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The Role of Crypto Trading in the Economy, Renewable Energy Consumption and Ecological Degradation

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Abstract: The rapid growth of information technology and industrial revolutions provoked digital transformation of all sectors, from the government to households. Moreover, digital transformations led to the development of cryptocurrency. However, crypto trading provokes a dilemma loop. On the one hand, crypto trading led to economic development, which allowed attracting additional resources to extending smart and green technologies for de-carbonising the economic growth. On the other hand, crypto trading led to intensifying energy sources, which provoked an increase in greenhouse gas emissions and environmental degradation. The paper aims to analyse the connections between crypto trading, economic development of the country, renewable energy consumption, and environmental degradation. The data for analysis were obtained from: Our World in Data, World Data Bank, Eurostat, Ukrstat, Crystal Blockchain, and KOF Globalisation Index. To check the hypothesis, the paper applied the Pedroni and Kao panel cointegration tests, FMOLS and DOLS panel cointegration models, and Vector Error Correction Models. The findings concluded that the increasing crypto trading led to enhanced GDP, real gross fixed capital formation, and globalisation. However, in the long run, the relationship between crypto trading and the share of renewable energies in total energy consumption was not confirmed by the empirical results. For further directions, it is necessary to analyse the impact of crypto trading on land and water pollution.

Keywords: bitcoin; crypto market; cryptocurrency; trading; digital currency; innovation; ecological degradation; economic growth

Citation: Miśkiewicz, R.; Matan, K.; Karnowski, J. The Role of Crypto Trading in the Economy, Renewable Energy Consumption and Ecological Degradation. *Energies* **2022**, *15*, 3805. https://doi.org/10.3390/en15103805

Academic Editors: Tetyana Pimonenko, Oleksii Lyulyov and Henryk Dźwigoł

Received: 6 May 2022
Accepted: 19 May 2022
Published: 22 May 2022

1. Introduction

The innovation development, industry revolution, and digital transformation provoke the development of a new currency type—cryptocurrency. The main feature of cryptocurrency is its apolitical and decentralised nature [1]. The study [2] called cryptocurrency the most significant innovation of this century. Bitcoins appeared in 2008 and restructured the financial market. Considering the official report of the company Triple A [3], the bitcoin price has increased by 540% in the period from 2012 to 2021. Moreover, the experts forecast that the cryptocurrency market will continue to grow with a compound annual growth rate of 56.4% from 2019 to 2025 [3]. Considering [3] in 2021, Ukraine has the highest share of the crypto owners' population—12.73%; Venezuela—10.34%; and the USA—8.31%.

The study [4] analysed the perspectives of bioeconomy development as the way for the EU countries to achieve the indicated goals of green growth based on smart and innovative technologies. Thus, Chiriac I. highlighted that cryptocurrency was the core financial source of bioeconomy development [4]. At the same time, cryptocurrency development requires a high volume of electrical energy consumption, which leads to environmental degradation. Considering the Bitcoin Energy Consumption Index [5], total bitcoin footprints could be characterised as follows:

- Electricity consumption is 204.50 TWh (Terawatt-hour) which is comparable to the power consumption of Thailand;
- The carbon footprint is 114.06 Mt of CO_2, which is comparable to the carbon footprint of the Czech Republic;
- The electronic waste is 34.36 kt which is comparable to the small IT equipment waste of the Netherlands [5].

Moreover, a single bitcoin transaction led to 358.10 g of electronic waste. It is equivalent to the weight of 2.18 iPhones 12 or 0.73 iPads [5].

Thus, crypto trading provokes a dilemma loop: on the one hand, crypto trading led to economic development, which allows attracting additional resources to extending smart and green technologies for decarbonising economic growth; on the other hand, crypto trading led to the intensification of energy sources, the use of which provoked an increase in greenhouse gas emissions and environmental degradation. Thus, the paper aims to analyse the links between crypto trading, economic development of the country, renewable energy consumption, and environmental degradation.

The paper has the following structure: the Section 1 highlights the topicality of the paper's purpose; the Section 2 analyses the critical view on crypto trading development to justify the research hypothesis; the Section 3 explains the methodology and steps of the research; the fourth part contains the findings on links between crypto trading, economic development of the country, renewable energy consumption, and environmental degradation; and the fifth part summarises the research results and compares them with the previous results.

2. Literature Review

The rapid penetration of innovations and information technologies in all spheres provoked the snowballing digitalisation of all economic sectors (financial, energy, agriculture, etc.) [6–25]. The dynamics of the research publications on cryptocurrency development has demonstrated the rapid growth since 2015. In 2021, the number of publications showed a 6-times increase compared to 2015 (Figure 1). The following parameters were applied for analysis:

- Keywords: cryptocurrency, bitcoin*;
- Boolean operators: OR;
- Subject areas: Business, Management, Accounting, Economics, Econometrics and Finance;
- Year: 2011–2021;
- Language: English.

Moreover, most papers were published by scientists from the United States of America, China, India, the United Kingdom, and Germany. These findings confirmed that the scientists' interests have been increasing from year to year, highlighting the theme's topicality.

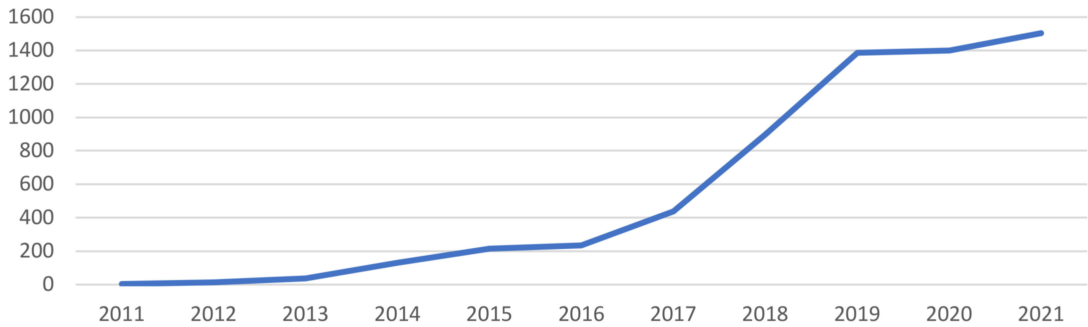

Figure 1. The dynamic of publications on researching cryptocurrency development (Scopus data).

Cryptocurrency development was highlighted by the worldwide community as a dilemma of future growth. Scientists [4,26–35] confirmed that cryptocurrency was the power for future economic growth. At the same time, studies showed that the development of cryptocurrency provoked the intensification of greenhouse gas emissions. Consequently, this could restrict reaching the goals of a decarbonised economy and mitigate climate changes under the Green Deal Policy and Sustainable Development Goals. In this case, it is topical to analyse the cryptocurrency development from different points of view.

2.1. Economic Growth and Cryptocurrency

The industry revolution provoked the development of blockchain technologies and transformation of the economy [16–25], education [26–28], and financial market [29–32], which boosted economic growth. Thus, it led to the development of cryptocurrency. The digital currency allowed the contractual costs to decline and transformed the institutional framework of economic growth [32]. Masharsky and Skvortsov [33] justified the positive role of cryptocurrency in economic development. At the same time, they concluded the necessity of relevant government reregulation in the financial market. The study [34] confirmed that bitcoin influenced economic growth positively. At the same time, the shocks in the bitcoin market destroyed the stable traditional market, impacted on investors' decisions, and reduced the macroeconomic indicators. The opposite conclusion was obtained in the paper [35], which confirmed that the exchange rate had a positive, statistically significant impact on bitcoin prices, while influencing the economic openness negatively. The study [36] concluded that bitcoin complicated the monetary policy and could restrict stable economic development.

2.2. Cryptocurrency and Energy Consumption

The paper [37] emphasised that the crypto market's development led to an increase in energy consumption. However, de Vries A. indicated that the bitcoin boom provoked rapid economic growth and changes in financial market architecture [37]. Trubby J. [38] justified that bitcoin led to increasing energy consumption. However, he emphasised that a relevant law and fiscal policy could decolonise bitcoin and allow a reduction in energy consumption. The studies [39–52] confirmed that energy consumption is a core factor of a country's energy security. Moreover, the economic dependence on energy sources and ecological issues required renewable energy development and increasing their share in total energy consumption. In this case, the country should allocate alternative financing sources to enhance renewable energy in the country. Considering the findings of the bibliometric analyses in the studies [53–61], the energy consumption should be greening through the development of smart and digital technologies, alternative energies, blockchain technology, and incentive financial instruments. Thus, the paper [61] confirmed that innovative approaches and smart technologies promoted renewable energies in the country.

Furthermore, the studies [62,63] concluded that a smart grid is a key to declining energy consumption from the traditional sources and increasing from renewable ones. Moreover, the studies [64,65] emphasised that extending energy resources required additional financing. It should be noted that the study [66] remarked that if the bitcoin cost was lower than the energy cost, it limited the bitcoin mining. O'Dwyer and Malone [67] concluded that the mining equipment and hardware should become energy efficient and fruitful. Additionally, Vranken H. [68] suggested that bitcoin mining could consume less energy due to use of alternative technologies for mining, such as "proof-of-stake". Similar conclusions were obtained in the studies [67,69]. However, the study confirmed the bidirectional relationship between energy consumption and bitcoin profitability. The studies [70–72] confirmed that the development of bitcoin led to inefficient use of traditional energy resources. Thus, it is topical to justify the character of the links between energy consumption and crypto trading.

2.3. Cryptocurrency and Environment Degradation

Applying the Toda–Yamamoto and bootstrap-augmented Toda–Yamamoto test, the study [73] confirmed the causal relationship between bitcoin development and ecological degradation. The core indicator of ecological degradation was carbon dioxide emissions. The papers [74–76] highlighted that cryptocurrency harmed the environment by increasing energy consumption and mining pollution. The study constructed the index of cryptocurrency environmental attention [74]. Based on the findings, the study concluded that cryptocurrency development and effective government policy allowed a decline in the negative anthropogenic impact on the environment. Similar conclusions were obtained in the paper [75], which forecasted that in 2024 Chinese energy consumption from bitcoins mining could increase to 296.59 TWh. This would provoke an increase in air pollution by 130.50 million metric tons of CO_2. In this case, the study justified the necessity of government regulation by providing a strict tax policy on carbon emissions and limiting the mining pollution through quotas.

The study [77] applied the MVMQ-CAViaR model (multivariate-quantile conditional autoregressive) and Granger causality to check the relationship between bitcoin price and the carbon credit market. Considering the empirical results, bitcoins' prices significantly impacted the carbon credit market. At the same time, the causality impact of the carbon credit market on bitcoin price was not confirmed. The study [78] empirically justified that cryptocurrency provoked an increase in the electricity waste, which polluted ground water and land. Thus, digital currency development requires the relevant mechanisms to overcome environmental issues through the development of alternative energy. Thus, the studies [79–83] confirmed that smart grids and green financing allowed overcoming the issues of air pollution. On the example of China and the USA, the paper [76] confirmed that USD 1 bitcoin value provoked health damage of USD 0.49 in the USA and 0.37 in China. The opposite conclusion was proved in the study [84]. Cocco L., Pinna A. and Marchesi M. justified that blockchain technologies and bitcoin allowed bootstrapping of the development of green technologies and achievement of the Sustainable Development Goals.

Considering the results mentioned above, the following hypothesis was tested:

H1. *There is a causal relation between crypto trading and economic development*.

H2. *Crypto trade growth requires the increase in energy consumption*.

H3. *GDP growth allows attracting investment into renewable energy*.

H4. *Renewable energy decreases the carbon dioxide emissions*.

The general hypothesis: there is a causal relationship among crypto trading, renewable energy consumption, and ecological degradation.

3. Materials and Methods

The analysis was based on the data of the top European crypto-trader countries for 2013–2020: the United Kingdom, Germany, Ukraine, Italy, Poland, the Netherlands, and France [3].

The study was based on the modified Cobb–Douglas function (which analysed the economic development). However, along with traditional factors of production (labour and capital), the modified function considered the energy resources and sources generated from the crypto trading:

$$GDP_{it} = f(LF_{it}, GFCF_{it}, RE_{it}\ CT_{it}) \quad (1)$$

where GDP is gross domestic product; LF is labour force; GFCF is gross capital formation; RE is a share of renewable energy in the final energy consumption; and CT is crypto trading.

At the same time, the explanation of the variables 'globalisation' and 'economic openness' were added to the model. The studies [85–88] confirmed that the country's involvement in the globalisation process was the core determinant of the ecological and economic development of the country. Consequently, it would influence the value and volume of crypto trading. Furthermore, the paper [85–88] (based on the panel data) proved the long-term relationship between globalisation and economic, social, and political indices of economic growth. The study [80,88] justified that economic openness allowed attracting and implementing innovation and information technology in the country. Thus, it could provoke intensification of crypto trading, which supports economic and ecological development.

It should be noted that each coefficient of function (1) could be interpreted as an indicator of elasticity. In this case, converting data into a natural logarithm eliminates their dynamism. This (1) could be presented as a panel cointegration equation:

$$\mathrm{lnGDP_{it}} = \mathrm{a_{0i}} + \alpha_{1i}\mathrm{lnLF_{it}} + \alpha_{2i}\mathrm{lnRE_{it}} + \alpha_{3i}\mathrm{lnGFCG_{it}} + \alpha_{4i}\mathrm{lnCT_{it}} + \alpha_{5i}\mathrm{lnGI_{it}} + \alpha_{6i}\mathrm{lnEO_{it}} + \mu_{it} \quad (2)$$

where $\alpha_{1i}, \ldots, \alpha_{6i}$ are regression's coefficients which were estimated and explain the elasticity of output related to total labour force (LF), real gross fixed capital formation (GFCF), share of renewable energy in final energy consumption (RE), crypto trading (CT), globalisation (GI), and economic openness (EO); GDP is gross domestic product per capita; a_{0i} is the country-specific intercept; μ is the error term; i = 1, . . . , N; t = 1, . . . , T.

The study [89,90] applied the Environmental Kuznets Curve (EKC) hypothesis to estimate the level of ecological degradation. The EKC hypothesis is based on the quadratic function of dependence:

$$\mathrm{CO_2} = \mathrm{f(GDP,\ GDP^2, RE, CT, GI, EO)} \quad (3)$$

where CO_2 is carbon dioxide emissions.

All data were linearised by being taken in logarithm. The logarithmic linear models allowed receiving more accurate findings than linear ones [91]. Thus, the model of the research could be presented as:

$$\mathrm{lnCO_{2_{it}}} = \beta_{0i} + \beta_{1i}\mathrm{lnGDP_{it}} + \beta_{2i}\mathrm{lnGDP^2{}_{it}} + \beta_{3i}\mathrm{lnRE_{it}} + \beta_{4i}\mathrm{lnCT_{it}} + \beta_{5i}\mathrm{lnGI_{it}} + \beta_{6i}\mathrm{lnEO_{it}} + \mu_{it} \quad (4)$$

where $\beta_{1i}, \ldots, \beta_{6i}$ are regression's coefficients which were estimated and explain the elasticity of output related to total real gross fixed capital formation (GFCF), share of renewable energy in final energy consumption, crypto trading (CT), globalisation (GI), and economic openness (EO); β_{0i} is the country-specific intercept; μ is the error term; i = 1, . . . , N; t = 1, . . . , T.

To test the causal relation between variables, the following steps were applied.

At the first stage, the analysis of the data stationarity was applied. For this purpose, the panel unit root test was applied:

$$\Delta \mathrm{y_{it}} = \mathrm{a_i} + \beta_i \mathrm{y_{i,t-1}} + \sum_{j=1}^{P_i} \rho_{ij}\Delta \mathrm{y_{i,t-j}} + \varepsilon_{it} \quad (5)$$

where Δy_{it} is the series for country, P_i is the number of lags selected for the ADF regression, and ε_{it} is the error term i = 1, . . . , N; t = 1, . . . , T.

If the data were stationary, the cointegration between data could be tested by applying the Pedroni and Kao panel cointegration tests (the second stage).

At the third stage, the long-term relationship was checked by applying the FMOLS (Least Square) and DOLS (Dynamic Ordinary Least Square) panel cointegration models.

At the next stage, based on the methodology [89], the study applied Vector Error Correction Models (VECM) to test the causality among selected parameters. Thus, the equations for VECM could be written as:

$$\Delta \ln GDP_{it} = v_{0i} + \sum_{j=1}^{k} v_{1i}\Delta \ln LF_{i,t-j} + \sum_{j=1}^{k} v_{2i}\Delta \ln RE_{i,t-j} + \sum_{j=1}^{k} v_{3i}\Delta \ln GFCG_{i,t-j} + \sum_{j=1}^{k} v_{4i}\Delta \ln CT_{i,t-j} + \sum_{j=1}^{k} v_{5i}\Delta \ln GI_{i,t-j} + \sum_{j=1}^{k} v_{6i}\Delta \ln EO_{i,t-j} + \sum_{i=1}^{k} v_{7i}\Delta \ln GDP_{it-i} + \omega_1 ECT_{t-1} + \mu_{it} \quad (6)$$

$$\Delta \ln LF_{it} = \tau_{0i} + \sum_{j=1}^{k} \tau_{1i}\Delta \ln LF_{i,t-j} + \sum_{j=1}^{k} \tau_{2i}\Delta \ln RE_{i,t-j} + \sum_{j=1}^{k} \tau_{3i}\Delta \ln GFCG_{i,t-j} + \sum_{j=1}^{k} \tau_{4i}\Delta \ln CT_{i,t-j} + \sum_{j=1}^{k} \tau_{5i}\Delta \ln GI_{i,t-j} + \sum_{j=1}^{k} \tau_{6i}\Delta \ln EO_{i,t-j} + \sum_{i=1}^{k} \tau_{7i}\Delta \ln GDP_{it-i} + \omega_2 ECT_{t-1} + \mu_{it} \quad (7)$$

$$\Delta \ln RE_{it} = \theta_{0i} + \sum_{j=1}^{k} \theta_{1i}\Delta \ln LF_{i,t-j} + \sum_{j=1}^{k} \theta_{2i}\Delta \ln RE_{i,t-j} + \sum_{j=1}^{k} \theta_{3i}\Delta \ln GFCG_{i,t-j} + \sum_{j=1}^{k} \theta_{4i}\Delta \ln CT_{i,t-j} + \sum_{j=1}^{k} \theta_{5i}\Delta \ln GI_{i,t-j} + \sum_{j=1}^{k} \theta_{6i}\Delta \ln EO_{i,t-j} + \sum_{i=1}^{k} \theta_{7i}\Delta \ln GDP_{it-i} + \omega_3 ECT_{t-1} + \mu_{it} \quad (8)$$

$$\Delta \ln GFCG_{it} = \phi_{0i} + \sum_{j=1}^{k} \phi_{1i}\Delta \ln LF_{i,t-j} + \sum_{j=1}^{k} \phi_{2i}\Delta \ln RE_{i,t-j} + \sum_{j=1}^{k} \phi_{3i}\Delta \ln GFCG_{i,t-j} + \sum_{j=1}^{k} \phi_{4i}\Delta \ln CT_{i,t-j} + \sum_{j=1}^{k} \phi_{5i}\Delta \ln GI_{i,t-j} + \sum_{j=1}^{k} \phi_{6i}\Delta \ln EO_{i,t-j} + \sum_{i=1}^{k} \phi_{7i}\Delta \ln GDP_{it-i} + \omega_4 ECT_{t-1} + \mu_{it} \quad (9)$$

$$\Delta \ln CT_{it} = \psi_{0i} + \sum_{j=1}^{k} \psi_{1i}\Delta \ln LF_{i,t-j} + \sum_{j=1}^{k} \psi_{2i}\Delta \ln RE_{i,t-j} + \sum_{j=1}^{k} \psi_{3i}\Delta \ln GFCG_{i,t-j} + \sum_{j=1}^{k} \psi_{4i}\Delta \ln CT_{i,t-j} + \sum_{j=1}^{k} \psi_{5i}\Delta \ln GI_{i,t-j} + \sum_{j=1}^{k} \psi_{6i}\Delta \ln EO_{i,t-j} + \sum_{i=1}^{k} \psi_{7i}\Delta \ln GDP_{it-i} + \omega_5 ECT_{t-1} + \mu_{it} \quad (10)$$

where ECT_{t-1} are the lagged error correction terms; μ_{it} is the error terms. ψ, ϕ, θ, τ are the coefficient parameters; Δ is the first difference operator; k is the lagged length of each variable chosen by the Schwarz data criteria (SIC).

Table 1 contains the description of variables and sources.

Table 1. The variables of the research and sources.

Variables	Symbol	Sources
Carbon dioxide emissions	CO_2	Our World in Data [90]
Gross domestic product per capita	GDP	World Data Bank [92]
A share of renewable energy in final energy consumption	RE	Eurostat [93]; Ukrstat [94]
International blockchain transactions received	CT	Crystal Blockchain [95]
Real gross fixed capital formation	GFCF	World Data Bank [92]
Labour force	LF	World Data Bank [92]
Globalisation	GI	KOF Globalisation Index [96]
Economic openness (Trade (% of GDP))	EO	World Data Bank [92]

All calculations were completed using the software EViews. The descriptive statistics of the variables are shown in Table 2.

Table 2. The findings of descriptive statistics of the selected variables.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera
CO_2	3.74×10^8	3.37×10^8	8.31×10^8	1.54×10^8	1.90×10^8	1.275	3.715	13.734
GDP	33,152.39	40,578.64	53,018.63	2124.662	16,392.180	−0.773	2.172	6.023
RE	11.421	11.495	18.267	2.6	5.036	−0.288	1.692	4.004
CT	117,665.5	10.199	4,681,000	0.006	691,092.7	6.347	42.252	3332.823
GFCF	3.66×10^{11}	3.62×10^{11}	8.71×10^{11}	1.45×10^{11}	2.62×10^{11}	0.261	1.799	3.357
LF	26,034,725	25,875,327	44,351,163	9,019,570	10,632,838	0.045	2.175	1.348
GI	84.501	87.185	92.838	70.241	5.744	−0.802	2.869	5.072
EO	88.954	86.246	158.823	54.868	32.627	0.916	2.787	6.657

4. Results

At the first stage, the stationarity of the selected variables was checked by the tests by Levin, Lin and Chu, Im, Pesaran and Shin W-stat, ADF-Fisher Chi-square, and Hadri. The findings of the panel unit root test are shown in Table 3.

Table 3. The empirical results of data stationarity using the panel unit root test (at 1st difference).

Variables	Statistical Values	Levin, Lin and Chu	Im, Pesaran and Shin W-Stat	ADF-Fisher Chi-Square	Hadri
CO_2	statistics	−1.334	1.248	14.034	2.216
	probability	0.091	0.089	0.059	0.000
GDP	statistics	−14.937	−3.870	47.044	2.437
	probability	0.000	0.000	0.000	0.007
RE	statistics	−9.527	−2.248	38.056	2.991
	probability	0.000	0.012	0.001	0.001
CT	statistics	−3.629	−0.952	41.061	5.916
	probability	0.000	0.017	0.000	0.000
GFCF	statistics	−8.942	−1.866	31.092	6.091
	probability	0.000	0.031	0.013	0.000
LF	statistics	−1.825	1.929	6.060	3.589
	probability	0.034	0.073	0.087	0.000
GI	statistics	−8.190	−4.337	68.398	4.622
	probability	0.000	0.003	0.000	0.000
OE	statistics	−1.789	1.327	23.990	3.789
	probability	0.036	0.009	0.089	0.000

Considering the findings, the following variables were stationary at a level: GDP, CT, GFCF, and GI in Levin, Lin and Chu test; GDP and GI in Im, Pesaran and Shin W-stat; GDP and GI in ADF-Fisher Chi-square; and CO_2, RE, GFCF, LF, GI, and OE in PP-Fisher Chi-square. However, all variables become stationary at the first level according to all tests (Table 3). This allowed rejecting the hypothesis of non-stationarity at 1% significance. If the data were stationary, the cointegration test could be applied. The findings of the cointegration test using the Pedroni panel cointegration technique are shown in Table 4.

The findings of the Pedroni panel cointegration test proved that6 out of 11 probabilities of the test had statistical significance at 1% and 5% levels. It allowed rejecting the hypothesis of non-cointegration between the Series: GDP, LF, GFCF, RE, CT, GI, EO and Series: CO_2, GDP, RE, CT, GI, EO. Furthermore, it allowed confirming the long-term relationship between the variables analysed. Table 5 contains the findings of the Kao Residual Cointegration Test.

Table 4. The empirical results of the Pedroni panel cointegration.

Statistical Values	Panel v-Statistic	Panel Rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Statistic Values	Group Rho-Statistic	Group PP-Statistic	Group ADF-Statistic
Series: GDP, LF, GFCF, RE, CT, GI, EO								
		Within-dimension				*Between-dimension*		
statistics	−0.797	1.905	−4.372	−2.409	statistics	2.552	−8.918	−0.504
probability	0.787	0.972	0.000	0.008	probability	0.995	0.000	0.007
		Weighted						
statistics	−1.416	1.352	−6.527	−1.979				
probability	0.922	0.912	0.000	0.024				
Series: CO_2, GDP, RE, CT, GI, EO								
statistics	2.922	0.518	1.117	1.493	statistics	1.805	1.627	1.582
probability	0.002	0.008	0.068	0.932	probability	0.065	0.948	0.943
		Weighted						
statistics	3.461	0.426	1.122	0.777				
probability	0.000	0.065	0.869	0.781				

Table 5. Kao Residual Cointegration Test.

Series: GDP, LF, GFCF, RE, CT, GI, EO Model Specification: No Deterministic Trend	*t*-Statistic	Prob.
ADF	−2.111216	0.0174
Residual variance	0.001322	
HAC variance	0.000894	
Series: CO_2, GDP, RE, CT, GI, EO Model specification: No deterministic trend		
ADF	−3.49021	0.0002
Residual variance	0.008482	
HAC variance	0.007344	

The empirical results (Table 5) allowed rejecting the null hypothesis—no cointegration at the level of 1% significance for Series: CO_2, GDP, RE, CT, GI, EO and 5% for Series: GDP, LF, GFCF, RE, CT, GI, EO. It confirmed the long-term relationship between the analysed variables for selected countries.

Considering the findings of the tests mentioned above, the FMOLS and DOLS panel cointegration techniques could be applied. Tables 6 and 7 contain the findings of FMOLS and DOLS panel cointegration techniques.

The findings in Table 6 allowed concluding that the increase in the real gross fixed capital formation, the share of renewable energies in total energy consumption and crypto trading led to GDP growth by 0.802 (significance at 1%), 0.064 (significance at 5%), and 0.017 (significance at 10%), respectively. The increase in gross domestic product per capita and real gross fixed capital formation led to RE growth to 2.214 and 2.558. However, the LF growth led to the decline in RE by 2.094. It should be noted that no parameters influenced crypto trading. However, the growth of crypto trading by 1% leads to the CO_2 increase by 0.019.

The findings of long-term relationship analysis confirmed that both tests FMOLS and DOLS had similar results (Table 7). A 1% increase in the share of renewable energies in total energy consumption, crypto trading, real gross fixed capital formation, labour force led to GDP growth by 0.208 (significance at 1%), 0.006 (significance at 5%), 1.018 (significance at 1%), and 0.941 (significance at 1%), respectively. At the same time, a 1% increase in crypto trading provoked the increase in carbon dioxide emissions by 0.013 (significance at 1%) and gross fixed capital formation by 0.005 (significance at 10%). Moreover, a 1% growth of crypto trading does not influence the change in the share of renewable energy in the total energy consumption. The elasticity of carbon dioxide emissions relative to real income and quadratic real income is positive and negative, respectively. It allows confirming the EKC hypothesis for Equation (4). Thus, the GDP growth results in the environment improvement after the countries analysed have overcome the threshold. In this case, the crypto trade's positive and statistically significant impact on GDP, the rapid growth of IT, and activisation of information society influence the government capacity to improve the environment and achieve the targets on the renewable energy share in the long-term.

Table 6. The findings of the FMOLS panel cointegration technique.

Dependent Variables	Independent Variables	Coefficient	Probability	Dependent Variables	Independent Variables	Coefficient	Probability
GDP	GFCF	0.802	0.002	RE	GDP	2.214	0.042
	LF	−1.598	0.498		GFCF	2.558	0.024
	RE	0.064	0.027		LF	−2.094	0.075
	CT	0.017	0.081		CT	−0.024	0.271
	GI	−0.126	0.937		GI	−1.290	0.303
	OE	0.519	0.348		OE	−0.177	0.593
GFCF	GDP	0.840	0.001	CT	GDP	7.533	0.423
	LF	1.845	0.378		GFCF	−5.842	0.552
	RE	0.034	0.846		LF	6.742	0.461
	CT	0.010	0.268		RE	−1.492	0.623
	GI	−0.688	0.621		GI	−3.732	0.800
	OE	−0.298	0.569		OE	−3.428	0.369
LF	GDP	−1.026	0.000	CO_2	GDP	−5.722	0.316
	GFCF	1.079	0.000		GDP^2	0.235	0.359
	RE	−0.207	0.129		RE	1.043	0.026
	CT	0.005	0.580		CT	0.019	0.071
	GI	−0.057	0.915		GI	11.939	0.106
	OE	−0.033	0.803		EO	−0.451	0.366

Table 7. The findings of the DOLS panel cointegration technique.

Dependent Variables	Independent Variables	Coefficient	Probability	Dependent Variables	Independent Variables	Coefficient	Probability
GDP	GFCF	1.018	0.000	RE	GDP	1.479	0.006
	LF	0.941	0.000		GFCF	1.864	0.000
	RE	0.208	0.002		LF	−1.409	0.007
	CT	0.006	0.078		CT	−0.003	0.870
	GI	0.005	0.990		GI	−1.662	0.155
	OE	−0.021	0.838		OE	−0.045	0.885
GFCF	GDP	0.932	0.000	CT	GDP	7.529	0.268
	LF	0.873	0.000		GFCF	−6.314	0.377
	RE	0.240	0.000		LF	6.482	0.325
	CT	0.005	0.085		RE	−0.484	0.852
	GI	0.347	0.367		GI	−1.896	0.890
	OE	−0.037	0.709		OE	−1.964	0.575
LF	GDP	1.010	0.000	CO_2	GDP	1.239	0.026
	GFCF	1.024	0.000		GDP^2	−0.081	0.502
	RE	0.213	0.003		RE	0.382	0.239
	CT	0.006	0.334		CT	0.013	0.043
	GI	0.277	0.510		GI	3.814	0.197
	OE	−0.078	0.467		EO	−0.520	0.142

At the next stage, the study applied VECM Granger causality analysis (Table 8).

Table 8. The VECM Granger causality analysis.

Variables	Characteristics	Short-Term							Long-Term
		D(GDP)	D(GFCF)	D(LF)	D(RE)	D(CT)	D(GI)	D(OE)	ECT_{t-1}
D(GDP)	statistics	-	0.636	0.985	0.113	0.000	−0.726	−0.732	−0.426
	probability		0.000	0.556	0.073	0.070	0.349	0.055	0.010
D(GFCF)	statistics	0.771	-	0.723	0.185	0.009	0.360	0.506	−0.176
	probability	0.000		0.695	0.286	0.096	0.675	0.238	0.354
D(LF)	statistics	0.012	0.007	-	0.007	−0.001	0.072	0.007	−0.040
	probability	0.556	0.695		0.699	0.267	0.407	0.874	0.030
D(RE)	statistics	0.158	0.212	0.764	-	0.002	−0.257	−0.811	−0.297
	probability	0.073	0.086	0.699		0.720	0.780	0.073	0.042
D(CT)	statistics	0.259	10.105	−67.307	2.076	-	56.250	11.184	−12.373
	probability	0.070	0.096	0.267	0.720		0.041	0.435	0.044
D(GI)	statistics	−0.042	0.017	0.332	−0.011	0.002	-	−0.065	−0.043
	probability	0.349	0.675	0.407	0.780	0.041		0.490	0.305
D(OE)	statistics	0.166	0.094	0.127	−0.132	0.002	-0.256	-	0.018
	probability	0.055	0.238	0.874	0.073	0.435	0.490		0.829

The first column in Table 8 shows the GDP impact on other variables, the second on the real gross fixed capital formation, and the third on the labour force. The fourth and fifth columns demonstrate the impact of the share of renewable energies in the total energy consumption and crypto trading on other variables. The sixth and seventh columns show the impact of globalisation and economic openness on other variables. The last column shows the long-term relationship between variables. Thus, the findings in the first column confirm that GDP had a positive and statistically significant impact on real gross fixed capital formation, the share of renewable energies in total energy consumption, crypto trading, and economic openness. At the same time, crypto trading had a positive and statistically significant impact on GDP, real gross fixed capital formation, and globalisation. However, in the long-term, the relationship between crypto trading and the share of renewable energies in the total energy consumption was not confirmed by the empirical results. The error correction terms were negative and statistically significant for GDP, labour force, renewable energies, and crypto trading models in the long-term. It showed that short-term adjustments to equilibrium were driven by adjustment back to the long-term equilibrium through the error correction term.

The Pairwise Granger Causality Tests (Table 9) allowed concluding the bidirectional causality between GFCF and GDP, RE and GDP, CT and GDP, GI and GDP, and CT and CO_2. At the same time, the unidirectional causality was among GDP → LF, GFCF → RE, GFCF → CT, GFCF → GI, OE → GFCF, GI → LF, CO_2 → GDP, and RE → CO_2.

Thus, it confirmed no bidirectional or unidirectional causality between crypto trading and renewable energy. It should be noted that an increase in renewable energy consumption requires a significant investment in the relevant infrastructure and long-term planning. Moreover, the renewable energy, crypto, and real income could be used for further forecasting of carbon dioxide emissions. The findings of Pairwise Granger Causality Tests jointly with DOLS and FMOLS confirmed the Granger causality. It proved that the high rates of renewable energy development and crypto trade could negatively influence carbon dioxide emissions in the long-term for the selected countries. The bidirectional causality between RE and GDP and CT and GDP allowed confirming that the decline in renewable energy and crypto trade could hinder economic development.

Table 9. The empirical results of Pairwise Granger Causality Tests.

H_0	F-Stat.	Prob.	H_0	F-Stat.	Prob.	H_0	F-Stat.	Prob.	H_0	F-Stat.	Prob.
GFCF → GDP	4.470	0.018	GFCF → LF	1.383	0.264	GI → LF	6.631	0.004	CT → OE	1.935	0.161
GDP → GFCF	5.808	0.006	RE → GFCF	1.706	0.196	LF → GI	1.527	0.234	OE → GI	0.240	0.788
LF → GDP	0.288	0.751	GFCF → RE	5.608	0.008	OE → LF	1.987	0.152	GI → OE	1.393	0.264
GDP → LF	2.419	0.003	CT → GFCF	1.824	0.178	LF → OE	1.058	0.358	GDP → CO_2	0.239	0.789
RE → GDP	2.527	0.094	GFCF → CT	4.286	0.022	CT → RE	0.676	0.516	CO_2 → GDP	14.476	0.000
GDP → RE	2.672	0.083	GI → GFCF	1.405	0.261	RE → CT	1.328	0.279	RE → CO_2	4.436	0.019
CT → GDP	2.714	0.082	GFCF → GI	2.629	0.089	GI → RE	0.687	0.511	CO_2 → RE	0.669	0.518
GDP → CT	4.119	0.026	OE → GFCF	6.857	0.003	RE → GI	0.607	0.552	CT → CO_2	3.492	0.043
GI → GDP	3.285	0.051	GFCF → OE	0.305	0.739	OE → RE	2.430	0.102	CO_2 → CT	2.656	0.086
GDP → GI	6.649	0.004	RE → LF	0.497	0.613	RE → OE	0.044	0.957	GI → CO_2	0.280	0.757
OE → GDP	0.259	0.773	LF → RE	2.133	0.133	GI → CT	0.361	0.701	CO_2 → GI	1.971	0.157
GDP → OE	0.349	0.708	CT → LF	0.524	0.597	CT → GI	0.165	0.849	OE → CO_2	0.784	0.464
LF → GFCF	0.367	0.695	LF → CT	1.183	0.320	OE → CT	1.250	0.300	CO_2 → OE	0.157	0.855

Note: →—is not Granger cause; H_0—null hypothesis; F-Stat.—F-Statistic.

5. Discussion and Conclusions

The rapid growth of information technology and its penetration in all sectors justified the crypto market and currency development. In this case, a lot of scientific discussions focus on the economic, ecological, and energy efficiency of cryptocurrency. The empirical findings confirmed the bidirectional causality between the share of renewable energy in the final energy consumption and gross domestic product per capita, international blockchain transactions received and gross domestic product per capita, carbon dioxide emissions and unidirectional causality from real gross fixed capital formation to share of renewable energy in final energy consumption, international blockchain transactions received, and the share of renewable energy in the final energy consumption to carbon dioxide emissions.

Moreover, considering the findings, the increase in crypto trading led to enhancing GDP, real gross fixed capital formation, and globalisation. However, in the long-term, the relationship between crypto trading and the share of renewable energies in the total energy consumption was not confirmed by the empirical results. Similar conclusions were obtained in the studies [32–34,37,38]. However, the papers [74,84] justified the opposite view on energy consumption and crypto trading development.

The core reasons for the opposite conclusions in the long-term relationship could be explained and caused by the convergence of government policies to support the cryptocurrency market and green transformation. Moreover, the crypto traders' social responsibility plays a crucial role in decreasing carbon dioxide emissions. Thus, the government should promote the principles of Create Share Value theory [97]. The crypto traders should understand that profitability and socially responsible behaviour are interdependent. Thus, the countries analysed differ in the level of social responsibility penetration among businesses. Furthermore, the gaps and social distance between society and crypto traders provoked the misunderstanding and limitation of green technologies' implementation. Thus, the collaboration between crypto traders and local community allows diminishing the negative effect on the environment [98].

Furthermore, the country's technological readiness influences efficiency and capability to apply smart technologies. It has a direct effect both on the carbon dioxide emissions and on the crypto trade development.

Considering the findings and recommendations in the studies [69–74,78], crypto traders should implement innovative technology, hardware, and protocols for mining and storing cryptocurrency. It allowed eliminating the energy over-consumption and environmental degradation from crypto trading. Although the core feature of cryptocurrency is freedom and absence of government regulation, the government should try to implement effective instruments to encourage crypto traders to direct part of their profit towards solving ecological problems. Moreover, the green tax on carbon dioxide emissions from crypto trading could be provided as proposed by the studies [99,100]. It would allow accumulation of additional funding to overcome the damage from carbon dioxide emissions and to extend green energy.

Furthermore, according to the paper [101], the EU climate policy on decarbonisation should be updated considering the rapid growth of the digital economy. However, for further directions, it is necessary to extend the number of countries and time for analysis. It allows empirically justified recommendations on approaching cryptocurrency development without increasing the negative impact on the environment. Moreover, it is necessary to analyse the impact of crypto trading on land and water pollution.

Author Contributions: Conceptualisation, J.K. and K.M.; methodology, R.M.; validation, R.M., K.M. and J.K.; formal analysis, R.M.; resources, R.M., K.M. and J.K.; data curation, R.M.; writing—original draft preparation, R.M.; writing—review and editing, R.M.; visualisation, R.M.; supervision, R.M.; project administration R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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