“Cryptocurrency energy consumption: Analysis, global trends and interaction”

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CRYPTOCURRENCY ENERGY CONSUMPTION: ANALYSIS, GLOBAL TRENDS AND INTERACTION

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Abstract

The rapid spread of cryptocurrencies is one of the most relevant trends today. One of the significant risks of their spread is the increase in energy consumption, which has a negative impact on the environment due to carbon emissions. This requires the development of a scientific toolkit for assessing relationships and predicting the impact of cryptocurrencies on energy consumption, which is the aim of this paper.

With the correlational regression analysis, the model of the dependence of spending on IT sector, energy consumption of Bitcoin, Ethereum and global capitalization of the cryptocurrency market was conducted, based on statistical data from Statista.com, Coinmarketcap.com and International Data Corporation. To check the possible relationship, tests for the adequacy of the results obtained (Fisher's test, Student's t-test) confirmed the correctness of coefficients for independent variables.

The results showed a significant direct correlation (Multiple R is 95%) of spending on IT sector, energy consumption and global capitalization of the cryptocurrency market. The established relationships allowed predicting that Bitcoin energy consumption may reach 142 Terawatt hours per year in 2026. And its impact on environment by mining in 2022 was at least 27.4 Mt of CO2 emission.

As a proposal, a conclusion was made on the expediency of linking mining to the use of certain sources of electricity production, such as "residual" natural gas, nuclear power, renewable energy sources. The obtained results and conclusions may be used as a basis for political decisions in the field of energy efficiency and climate change mitigation.

Keywords cryptocurrencies, energy resources, energy consumption, green economy, IT, Bitcoin

JEL Classification Q40, C21, O16, O33

INTRODUCTION

Cryptocurrencies are rapidly spreading and create special conditions for the development of the economy. One of such conditions is the influence of cryptocurrencies on the energy markets paraments, which in turn is of great importance for the development of the global economy and especially small open economies. The development of the crypto-asset sector causes additional energy costs, which is a critical factor affecting the environment, energy security and demand in the energy market.

In the conditions of the rapid spread of cryptocurrencies around the world, the attention on their energy consumption should be paid as well as determining what effect can occur. The relevance of investigating the latest changes in the dynamically developing branches of the Information Technologies' sector is confirmed by the fact that IT is the only tool for optimization and productivity growth resulted in sustainable development.

Conflict of interest statement:
Author(s) reported no conflict of interest

There is a point of view that the benefits of using cryptocurrencies are offset by their energy consumption (Huynh et al., 2022). The increase in energy consumption caused by Bitcoin has a noticeable impact on the environment, both through the associated local emissions and global warming.

So, the question of energy intensity of cryptocurrencies, their impact on global energy sector and economic environment is a relevant task to be analyzed. From this point of view, the possibility of forecasting the potential demand in the markets of energy resources, such as natural gas and renewable energy sources with zero emission, depends on the results of this task.

1. LITERATURE REVIEW

Cryptocurrencies, which in general should be considered more as cryptoassets (Brukhanskyi & Spilnyk, 2019; Hougan & Lawant, 2021), confidently occupy their niche in the financial markets and at the same time represent a separate ecosystem (Ferreira & Sandner, 2021). The potentially significant impact of the crypto-asset ecosystem on various spheres of socio-economic life attracts the attention of different regulators (Nabilou, 2019; Chokor & Alfieri, 2021).

The problem of IT development, human's privacy, data protection, transborder data flows, question of emergence, existence and functioning of cryptocurrencies and e-money have been revealed by Lloyd (2020). Liu and Tsyvinski (2021) have established that cryptocurrency returns are driven and can be predicted by factors that are specific to cryptocurrency markets. Scientist developed and analyzed these factors. Corbet et al. (2019) provide a systematic review of the empirical literature based on the major topics that have been associated with the market for cryptocurrencies since their development.

One of the important aspects of the manifestation of the impact of the spread of cryptocurrencies is the field of energy markets. Recent publications on these questions are reviewed below. There are some spillover effects from natural gas to cryptocurrencies that cause changes in demand on energy markets (Omura et al., 2023). Bitcoin is not the only reason causing splashes, ups and downs on energy markets. Other cryptocurrencies have been causing near to 1/3 of energy consumption (Gallersdörfer et al., 2020).

Volatility spillover effects in leading cryptocurrencies were analyzed by Katsiampa et al. (2019). They presented their findings in three pair-wise bivariate BEKK models that examine the conditional volatility dynamics along with interlinkages and conditional correlations between three pairs of cryptocurrencies, namely Bitcoin-Ether, Bitcoin-Litecoin, and Ether-Litecoin. They concluded bi-directional shock transmission effects between Bitcoin and both Ether and Litecoin, and unidirectional shock spillovers from Ether to Litecoin.

Moussa et al. (2021) used the STECM model to approve an relationship between Bitcoin and some commodities like Gold and Crude Oil Brent, as the logarithmic prices have a significant influence on the Bitcoin logarithmic prices. The sharp fluctuations in the price of Bitcoin are noticeable on the prices of Brent crude oil by the Bayesian VAR model and generalized impulse response functions (Kaabia et al., 2020). The empirical analysis by nonlinear autoregressive distributed lag approach NARDL on a long time of 2014–2020 weekly data also clearly showed the existence of asymmetric connection between Bitcoin price and resource commodity futures price (Lin & An, 2021). According to these cases, cryptocurrencies could play a significant role in financial modelling and risk management on the energy markets (Huynh et al., 2020).

Li et al. (2019) discovered global electricity consumption of the Monero mining activity. Data analysis, experiments and estimated Monero mining electricity consumption in the world and its carbon emission in China were taken as a case study. Not just mining but even information transmission on cryptocurrency markets has its influence, for example, on West Texas Intermediate and Brent oil prices (Ghabri et al., 2022). Such relations are especially strengthened during crises (Attarzadeh & Balcilar, 2022). Schinckus et al. (2022) investigated cryptocurrencies' hashrate and

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Table 1. CO2 emission in main Bitcoin mining centers

Source: Statista (2022), Our world in data (2022), author estimations.

Country	CO2 emission in electricity sector, Mt per tWh	Share of Global Bitcoin mining volume, %	CO2 emission by Bitcoin mining, Mt
USA	0.367	41	10.34
China	0.531	23	8.39
Kazakhstan	0.636	14	6.12
Malaysia	0.544	3	1.12
Germany	0.385	3	0.79
Canada	0.128	7	0.62
Total			27.37

electricity consumption. They have found that the hashrate has a positive cointegration with energy and electricity consumption. Despite the launch of the Segregation Witness (SegWit) mechanism allowing blocks to handle a higher number of transactions per block, since October 2019, the need for electricity for hashrate has increased significantly.

Bitcoin is the largest consumer of electricity among all cryptocurrencies. The annual electricity consumption of the Bitcoin network is 93.78 TWh. The world produces approximately 27 thousand TWh of electricity. In 2021, consumed primary energy by source worldwide is characterized by the following structure: oil – 31 %, coal – 27%, natural gas – 24%, renewables – 13%, and nuclear energy – 4% (Statista, 2023e).

Not only mining, but also the mechanism of operation requires expensive equipment and significant costs of electricity (Slozko & Pelo, 2015). Bitcoin transaction energy consumption is 703.25 kWh, whereas 100 Visa transaction energy consumption is 148.63 kWh (Statista, 2023d). Energy intensity of 1 Bitcoin transaction exceeds 100 Visa transaction by about 5 times. This could be a significant obstacle for cryptocurrency development against casual electronic payments sharing.

The proliferation of cryptocurrency mining farms significantly increases energy consumption and CO_2 emissions (Treiblmaier, 2023). According to some estimates, it can lead to an additional almost 2.0 million tons of CO_2 annually (Roeck & Drennen, 2022). Badea and Mungiu-Pupăzan (2021) analyzed many works devoted to various aspects of Bitcoin and confirmed the negative impact on the environment and beyond. Probably 2°C of global warming (Mora et al., 2018) is overestimated threshold (Masanet et al., 2019), but the certain impact of Bitcoin on the environment is not in doubt (Krause & Tolaymat, 2018).

Estimates of the impact of Bitcoin mining on the environment depend on the source data. If we take as a basis the data on the Bitcoin energy consumption worldwide in terawatt hours minimum (Statista, 2023a), the main Bitcoin mining centers (Statista, 2022), the volume of CO2 emissions from electricity production in these countries (Our world in data, 2022), it can be roughly estimated that in 2022, Bitcoin mining alone was accompanied by the emission of more than 27.4 megatons of CO2 (Table 1).

As an advantage, Bitcoin mining is relatively mobile. Unlike most industries, cryptocurrencies easily could be adapted to mining throughout the world where there is electricity. For this reason, most of the crypto mining in China is provided next to giant power plants, in the USA next to flaring plants that burn excess natural gas, or next to some other source of energy that is wasted.

An attempt to reorient the mining of crypto assets to clean energy sources will lead to changes in the structure of electricity production in favor of natural gas, nuclear energy and other renewable sources. European countries account for 6% of Bitcoin mining (Germany – 3%, Ireland 2%, Sweden – 1%). Ukraine's share in Bitcoin mining is only 0.15% (Neumueller, 2023). Based on this, the demand for natural gas will increase on the territory of the EU, which will further aggravate the issue of energy security. However, there is potential for the development of mining and circling cryptocurrency in Ukraine (Bublyk et al., 2023), but it requires restoration of the energy sector.

The volatility of the crypto-assets and energy markets is interrelated. Acceleration in the price of crude oil or natural gas in the market encourages the price of cryptocurrencies to rise. While the rise in cryptocurrency prices leads to an increase in demand and prices in energy markets (Meiryani et al., 2022). Some studies even show the likelihood of crypto bubbles bursting will increase systemic risks in the energy sector (Ji et al., 2022). On the other hand, the blockchain technology itself opens new opportunities for controlling the form of energy production, increasing its green component (Mannaro et al., 2017).

Despite the popular question, some aspects of the development of cryptocurrencies, in particular their impact on the environment, remain much less researched (Wang et al., 2022). There are a lot of studies about cryptocurrencies' functioning, IT development, there are some about the energy intensity of crypto, but not so many about possible correlations and influence directions of mentioned above. A review confirms the necessity of further research of the impact of cryptocurrency electricity intensity on the IT sector resulted in further energy sector investigation (Andrae, 2020) and economic environment impact. One of key issue is the development of tools for forecasting the impact of cryptocurrencies on the environment in near future.

In such conditions, the availability of methodical tools for evaluating and forecasting the impact of the development of cryptocurrencies on the demand for energy resources and the state of the energy markets is important for the development of green economy development programs.

The aim of the paper is to develop a toolkit for forecasting changes in demand on energy markets under the influence of the spread of cryptocurrencies. Such a toolkit can be used within the energy security policy of the state or the investment strategy of private investors.

2. METHODOLOGY

The information base of the conducted analysis is quartal and annual data for 2017–2022 (from the beginning of cryptocurrencies' rising) from the statistical portals Statista.com, Coinmarketcap.com. For analytical comparison, data from the Worldwide Digital Transformation Spending Guide conducted by the International Data Corporation (IDC) was used.

Research methods of the paper are based both on general scientific methods of cognition and specific economic-mathematical instruments of investigation. The subject of research and tasks encourage to the use of general methods (systems analysis, induction, deduction, systematization and generalization, abstract-logical, comparative methods), as well as correlation-regression analysis of the impact of energy consumption of Bitcoin, Ethereum and cryptocurrency market capitalization on IT spending. Multivariable linear dependence is expressed as follows:

$$y_x = f\left(x_1,\ x_2, \ldots,\ x_n\right), \tag{1}$$

where y_x – dependent variable (in this case it is IT spending); x_1, x_2, x_3 – independent variables (energy consumption of Bitcoin, energy consumption of Ethereum, cryptocurrency market capitalization).

A universal characteristic of the closeness degree of the relationship between quantitative features is the coefficient of determination. The coefficient of determination (Multiple R) was used to check the closeness of the relationship between the dependent and independent variables. It is determined by the following formula:

$$R_{xy} = \frac{\sum_{i=1}^{n}\left(x_i - x\right)\left(y_i - y\right)}{\left(n-1\right)s_x\,s_y} = \frac{\sum_{i=1}^{n}\left(x_i - x\right)\left(y_i - y\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - x\right)^2\ \sum_{i=1}^{n}\left(y_i - y\right)^2}}, \tag{2}$$

where x – the factors of the model; y – dependent variable; s – root mean square deviations of statistical series of parameters x and y.

Basically, regression analysis used in the study is represented by the general equation:

$$y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n, \tag{3}$$

where a_0 – free coefficient; a_1, a_2, ..., a_n – coefficients for variables; x_1, x_2, …, x_n – respectively.

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To test the model for adequacy, the study used Fisher's test expressed as follows:

$$F_p = \frac{\sum\left(y-\overline{y}\right)^2 / m}{\sum\left(y-\overline{y}\right)^2 / \left(n-m-1\right)} = \frac{r_{xy}^2}{1-r_{xy}^2}\left(n-2\right), \quad (4)$$

where n – number of observations; m –number of parameters at x.

To establish whether the obtained coefficients are statistically significant, the T-test (Student's t-test) was used.

$$T = \frac{r \cdot \sqrt{n-2}}{\sqrt{1-r^2}}. \quad (5)$$

The tests showed that multivariate linear dependence is adequate, and the obtained coefficients are statistically significant.

3. RESULTS AND DISCUSSION

At the beginning of cryptocurrency and proof-of-work technology emergence, crypto mining was not so energy-intensive, but now the algorithm for creating new blocks and confirming transactions (e.g., Bitcoin) requires a lot of energy (Figure 1).

The main factors of the cryptocurrency market development are energy consumption and spending on digital transformation technologies and services worldwide. Composition of these factors with regression analysis allows us to model cryptocurrency development process. To be more precise, a multivariate linear dependence of digital transformation technologies and services spending worldwide on total cryptocurrency market capitalization, Bitcoin energy consumption (worldwide) and Ethereum energy consumption (worldwide) is derived. The number of observations is 24. The period is 2017–2022. Input data is given in Table 2.

Multiple R is 95%. There is no collinearity (Table 3).

The adequacy of the model is confirmed by Fisher's test, the coefficients are statistically significant (confirmed by Student's t-test). Summary output is given in Table 4, Table 5, Table 6.

The regression result is described by the following linear relationship:

$$y = 515.98 + 0.22 \cdot x_1 + 13.288 \cdot x_2 - 9.59 \cdot x_3, \quad (6)$$

Source: Statista (2023a).

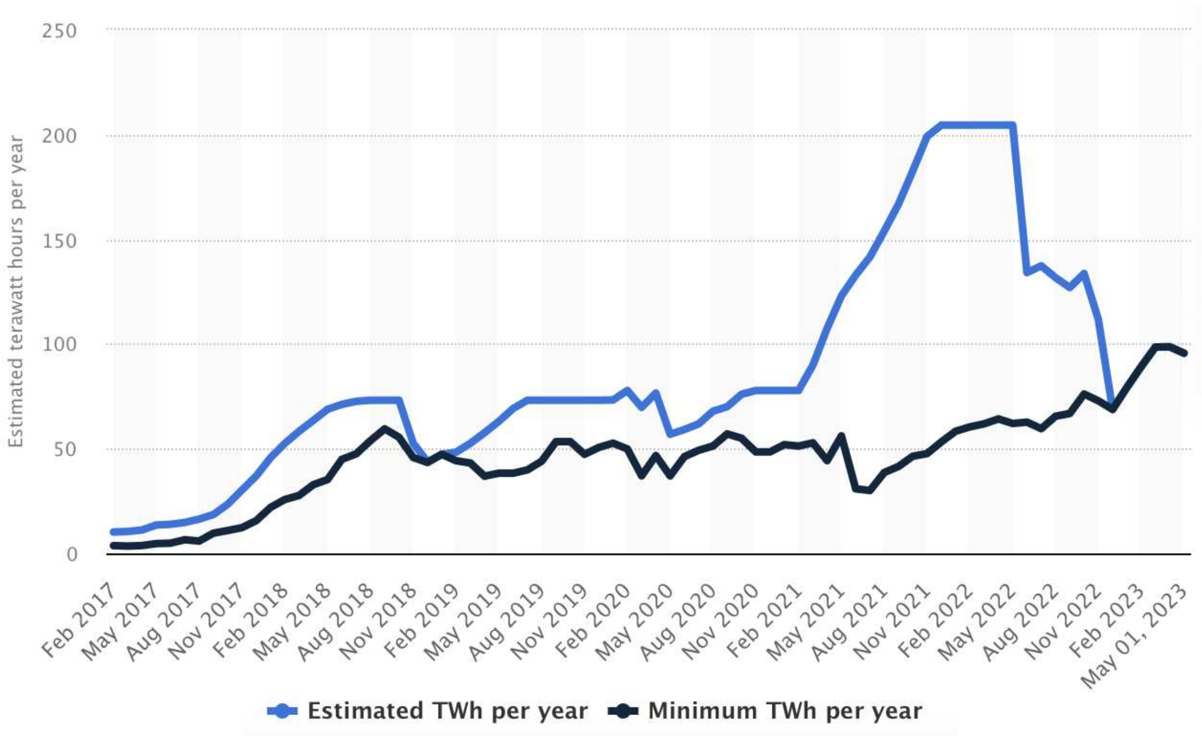

Figure 1. Bitcoin energy consumption index

Table 2. Input data for regression analysis

Source: Coinmarketcap (2023), Statista (2023a, 2023b, 2023c).

No.	Date	Total Cryptocurrency Market Cap (billion USD) (7)	Bitcoin energy consumption worldwide (in terawatt hours minimum per year) (8)	Ethereum energy consumption worldwide (in terawatt hours minimum per year) (9)	Spending on digital transformation technologies and services worldwide (billion USD) (10)
		X_1	X_2	X_3	Y
1	1q 2017	25	3.7	1.7	500
2	2q 2017	101	4.7	4.4	490
3	3q 2017	136	6.5	4.6	556
4	4q 2017	571	15.6	9.5	960
5	1q 2018	300	27.6	14	932
6	2q 2018	243	44.9	12.6	1,050
7	3q 2018	220	59.5	9.6	1,001
8	4q 2018	120	43.4	4	1,000
9	1q 2019	143	43.1	2.1	1,100
10	2q 2019	345	38.3	2.7	1,073
11	3q 2019	218	53.3	3	1,164
12	4q 2019	193	50.6	2.4	1,180
13	1q 2020	167	37	2.7	1,090
14	2q 2020	257	46.2	2.8	1,173
15	3q 2020	345	57	4.3	1,300
16	4q 2020	728	48.5	5	1,310
17	1q 2021	1,758	52.8	8.3	1,400
18	2q 2021	2,456	30.8	0	1,440
19	3q 2021	2,131	41.5	12.2	1,439
20	4q 2021	2,770	53.2	15.8	1,590
21	1q 2022	2,103	61.9	17.4	1,690
22	2q 2022	901	62.7	14.1	1,470
23	3q 2022	933	66.8	0	1,627
24	4q 2022	814	68.7	0	1,850

Table 3. Collinearity checking

Variable	X_1	X_2	X_3
X_1	1	–	–
X_2	0.29341971	1	–
X_3	0.4211594	0.14327945	1

Table 4. Summary output for the model

Regression Statistics	
Multiple R	0.957571683
R Square	0.916943528
Adjusted R Square	0.904485057
Standard Error	110.1303355
Observations	24

Table 5. Fisher's test checking

Variable	df	SS	MS	F	Significance F
Regression	3	2,678,015.143	892,671.7142	73.60000595	5.55779E-11
Residual	20	242,573.8158	12,128.69079	–	–
Total	23	2,920,588.958	–		

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Table 6. Coefficients for the model and the T-test checking

Variable	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	515.9822673	59.29780539	8.701540705	3.10624E-08	392.2892128	639.67532
x1	0.219548633	0.031267212	7.021688903	8.22144E-07	0.154326373	0.2847709
x2	13.28092051	1.258651296	10.55170765	1.27282E-09	10.65541991	15.906421
x3	–9.592565947	4.682913385	-2.048418401	0.053873468	-19.3609521	0.1758202

where x_1 – total cryptocurrency market capitalization (billion USD), x_2 – Bitcoin energy consumption worldwide (in terawatt hours), x_3 – Ethereum energy consumption worldwide (in terawatt hours), y – Spending on digital transformation technologies and services worldwide (billion USD). After the modelling, the real given data were compared with the data obtained after the simulation. Comparative analysis is shown in Figure 2.

Thus, it has been proven that all the taken factors, namely total cryptocurrency market capitalization, Bitcoin energy consumption (worldwide) and Ethereum energy consumption (worldwide), affect spending on digital transformation technologies and services. The established dependence and the correlation have confirmed the importance of cryptocurrency energy intensity in digitalization processes in the financial sector particularly, and IT sector development in general.

Now the approach can be made to predict future energy consumption by cryptocurrency development due to planned spending. As mentioned before, Bitcoin energy consumption (because of its intensity) calls into question the expediency of functioning of cryptocurrencies based on proof-of-work. To test the inverse relationship between Bitcoin's dependence on IT development, the influence of IT spending on Bitcoin energy consumption was also checked (data from Table 2). The established linear one-factor model is described as follows:

$$B_{ec} = 0.045 \cdot IT_s - 11, \tag{7}$$

Source: Predicted spending – authors' estimation; real spending – (Statista, 2023c).

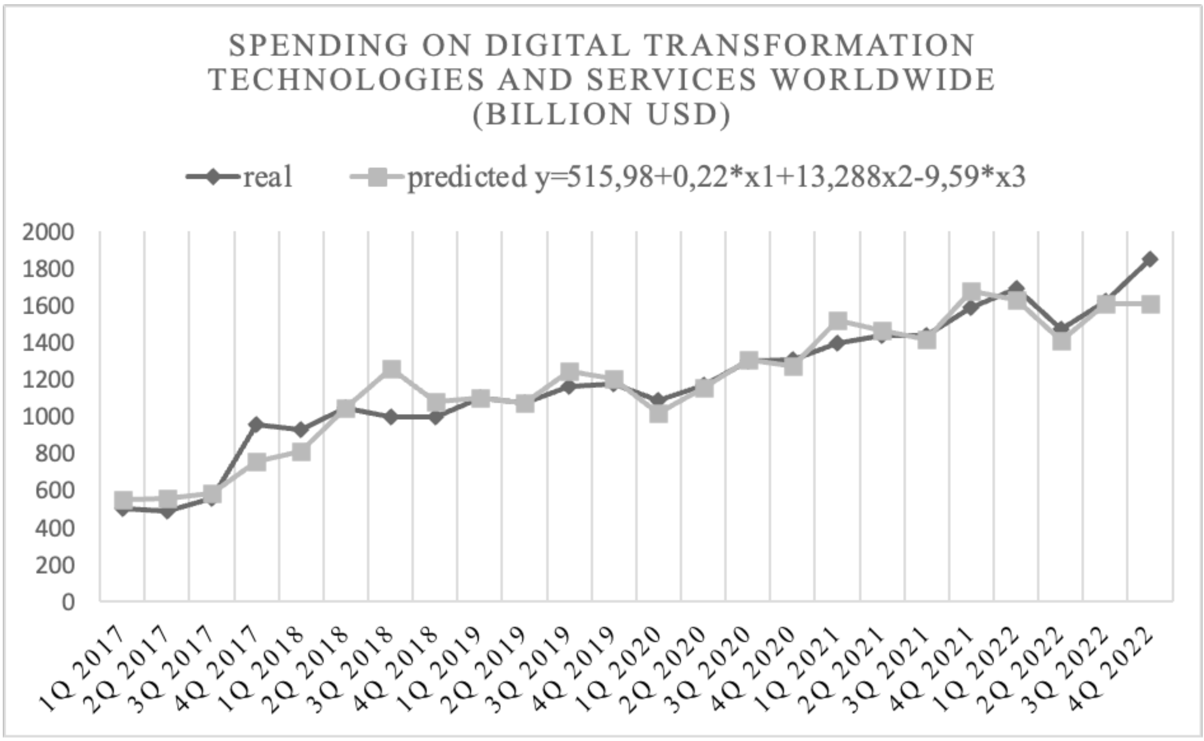

Figure 2. Comparison of real and predicted data of spending on digital transformation technologies and services worldwide

Source: Predicted energy consumption – authors' estimation; real energy consumption – IDC (2022).

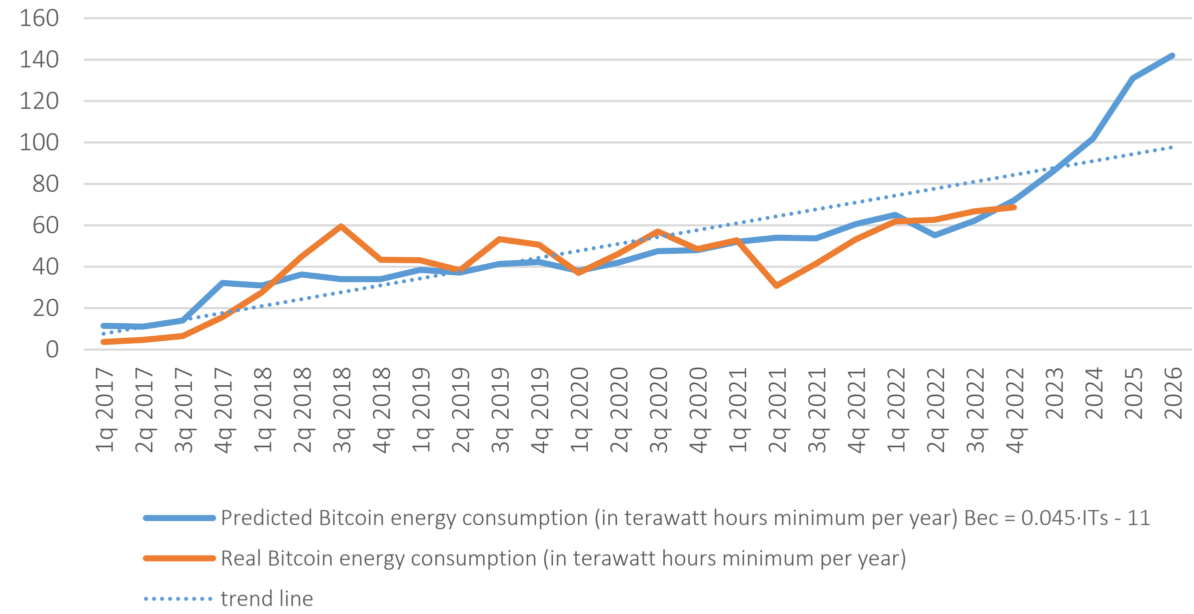

Figure 3. Prediction of Bitcoin energy consumption worldwide in 2023–2026 (tWh)

where B_{ec} – Bitcoin energy consumption worldwide, IT_s – spending on digital transformation technologies and services worldwide (Multiple R is 84%, Fisher's test confirmed the adequacy).

Global digital transformation spending is projected to reach USD 3.4 trillion in 2026 with a five-year compound annual growth rate (CAGR) of 16.3%, according to the International Data Corporation (IDC) Worldwide Digital Transformation Spending Guide. Considering this information, the level of energy consumption of Bitcoin (B_{ec}) until 2026 was predicted based on the established dependence. It is described in Figure 3.

The results showed that with the growth of IT sector spending annually by 16.3% from the level of USD 2.162 trillion in 2023 to USD 3.4 trillion in 2026, the energy intensity of Bitcoin will increase to 142 terawatt-hours minimum per year (estimated values) in 2026. This is a significant indicator that must be obtained in conditions of limited energy resources and their price.

CONCLUSION

To develop a toolkit for forecasting changes in demand on energy markets due to cryptocurrencies, a regression analysis model was built. The result of correlational regression analysis shows the dependence (Multiple R is 95%) of spending on IT sector (y) on energy consumption of Bitcoin (x_1), Ethereum (x_2), global capitalization of the cryptocurrency market (x_3). The results obtained during the modeling showed the adequacy of the indicator "planned spending on the IT sector" as a predictive indicator of additional demand on energy resources and related emissions. The proposed model also showed Bitcoin energy consumption is going to reach 142 tWh minimum per year in 2026. Bitcoin is the most energy consuming crypto in contrast to Ethereum, the second most common cryptocurrency in the world.

The environmental impact of Bitcoin mining in 2022 was at least 27.4 Mt of CO2 emissions. To reduce the harmful impact on the environment from the spread of crypto assets, there are a number of measures to link their use to "green energy", in particular "residual" natural gas, nuclear power, renewable energy sources. The search for the most effective forms of binding requires further scientific research.

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