and (2). It should be noted that η symbolizes the effectiveness of related components.

The net value of generated power by the proposed system can be calculated as follows[46]:

TABLE 1 Fundamental balance equations for the designed configuration.

Component	Mass balance	Energy balance
Separator	$\dot{m}_2 = \dot{m}_3 + \dot{m}_4$	$\dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_4 h_4$
Turbine	$\dot{m}_3 = \dot{m}_6$	$\dot{W}_{\text{T}} = \dot{m}_3(h_3 - h_6)$
Evaporator	$\dot{m}_7 = \dot{m}_8$ $\dot{m}_{10} = \dot{m}_{11}$	$\dot{m}_{11}h_{11} - \dot{m}_{10}h_{10} = (\dot{m}_7 h_7 - \dot{m}_8 h_8)\eta_{\text{Evaporator}}$
Expansion valve I	$\dot{m}_1 = \dot{m}_2$	$h_1 = h_2$
Expansion valve II	$\dot{m}_4 = \dot{m}_5$	$h_4 = h_5$
Mixing chamber	$\dot{m}_5 + \dot{m}_6 = \dot{m}_7$	$\dot{m}_5 h_5 + \dot{m}_6 h_6 = \dot{m}_7 h_7$
Expander I	$\dot{m}_{11} = \dot{m}_{12}$	$\dot{W}_{\text{EXPI}} = \dot{m}_{11}(h_{11} - h_{12})$
Expander II	$\dot{m}_{14} = \dot{m}_{15}$	$\dot{W}_{\text{EXPII}} = \dot{m}_{14}(h_{14} - h_{15})$
Pump	$\dot{m}_9 = \dot{m}_{10}$	$\dot{W}_{\text{P}} = \dot{m}_9(h_{10} - h_9)$
Condenser	$\dot{m}_9 = \dot{m}_{12}$ $\dot{m}_{13} = \dot{m}_{14}$	$\dot{m}_{14}h_{14} - \dot{m}_{13}h_{13} = (\dot{m}_{12}h_{12} - \dot{m}_9 h_9)\eta_{\text{Condenser}}$
Cooler	$\dot{m}_{15} = \dot{m}_{16}$	$\dot{Q}_{\text{Cooler}} = \dot{m}_{15}h_{15} - \dot{m}_{16}h_{16}$

$$\dot{W}_{\text{net,sys}} = \dot{W}_{\text{T}} + \dot{W}_{\text{EXPI}} + \dot{W}_{\text{EXPII}} - \dot{W}_{\text{P}}. \quad (3)$$

To calculate the effectiveness of the energy performance of the CO_2 cycle and total system, the following equations are presented[47]:

$$\eta_{CO_2\ \text{cycle}} = \frac{\dot{W}_{\text{EXPI}} - \dot{W}_{\text{P}}}{\dot{m}_7 h_7 - \dot{m}_8 h_8}, \quad (4)$$

$$\eta_{\text{sys}} = \frac{\dot{W}_{\text{net,sys}}}{\dot{m}_1 h_1 - \dot{m}_8 h_8}. \quad (5)$$

On the basis of the definition, specific exergy comprises physical, chemical, kinetic, and potential sections as follows[48,49]:

$$e = \sum x_i ex_{\text{chi}} + \frac{Ve^2}{2} + gz + (h - h_0) - T_0(s - s_0) + T_0 \sum xm_i R_i \ln y_i, \quad (6)$$

while x_i and e symbolize mass fractions and specific exergy. Ve, g, and z represent velocity, gravity acceleration, and height. Also s and y symbolize specific entropy and molar fraction, respectively. Subscripts ch, i, and 0 characterize the chemical, component number, and environmental conditions, respectively.

To calculate the exergy efficiency of the CO_2 cycle and the total cycle, the following expressions are applied:

$$\varepsilon_{CO_2\ \text{cycle}} = \frac{\dot{W}_{\text{EXPI}} - \dot{W}_{\text{P}}}{\dot{m}_7 e_7 - \dot{m}_8 e_8}, \quad (7)$$

$$\varepsilon_{\text{sys}} = \frac{\dot{W}_{\text{net,sys}}}{\dot{m}_1 e_1}. \quad (8)$$

To study the economic behavior of the proposed system, the annual income (CF) is calculated by Equation (9).[50]

$$CF = Y_{\text{Power}} k_{\text{Power}}, \quad (9)$$

here Y_{Power} stands for the produced power per annum and k_{Power} represents the specific cost of generated power which is equal to 0.22 US$/kWh.[51]

The investment charge (C_0) for the total system is written as[52,53]

$$C_0 = C_{\text{I,Geothermal loop}} + C_{\text{I,Miner}} + C_{\text{I},CO_2\ \text{cycle}} + C_{\text{I,LNG line}}, \quad (10)$$

here C_{I} represents the charge of investment and setting up for involved subsystems. Table 2 provides the associated equations for the investment and commissioning of each subsystem. Besides, calculating the operational charges, a 3% surplus of the initial capital costs is measured.[52,53] In Table 2, z and A designate the well's depth and area, respectively.

The surface area of heat exchangers is a crucial parameter in economic analysis. In this case, the logarithmic method is employed to calculate this parameter[59]:

$$\dot{Q} = UAF_{\text{t}} \Delta T_{\text{ln}}, \quad (11)$$

TABLE 2 Related equations of investment cost for the subsystem.

Component	Cost function	Reference
Geothermal loop		
Geothermal well	$16.5 \times z^{1.607}$	[54]
LNG loop		
LNG expander	$479.34\left(\frac{\dot{m}_{31}}{0.93 - \eta_T}\right)\ln\left(\frac{P_{31}}{P_{32}}\right)(1 - \exp(0.036T_{31} - \exp(0.036T_{31} - 54.4)))$	[49]
LNG cooler	$1.218 \times \exp(0.4692 + 0.1203\ln(\dot{Q}) + 0.0931(\ln(\dot{W}))^2)$	[55]
CO_2 cycle		
Pump	$10^{3.3892+0.05361\log\dot{W}+0.1538(\log\dot{W})^2}$	[56]
Turbine	$10^{2.6259+1.43981\log W-0.1776(\log\dot{W})^2}$	[57]
Heat exchanger	$(A/0.093)^{0.78}$	[57]
Miner		[58]
Miner	12,000	

Abbreviation: LNG, liquefied natural gas.

TABLE 3 Values of U for designated components.

Component	U (W/m^{2}K)
SEP (separator)	300
COND (condenser)	800
Heat exchanger	700
Evaporator	700

where U stands as the coefficient of the overall heat transfer, A represents the surface area (m^2), F_t is a correction factor, and ΔT_{ln} is the logarithmic mean temperature difference. Table 3 presents the values of the overall heat transfer for each component.[60,61]

The inflation rate is an important parameter that influences the cost functions. On the basis of the operational ears, the related impacts can be considered by[62]

$$C_n = C_0(1 + i)^n, \quad (12)$$

while n signifies the number of years, and i stands for the inflation rate and is 3.1% for all operating years.[31]

To calculate the simple payback period (SPP), a ratio of expenses and revenues is provided as[52,53]

$$SPP = \frac{C_n}{CF}. \quad (13)$$

Also, the payback period (PP), which calculates the payback time of a paid investment, is defined as[52,53]

$$PP = \frac{\ln\left(\frac{CF}{CF - r \cdot C_n}\right)}{\ln(1 + r)}, \quad (14)$$

where r represents the discount rate and is equal to 3% for all operating years.

To calculate the net present value (NPV), Equation (15) is employed. In this equation, a trade-off between income and investment costs is established[52,53]:

$$NPV = CF\frac{(1 + r)^N - 1}{r(1 + r)^N} - C_n, \quad (15)$$

where N stands for the system's lifetime and is expected to be 25 years.

One of the main parameters in the economic study is the internal rate of return (IRR), presented as[52,53,63]

$$IRR = \frac{CF}{C_n}\left[1 - \frac{1}{(1 + IRR)^N}\right]. \quad (16)$$

5 | ELECTRICAL POWER CONSUMPTION TO PRODUCE ONE BITCOIN

On the basis of ASIC models and the manufacturer's market share, the power consumption of miners to produce each Bitcoin can be calculated. For this purpose, many ASIC models are allocated in proportion to the market share of each manufacturer.[64–67]

According to the mining pool data, it takes about 122,000 TH/s (hash rate) over 24 h to generate 1 Bitcoin based on BTC price, difficulty level, and network size.[64–67]

The hash rate (hash per second, h/s) is a unit derived from SI that represents the number of dual calculations in the Bitcoin network per second.[64]

On the basis of the data provided for the 25 miners who have the major market share and their information, which includes the model name, number of calculations per second, and their efficiency, we reach 142,498 kW per Bitcoin production.[66]

6 | RESULTS AND DISCUSSION

6.1 | Results validation

The actual case of the Kamojang Geothermal Power Plant in Indonesia has been used for validation.[68] The

TABLE 4 Computer code input data.

No.	Parameter	Unit	Value
1	P_1	Bar	9
2	η_T	–	0.85
3	T_1	°C	170
4	η_P	–	d.85
5	M_1	kg/s	111.1
6	P_2	Bar	1.2
7	P_6	Bar	1
8	T_8	°C	60
9	P_{10}	Bar	14
10	P_9	Bar	5.5
11	η_{HX}	–	0.8
12	P_{13}	Bar	6.6
13	T_{14}	°C	48
14	P_{15}	Bar	1
15	T_6	°C	20

capacity of the power plant is 55 MW and its geothermal source is steam with a temperature of 245°C Which is extracted from 10 geothermal wells. On the basis of the data collected from the operating power plant, the energy efficiency of the considering power plant is 35.86%.

This efficiency means that 111,138.92 kW of electrical energy is extracted from 309,000 kW of geothermal energy. To validate the data of the considered power plant, input data have been collected from Tables 1 to 3 of Rudiyanto et al.[68] and have been considered as input to the EES code written for this article. It is worth noting that changes have been made to the EES code to match the layout of the reference geothermal power plant.[68] On the basis of the input data, the geothermal efficiency of the cycle is calculated to be about 37.1%. The error rate is about 3.4%.

To confirm the system simulation codes, the CO_2 cycle and LNG line are selected as the design parameters for model validation. In this prospect, research conducted by Naseri et al.[69] is designated to validate this subsystem performance. Three important outputs are compared: power generation by the CO_2 cycle and the LNG expander and power consumption by the CO_2 cycle pump. Table 4 presents the results of the current model obtained results by Naseri et al.[69] From the main perspective, the results are in good agreement. The errors present are due to the calculation of the thermodynamic properties with different software libraries (Table 5).

TABLE 5 Comparison of main parameters from the current model and Naseri et al.[69]

Parameter	Current research	Naseri et al.[69]	Error (%)
$\dot{W}_{EXPI}$ (kW)	14.2	14.66	3.13
$\dot{W}_{EXPII}$ (kW)	7.19	7.46	3.61
$\dot{W}_{Pump}$ (kW)	4.98	4.78	4.01

6.2 | Results discussion

A computer code has been developed in EES software for the studied system and modeling of energy, exergy, and economy. The same software has been used to calculate the thermodynamic properties of fluids. Computer code input data are shown in Table 4.

Table 6 shows the thermodynamic properties of each point in the system, including mass flow rate, pressure, temperature, specific enthalpy, entropy, and exergy.

Table 7 shows the specifications of the system products in their basic state. In the basic state, no Bitcoin is produced. The whole system generates 4202 kW of electricity, which is 3838 kW of the CO_2 cycle. The amount of cooling produced by the cooler located in the LNG line is equal to 19,613 kW. The energy

TABLE 6 Thermodynamic properties of each point in the system, including mass flow rate, pressure, temperature, specific enthalpy, entropy, and exergy.

No.	$\dot{m}$ (kg/s)	P (bar)	T (°C)	h (kJ/kg)	s (kJ/kg K)	e (kJ/kg)
1	111.1	9	170	719.3	2.042	115.1
2	111.1	1.2	105.8	719.3	7.303	−1454
3	13.86	1.2	105.8	2683	7.298	512
4	97.24	1.2	105.8	439.4	1.361	38.18
5	97.24	1	99.63	439.4	7.359	−1750
6	13.86	1	99.63	2657	7.359	467.5
7	111.1	1	99.63	716.1	2.104	93.43
8	111.1	1	60	251.2	0.8311	7.973
9	96.43	5.5	−55.17	−424	−2.205	234.5
10	96.43	14	−54.85	−423.2	−2.205	235.2
11	96.43	14	45	5.305	−0.4669	145.5
12	96.43	5.5	−9.398	−35.35	−0.4392	96.63
13	84.95	658.5	−65.17	−502.4	−5.095	1019
14	84.95	658.5	48	−149.4	−3.741	968.1
15	84.95	101.3	−39.87	−348.9	−3.588	723.1
16	84.95	101.3	20	−118	−2.697	688.4

TABLE 7 Specifications of the system products in the basic state.

Parameter	Unit	Value
$\dot{W}_{net,CO_2}$	kW	3838
$\dot{W}_{net,sys}$	kW	4202
$\dot{Q}_{cooler}$	kW	19,613
$\eta_{en,sys}$	–	45.8
$\eta_{ex,sys}$	–	38.1

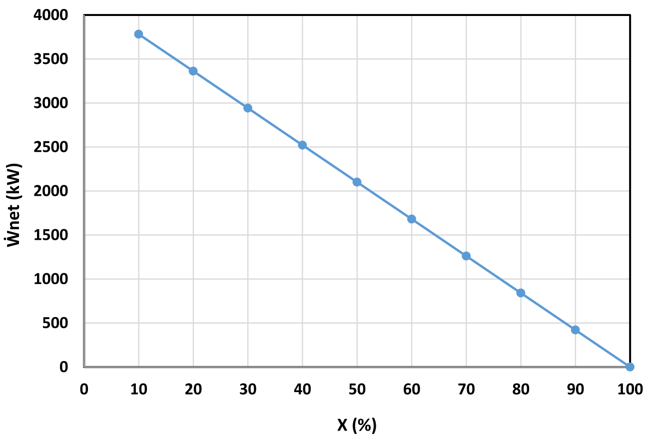

FIGURE 2 Changes in power output along with the X ratio.

TABLE 8 Economic indicators of the system in the basic state.

Parameter	Unit	Value
PP	Year	2.22
SPP	Year	2.11
NPV	Million US$	113.2
IRR	–	0.473

Abbreviations: *IRR*, internal rate of return; *NPV*, net present value; *PP*, payback period; *SPP*, simple payback period.

and exergy efficiencies of the system are equal to 45.8% and 38.1%, respectively. Exergy efficiency is about 16.8% lower than energy efficiency due to a lower exergy cooling value compared with energy.

Figure 2 shows the changes in power output along with the ratio of the amount of power consumed by the miners to the total power output. In other words, the ratio X represents the amount of electrical consumption of the miners to the total electricity generated. The trend of this chart is linear due to the electrical consumption of miners.

Figure 3 shows the changes in system energy and exergy efficiencies along with the X ratio. The trend in both charts is downward. That is, by increasing x from

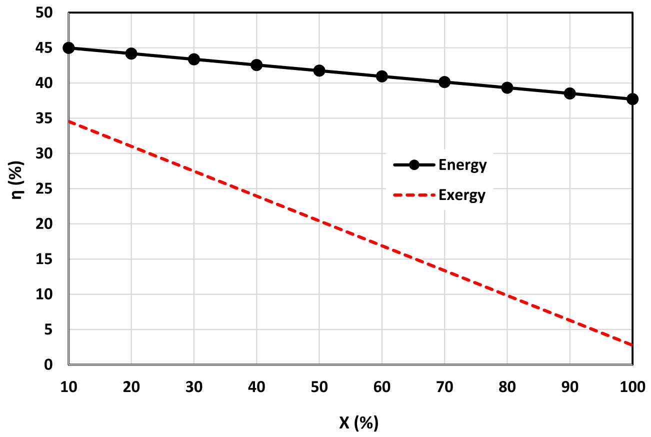

FIGURE 3 Changes in system energy and exergy efficiencies along with the X ratio.

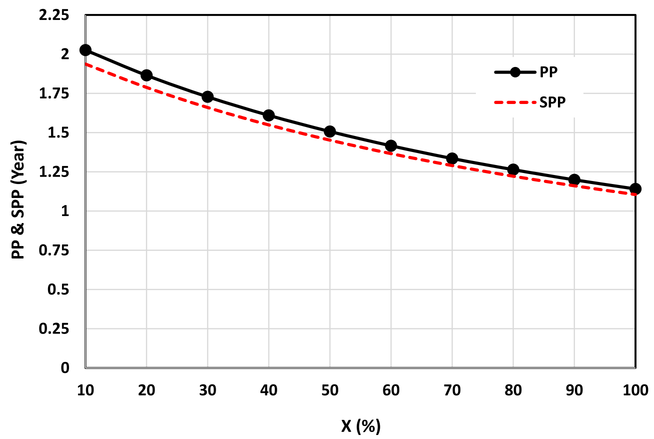

FIGURE 4 *PP* and *SPP* changes of the system with X ratio. *PP*, payback period; *SPP*, simple payback period.

0% to 100%, the energy and exergy efficiencies of the system decrease from 45% and 34.5% to 37.7% and 2.8%. The reason for this decline is that the production of Bitcoin cryptocurrency is not valuable from the point of view of energy and exergy and is only of economic value. For example, if the electricity generated by this system was used to generate hydrogen by decomposing water in the electrolysis machine instead of producing Bitcoins for the miners, the process of energy efficiency and exergy of the system would not be so declining.

It should be noted that the negative slope of the exergy efficiency curve is greater than the energy efficiency, which is more sensitive to the reduction of generated electricity due to the lower value of cooling produced from the exergy perspective (note the exergy efficiency equation).

Table 8 shows the economic indicators of the system in its basic state. As previously explained, the basic state is one in which no Bitcoin is produced.

In this table, the price of Bitcoin is estimated at US $47,743 which is the average price in 2022. Due to the production of Bitcoin by the studied system, compared with other power-generating systems with geothermal sources, the economic indicators of the system have improved significantly.

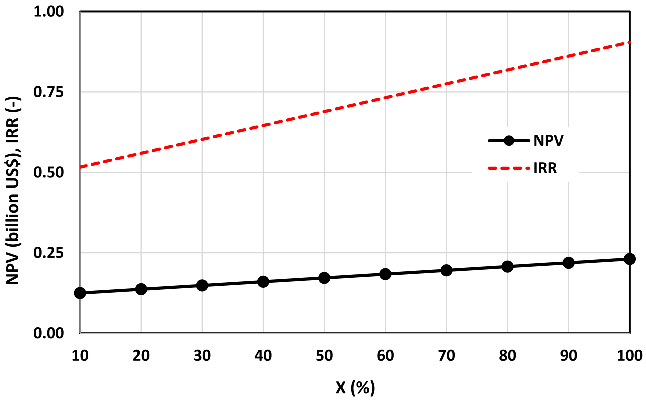

FIGURE 5 *NPV* and *IRR* changes with the *X* ratio. *IRR*, internal rate of return; *NPV*, net present value

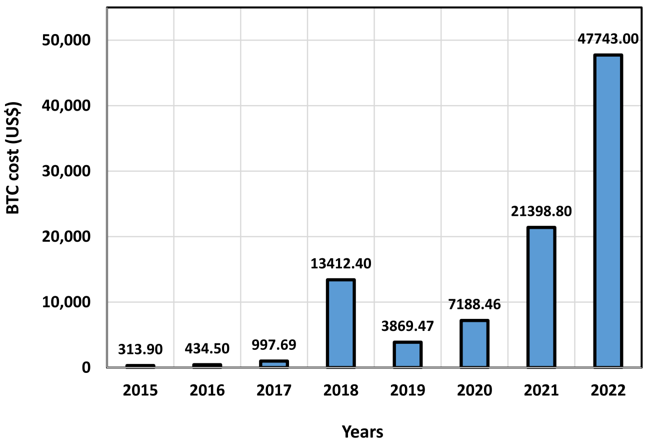

FIGURE 6 Final average price of Bitcoin from 2015 to 2022.

Figure 4 shows the *PP* and *SPP* changes in the system with the *X* ratio. In Figure 4, the price of Bitcoin is estimated at $40,000. By increasing the *X* ratio, both *PP* and *SPP* economic parameters decrease. This means that the higher the percentage of generated electricity to produce Bitcoin, it is the more economically viable it. This economic benefit depends on the price of Bitcoin in the cryptocurrency market. Figure 5 shows the changes in *NPV* and *IRR* with the *X* ratio, the process, and logic of which are similar to Figure 4.

In the next part of the article, the changes in the economic parameters of the system based on the average price of Bitcoin from 2015 to 2022 are examined. Figure 6 shows the final average price of Bitcoin from 2015 to 2022. From 2015 to 2022, the average price of Bitcoin has always been up, except in 2019 and 2020.

Figure 7 shows the changes in *PP* and *SPP* from 2015 to 2022. In this case, it is assumed that 100% of the power generated by the system is used to generate Bitcoins. Comparing the data in Figure 7 with the values in Table 2, it can be concluded that in 2018, 2021, and 2022, when the price of Bitcoin was US$13,412.4, US$21,398.8, and US$47,743, respectively, *PP* and *SPP* values were lower than the baseline. So it can be concluded that the price of Bitcoin has a direct effect on *PP* and *SPP*.

Similar to Figure 7, *NPV* and *IRR* in different years are shown in Figure 8. The price effects of Bitcoin on *NPV* and *IRR* are similar to *PP* and *SPP*.

Figure 9 shows the changes in PP based on the percentage of electricity spent on Bitcoin production (*X*%) based on the average price of Bitcoin during the years 2018–2022. During the years 2018–2020, when the price of Bitcoin was US$13,412.40, US$3869.4, and US$7188.46, respectively, the system *PP* increased by a percentage of *X*.

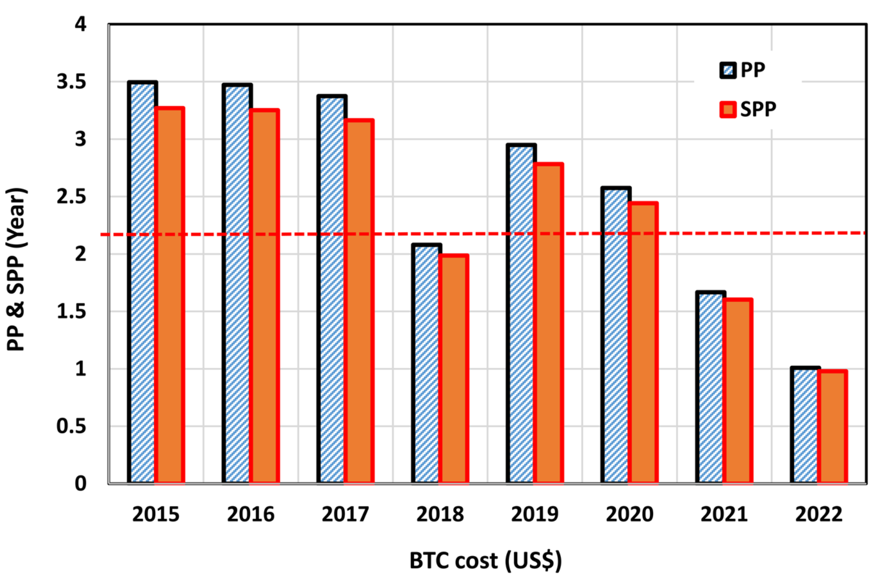

FIGURE 7 The changes in *PP* and *SPP* over different years, assuming that 100% of the system's electricity is used to generate Bitcoins. *PP*, payback period; *SPP*, simple payback period.

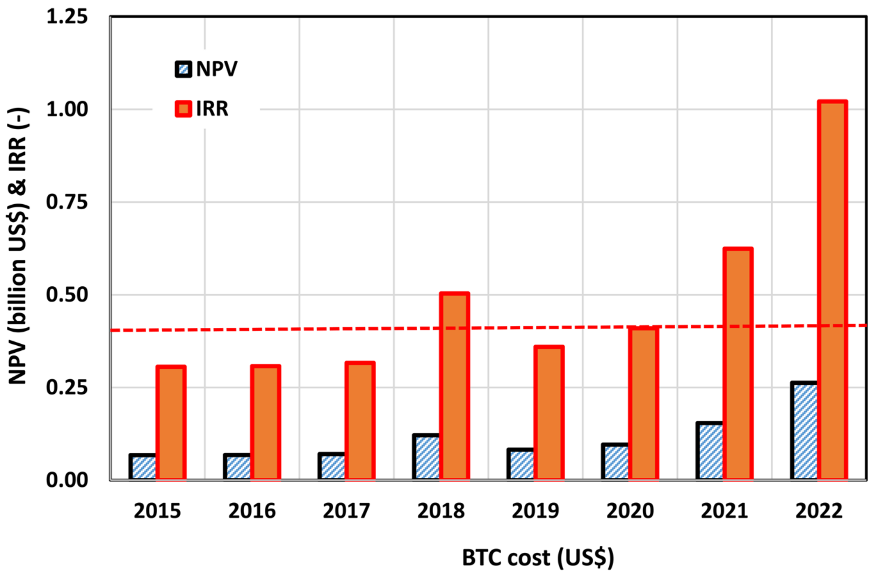

FIGURE 8 Changes in *PP* and *SPP* over different years, assuming that 100% of the system's electricity is used to generate Bitcoins. *IRR*, internal rate of return; *NPV*, net present value; *PP*, payback period; *SPP*, simple payback period.

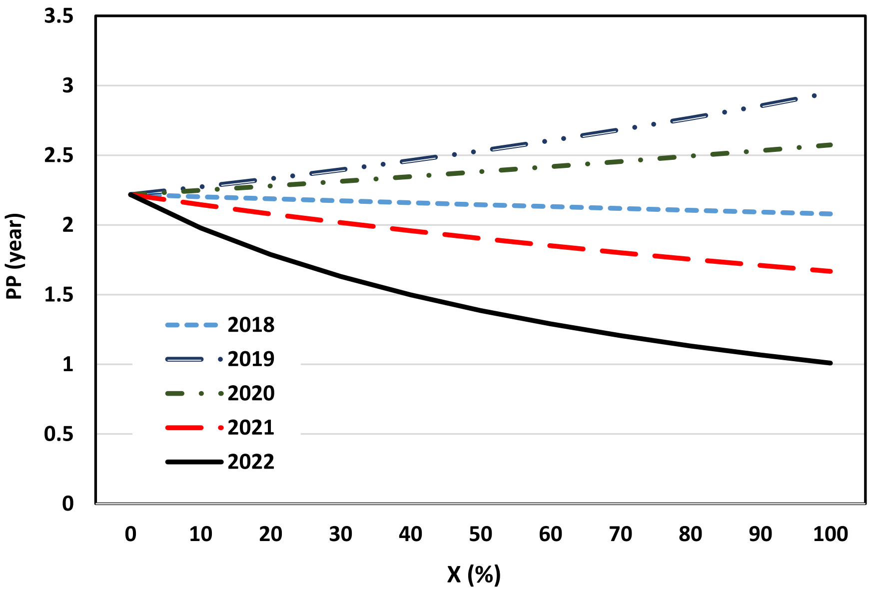

FIGURE 9 Changes in *PP* based on the percentage of electricity spent on Bitcoin production (*X*%) based on the average price of Bitcoin during the years 2018–2022. *PP*, payback period.

Of course, the slope of this increase in 2019 will reach its maximum. In 2021 and 2022, when the average price of Bitcoin reached US$21,398.8 and US$47,743, the slope of the chart became negative.

It should be noted that the price of Bitcoin depends on the price of electricity in addition to market conditions. In other words, the base price of Bitcoin depends on the price of electricity in that area. For example, in Qatar, where the price of electricity is 0.03 US$/kWh, the base price of Bitcoin is US$3610.8. Also, in Denmark, where the price of electricity is 0.36 US$/kWh, the base price of Bitcoin is US$43,329.

So, in the country or geographical region, first of all, you should calculate the basic price of Bitcoin based on the price of electricity, and then based on the market price of Bitcoin, you should conclude whether Bitcoin production is cost-effective or not.

7 | CONCLUSION AND RECOMMENDATION

The combination of renewable energy resources with financial concepts can provide a sustainable approach to policy-making decisions. Limited controls over the currency supplies is one aspect that springs from the decentralized features of Bitcoin and the absence of a fundamental supervisory entity, standard financial policies tools have the potent effects on sustainable financial methods. Moreover, original sources of data, improved financial inclusions, and enhanced financial competitions can be extracted from such a consideration.

This study introduces a new way to use geothermal energy to make electricity for Bitcoin mining. This new system has three parts: the steam cycle, the carbon dioxide cycle, and the liquid gas line. The steam cycle's condenser is used as the evaporator for the carbon dioxide cycle, and the liquid gas line absorbs heat from the carbon dioxide cycle. The system also uses LNG to make natural gas, which powers a turbine and produces cooling. The electricity generated by this system is used to mine Bitcoin. In summary, the system produces electricity, cooling, and Bitcoin. The key findings from this research are as follows:

- The system generated 4202 kW of electricity, mostly from the CO_2 cycle without Bitcoin production. The cooling system provided 19,613 kW of cooling. The system's energy efficiency and exergy were calculated to be 45.8% and 38.1%, respectively. The difference in cooling value resulted in exergy efficiency being about 16.8% lower.
- Bitcoin production had a positive impact on the system's economic indicators. With Bitcoin production, the *PP* was estimated to be 2.22 years, the sensitivity *PP* was 2.11 years, the *NPV* was $113.2 million, and the *IRR* was 0.473.
- These economic parameters were sensitive to Bitcoin price fluctuations. As the percentage of electricity allocated to Bitcoin production (*X*%) increased, and especially with higher Bitcoin prices, the economic outcomes became more favorable.

The study highlights the interdependence of geothermal power plant performance and Bitcoin mining profitability, with the economic attractiveness of the system closely tied to Bitcoin price fluctuations. Policies regarding the integration of geothermal power plants with Bitcoin mining should consider the dynamic nature of the cryptocurrency market, and incentives may be more favorable when Bitcoin prices are high. This approach not only contributes to the growth of the cryptocurrency industry but also promotes the utilization of renewable energy sources, fostering a more sustainable and economically viable future.

NOMENCLATURE

A	area (m^2)
C_0	investment cost (US$)
C_{ei}	exergoenvironmental impact coefficient
CF	annual income (US$)
C_I	investment and installations charge (US$)
C_n	investment cost in the nth year (US$)
e	specific exergy (kJ/kg)
$\dot{E}$	exergy rate (kW)
f_{ei}	exergoenvironmental factor
f_{es}	stability factor
F_t	correction factor
g	acceleration due to gravity (m/s^2)
h	specific enthalpy (kJ/kg)
IRR	internal rate of return
k	specific cost of the product (US$/kWh)
$\dot{m}$	mass flow rate (kg/s)
N	lifetime of system (year)
NPV	net present value (US$)
P	pressure (kPa)
PP	payback period (year)
$\dot{Q}$	heat transfer rate (kW)
r	discount factor
R	universal gas constant (kJ/kmol K)
s	specific entropy (kJ/kg K)
SPP	simple payback period (year)
T	temperature (°C, K)
U	coefficient of overall heat transfer (W/m^2 K)
V	volume (m^3)
Ve	velocity (m/s)
$\dot{W}$	work rate (kW)
Y	annual capacity of system production (kWh/year)
z	depth of geothermal well (m)

GREEK SYMBOLS

η	polytropic efficiency

SUBSCRIPTS

0	dead state
ch	chemical
D	destruction
en	energy
ex	exergy
f	formation
i	species i
in	inlet
out	outlet
P	product
R	reactant
Sep	separator
T	turbine

ORCID

M. A. Ehyaei http://orcid.org/0000-0002-4721-9427
F. Esmaeilion http://orcid.org/0000-0001-9674-2153
Biplab Das http://orcid.org/0000-0002-0246-7312

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