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Impact of Economic Growth, Agriculture, and Primary Energy Consumption on Carbon Dioxide Emissions in the Czech Republic

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Abstract: One of the primary difficulties we have recently is environmental degradation. The deterioration of the environment was visible in the rise in carbon dioxide emissions, which has a detrimental impact on various life matters. A variety of factors caused this growth. Inappropriate human behaviors caused the majority of them. This study aimed to ascertain how energy consumption and economic growth with its components in the Czech Republic, affected CO_2 emissions. The relationship between CO_2 emissions, economic growth, agriculture, and energy consumption was studied using econometric analysis, specifically the Johansen, Vector Error Correction (VEC) Model, and granger causality. The findings revealed that all variables are cointegrated. Economic growth, agricultural, and energy consumption output are all positively correlated with CO_2 emissions. There is a unidirectional Granger Causality between economic growth, and Agriculture towards carbon dioxide emissions. A unidirectional Granger Causality agriculture towards economic growth, and energy consumption. In addition, there is no Granger Causality between energy consumption and CO_2 emissions, and economic growth. This is the first study to use the most recent data to empirically evaluate the environmental impact of economic growth and energy use in the Czech Republic. This study includes pertinent advice for reducing emission ns and supporting the environment by increasing renewable energy sources and adhering to the Czech Ministry of Environment's strategy.

Keywords: economic growth; energy; carbon dioxide; Johansen; agriculture; Czech Republic

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1. Introduction

The global economy is particularly dynamic and significant since it deals with historical and recent chaotic events that have plagued the world, such as the worldwide COVID-19 pandemic and geopolitical uncertainty. According to the International Monetary Fund's (IMF) previous three annual reports, the globe is still working hard to achieve sustainable economic growth to overcome consecutive crises following the 2030 Sustainable Development Goals [1–3]. In 2021, the world economy experienced a considerable recovery as the economy appeared to recover from the Corona virus-induced slump. The global economic production was expected to be 5.9%, a significant increase over the 2020 ratios. Economic growth in advanced economies was predicted to be 5.0 percent, while growth in emerging and developing nations was estimated to be 6.5 percent [4,5]. The economy is likely to be harmed today due to the continual rise in the price of goods and services, particularly now with political uncertainty and violence in several regions, particularly between Ukraine and Russia [6]. To attain economic stability and meet global demands, the world has continued to engage in activities that primarily result in rising greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2) [7].

Climate change, primarily caused by a rise in GHG emissions, results from economic growth, represented by energy consumption because all economic activities are inextricably linked to energy consumption [8]. On the other hand, energy is at the top of the list of industries that emit greenhouse gases. According to the World Resources Institute, energy use accounted for 73.2 percent of total emissions in 2016 [8].

The impact of economic growth, mainly through energy use, on environmental deterioration and, indirectly, greenhouse gas emissions have been thoroughly studied and examined by [9]. The European Commission (CE) aspires to reduce greenhouse gas emissions and turn European economies into greener economies by assessing present reality and determining the impacts on emissions [9]. The European Union has created a 10-year plan to cut greenhouse gas emissions, starting with a 20% cut in 2020 compared to 1990, a 40% cut in 2030, a 60% cut in 2040, and an 80% to 90% cut in 2050. Many initiatives, agreements, and treaties have been undertaken under the auspices of international bodies to achieve these goals, including the Kyoto and Montreal Protocols, the United Nations Convention on Climate Change, European Climate Law, the Nairobi Conference, and, most recently, the Paris Agreement [10].

In the Czech context, between 1990 and 2020, there was no significant rise in the population of the Czech Republic. Over thirty years, the overall population increased by 364,230 individuals, or an average of 12,141 people, according to the world bank. The Czech Republic lies in the middle of ranking European countries in terms of wealth. Superior to Eastern European countries and many Central European countries [11]. According to the Statista database, the Czech Republic ranks 18 among EU countries in 2021 GDP. The Czech Republic achieved significant economic growth between 1990 and 2020 as the GDP increased from 120.14 billion USD in 1990 to 126.27 billion USD in 2000 [12].

In comparison, the significant increase happened after 2000 as GDP reached 203.09 billion USD in 2020, according to the world bank. On the one hand, since the dissolution of the Soviet Union and the collapse of many inefficient enterprises, and on the other hand, since the improvement in energy efficiency and the launch of new carbon-free energy sources, greenhouse gas emissions have been steadily declining [13]. The Global Carbon Project's figures are backed by what Dubravska et al. concluded in their research. Carbon dioxide emissions fell by 25.4 percent in 2000 compared to 1990 and 31.7 percent in 2020 compared to the same base year [14].

In an in-depth bibliographic survey, no research on the impact of energy consumption and economic growth with its three main components on the environment through its effects on CO_2 emissions at a macro level has yet been conducted in the Czech Republic using the most recent published data; as a result, this article will provide a visual representation of the crucial contribution in the call to reduce carbon dioxide emissions by promoting the use of sustainable renewable energy solutions and environmentally friendly economy transform.

The paper aimed to evaluate the impact of economic growth, agriculture, and primary energy consumption on carbon dioxide emissions. The goal was also to help Czech authorities develop and implement policies contributing to the Paris Agreement. The following is the format of the paper: The study is divided into five sections: Section 1 has the introduction; Section 2 is a review of the literature; Section 3 contains the data and technique utilized; Section 4 includes the results and discussion, and Section 5 is the conclusion.

2. Literature Review

Numerous studies have examined the connection between economic growth, energy use, and CO_2 emissions. The authors sought to summarize studies using different approaches and for a single country per study.

A study was conducted in Romania to check the dynamic relationship between economic growth, energy consumption, and CO_2 emissions for the period 1980–2010 by using the ARDL approach. The results indicate a long-run relationship between economic growth, energy consumption, and energy pollutants. And they concluded that energy consumption significantly contributes to energy pollutants [15].

A couple of papers studied the impact of energy consumption on economic growth in Spain and Turkey. Authors in the Spanish paper used Multivariate cointegration from 1984–2003, and they indicated unidirectional causality from energy consumption toward economic growth [16]. The Turkish paper was conducted using the same approach for a longer duration, 1960–2003. However, there was no causality between energy consumption and economic growth [17].

Shifting to African studies, A paper which discussed Ugandan case to examine the impact of energy consumption and GDP on CO_2 emissions from 1986–2018. The methodology used was Vector Error Correction techniques. The Johansen cointegration test presents a long-run relationship between the variables, and the Granger causality shows a unidirectional causality from GDP to CO_2 emission. In contrast, it shows that energy consumption does not Granger cause CO_2 emission [18].

Two different studies covered Nigeria. The first paper examined the period 1970–2010 and discussed the relationship between energy consumption, CO_2 emissions, and GDP performing ARDL. The results show short and long-run relationships between energy consumption, CO_2 emissions, and GDP. CO_2 emissions significantly positively impact GDP in both the short and long run. At the same time, energy consumption significantly negatively impacts GDP in the short run [19].

Authors in the second paper added more variables such as crude oil and Agriculture. Besides, they changed the study duration to 1981–2014. authors used ARDL and Granger causality tests. The results indicated that the amount of CO_2 released tends to rise as the economy's output, and industrial sectors grow. The results also showed no significant relationship between agriculture and CO_2 emissions. Granger causality tests indicated that there is granger causality for $CO_2 \Rightarrow$ Agriculture. GDP$\Rightarrow$ Crude oil production. GDP$\Rightarrow$ Electricity consumption. Agriculture $\Rightarrow$ GDP. $CO_2 \Rightarrow$ GDP [20].

Ghana was also one of the studied countries for the relationship between carbon dioxide and agriculture. Two techniques were used to investigate the association from 1961 to 2012. Both tests showed a causal relationship between CO_2 emissions and agriculture [21].

In the case of South Africa, Johansen and VECM tests between 1971–2013 were performed to study the relationship between energy consumption, CO_2 emission, economic growth, trade openness, and urbanization. Results show a long-run relationship between all variables. A bidirectional causality between energy consumption and economic growth was found by (VECM) Granger causality. However, a unidirectional causality was found as follows: $CO_2 \Rightarrow$ economic growth. Urbanization & trade openness $\Rightarrow$ energy consumption. Energy consumption, CO_2 emissions, trade openness, and urbanization $\Rightarrow$ economic growth [22].

For the Asian studies in India, a paper conducted to investigate the relationship between energy consumption, economic growth, and carbon emissions from 1971 to 2009. The Johansen cointegration technique and the (VECM) Granger-causality test were performed. The results showed a long-term relationship between the studied variables. Besides, a unidirectional causality flows from energy consumption and CO_2 emissions toward economic growth [23].

Over the period 1972 to 2008, A study in Pakistan investigated the relationship between CO_2 emissions, energy consumption, and economic growth. Johansen's cointegration technique was implemented. The study confirmed the existence of EKC as there is a quadratic long-run relationship between carbon emissions and income. In addition, energy consumption and foreign trade positively impact CO_2 emissions. In the short run, the results were contradictory as they showed no existence of the EKC [24].

In Malaysia, a study was conducted to check the contribution of renewable energy to the verification of dynamic CO_2 emissions and GDP interaction over the period 1971–2015, utilizing ARDL and VECM Granger causality tests. The results show that the causality runs from CO_2 emissions to renewable energy, and there is a significant negative relationship between renewable energy and CO_2 emissions [25].

Throughout 1980 and 2014, ARDL and (VECM) Granger causality approaches were performed to indicate the relationships among CO_2 emissions, GDP, foreign trade, and energy production in China. These variables showed a long-term association. GDP growth and non-renewable energy production increase CO_2 emissions, but foreign trade and renewable energy have the opposite effect. According to the short-run Granger causality tests, there are bidirectional causal relationships connecting foreign exchange, CO_2 emissions, and renewable and non-renewable energy [26].

Qatar was one of the important case studies where a paper examined the effects of GDP, FDI, Energy consumption, and financial development on environmental quality from 1980–2016. The authors utilized ARDL and Toda-Yamamoto causality tests. The results determined a negative long-run effect of energy consumption on ecological quality. FDI has a negative long-run effect on environmental quality when measured only by one of the indicators. While no significant impact on financial development on the environment. Three variables—economic growth, energy use, financial development, and all three environmental quality indicators—are found to be causally related in both directions [27].

3. Materials and Methods

This empirical study's annual data (1995 to 2018) was collected from World Bank's and our world in data. Annual data throughout the period 1995–2018 were used in this study. The studied duration matches or exceeded the duration of many previous studies [16,28–30]. Besides, the specified period includes all the data published for the study variables, and no period has been omitted or deleted.

EVIEWS 12 has been used to perform econometric analyses. CO_2 emissions and Primary energy consumption data were obtained from our world in a data database [14,28]. Our world in data database took the data of CO_2 emissions from the Global Carbon Project. Economic growth, GDP constant 2015 USD; agricultural, forestry, and fisheries value-added constant 2015 USD; industry value-added regular 2015 USD; services value-added constant 2015 USD data were taken from the world bank database [29–32]. The used variables were carbon dioxide (CO_2) emissions: Annual production-based emissions of carbon dioxide (CO_2), measured in tonnes. Gross domestic product (GDP) at purchaser's prices is the total of the gross value contributed by all resident producers in the economy, plus any applicable product taxes minus any subsidies not included in the product value. Agriculture, forestry, and fishing corresponds to International Standard Industrial Classification (ISIC) divisions 01–03 and includes forestry, hunting, fishing, and cultivation of crops and livestock production. Data are in constant 2015 prices, expressed in US dollars.

Services correspond to ISIC divisions 45–99. They include value added in wholesale and retail trade (including hotels and restaurants), transport, government, financial, professional, and personal services such as education, health care, and real estate. Also included are imputed bank service charges, import duties, any statistical discrepancies noted by national compilers, and differences arising from rescaling. Data are in constant 2015 prices, expressed in US dollars. Industry (including construction) corresponds to ISIC divisions 05–43 and includes manufacturing (ISIC divisions 10–33). It comprises value added in mining, manufacturing, construction, electricity, water, and gas. Data are in constant 2015 prices, expressed in US dollars. Primary energy consumption is expressed in terawatt-hours per year and was obtained from Our World in Data. It is estimated without considering the depreciation of manufactured assets or natural resource depletion and degradation. Data is provided in US dollars at constant 2015 prices [14,28–32].

Our empirical model examines the impact of economic growth, agriculture, and primary energy consumption on carbon dioxide emissions. The functional link between these variables yields the result of these variables functional connection is:

$$CO_2 \ = F\,(GDP,\ AGR,,\ PEC) \tag{1}$$

To enrich the paper and make the discussion more fruitful, authors added the industry and services as additional variables which will be reflected as extra functions, tests, and results. Everything related to this addition does not fall within the objective of the study. The functions will be mentioned hereunder while the tests and results will be shown in the Appendix A.

$$CO_2 = F\,(GDP,\ AGR,\ PEC,\ IND,\ SERV) \quad (2)$$

CO_2, GDP, AGR, PEC, IND, and SERV represent carbon dioxide emissions, economic growth, Agriculture, primary energy consumption, Industry, and Services.

The stochastic form of the model is

$$CO_2 = a_0 + a_1GDP + a_2AGR + a_3PEC + \mu_t \quad (3)$$

where = a_0, a_1, a_2, and a_3, are coefficients for intercept, GDP, AGR, and PEC, respectively, and μ_t the stochastic term. After adding industry and services variables, the stochastic form of the model is

$$CO_2 = a_0 + a_1GDP + a_2AGR + a_3PEC + a_4IND + a_5SERV + \mu_t \quad (4)$$

where = a_0, a_1, a_2, a_3, a_4, and a_5 are coefficients for intercept, GDP, AGR, PEC, IND, and SERV, respectively, and μ_t the stochastic term.

All equations represent the used model prepared by the authors and used in previous studies [33].

CO_2 emissions, GDP, and Energy consumption were adopted in previous studies [34–39]. However, to make the study unique and valuable, the authors added agriculture on top of the GDP and energy consumption. This study is novel because it explains the causality between carbon dioxide emissions and GDP, and energy consumption and goes beyond it to explain the relationship and causation between emissions and each component separately in the main results and Appendix A.

The natural logarithmic transformation was used for Equation (1), interpreted as elasticities. The transformation yields the following equation:

$$LnCO_2 = a_0 + a_1LnGDP + a_2LnAGR + a_3LnPEC \quad (5)$$

The natural logarithmic transformation was used for Equation (2), interpreted as elasticities. The transformation yields the following equation:

$$LnCO_2 = a_0 + a_1LnGDP + a_2LnAGR + a_3LnPEC + a_4LnIND + a_5LnSERV \quad (6)$$

where = a_0, a_1, a_2, a_3, a_4, and a_5 are coefficients.

A unit root test was implemented to give the upcoming steps for reaching the paper goal as a first step to checking the required econometric analysis. The widely used Augmented Dickey-Fuller was applied to determine whether the variables had unit roots. H0 suggests that it is not stationary and has a unit root, while the alternative hypotheses indicate that a series is stationary [40]. The ADF stationery will be determined in further steps.

Engle & Granger and Johansen & Jeselius [41,42] have limited the cointegration steps to variables of the same order of integration, I(1). While ARDL can be used when the variables have an order of integration I(0), I(1), or a mix of both, without having any I(2) or higher [43]. We used Johansen cointegration test (Johansen and Juselius, 1990). It determines whether long-run cointegrating equations exist between or among the variables in the I(1) series. The variables are in natural logarithmic form, and the long-term relationship is examined using the log converted variables. The Johansen and Juselius cointegration model is written as:

$$\Delta Y_t = \varphi + \pi Y_{t-1} + \sum_{i-1}^{P-1} \Gamma_i \Delta Y_{t-1} + \mu_t \quad (7)$$

where π and Γ_i are coefficient matrices, Δ is the difference operator, and P is the lag order selected.

Two likelihood ratio tests—the trace and max eigenvalue tests—are used in the Johansen and Juselius cointegration, and they are computed as follows:

$$T(r) = -T\sum_{i=r+1}^{n} Ln(1-\lambda_i) \tag{8}$$

$$\lambda_{max}(r, r+1) = -T\ Ln(1-\lambda_{r+1}) \tag{9}$$

where λ_i is the expected eigenvalue of the characteristic roots, and T is the sample size in the λ_{trac} test.

When one or more cointegrating vectors are present, the Johansen and Juselius cointegration test show evidence of long-run equilibrium between or among the variables. The following null hypothesis was found to determine the relationship:

H0: *No equation for cointegrating (s).*

The 5% level of significance is the basis for the choice criterion. The null is rejected if the sum of trac and max exceeds the 5% critical value. If not, we are unable to reject the null. If n variables are all unit rooted, then there can only be a maximum of $n-1$ cointegrating vectors [43]. The following describes the VECM model used in this research:

$$\Delta \mathrm{Y_t} = \theta_0 + \sum_{i=1}^{k-1} \theta_i \Delta \mathrm{Y}_{t-1} + \propto \beta^{\mathrm{Y}_{t-k}} + \varepsilon_t \tag{10}$$

where Δ is the difference operator, Y_t is (LCO_2, LGDP, LAGR, LPEC), θ stands for the intercept, and ε is the vector of the white noise process.

Although the presence of cointegration suggests a causal relationship between the variables, it does not reveal its direction. The VECM determines the causal relationships between CO_2 emissions, economic growth, agriculture, and energy use [43]. Following is a presentation of the empirical equations for Granger-causality:

$$\mathrm{Y}_t = \sum_{i=1}^{m} \alpha_i Y_{t-\mathrm{i}} + \sum_{j=1}^{m} \beta_j X_{t-j} + \varepsilon_{1t} \tag{11}$$

$$\mathrm{X}_t = \sum_{i=1}^{m} \rho_i X_{\mathrm{t-i}} + \sum_{j=1}^{m} \sigma_j Y_{t-j} + \varepsilon_{2t} \tag{12}$$

The causality might flow both ways or in either direction. According to this paradigm, a period value of x(y) results in y(x).

β_j and σ_j are a measure of the influence of $x_t - j$ ($y_t - j$) on $y_t - j$ ($x_t - j$) If H0: $\beta_j = 0$ ($H0$: $\sigma_j = 0$) is denied, then this exists Granger causality between the two variables.

Continuing the quality checks after evaluating the results of Johansen, and VECM tests, a post-estimation model diagnosis can be conducted. The primary purpose is to test the absence of heteroskedasticity and the presence of normality. H0 indicates the absence of heteroskedasticity and the presence of normality [44].

4. Results

4.1. Unit Root Test

In this empirical study, we used Augmented Dickey-Fuller Stationary unit root tests to check for stationarity at each variable's level. Table 1 presents that all factors are nonstationary at their level but stationary at their first differences.

Table 1. Unit root results.

Variable	Level		1st Difference	
	ADF Statistics	Results	ADF Statistics	Results
CO_2	−2.203	Nonstationary	−4.782 **	Stationary
GDP	−2.392	Nonstationary	−3.105 **	Stationary
IND	−1.721	Nonstationary	−3.831 **	Stationary
AGR	−3.004	Nonstationary	−5.983 **	Stationary
SERV	−2.105	Nonstationary	−3.292 **	Stationary
PEC	−1.624	Nonstationary	−4.539 **	Stationary

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021). Note: ADF is tested with a constant trend. ** significance at the 5% level.

4.2. Optimal Lag Length Structure

One of the most critical issues in time series analysis is choosing the best lag for a limited number of data (Hamilton, 2020). The choice of a lag structure in VECM is a matter of empirical investigation since either an excessive or inadequate fit of the model with lag leads to false results and negligible coefficients. Therefore, an Optimal Lag Length Structure was performed.

In order to choose the best lag structure for this study, we take into account the Hannan-Quinn information criterion (HQ), Schwarz information criterion (SC), Akaike information criterion (AIC), and Final prediction error (FPE). The findings are shown in Table 2, where one is the ideal lag length determined by the criteria. Since we are working with 24-year annual observations, this is appropriate.

Table 2. Optimal lag selection criteria.

Lag	FPO	AIC	SC	HQ
0	5.8	−9.7	−9.70	−9.86
1	2.46	−15.4	−14.4	−15.1
2	1.10 *	−16.3 *	−145 *	−15.9 *

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021). * Indicates lag order selected by the criterion. HQ: Hannan-Quinn information criterion, SC: Schwarz information criterion, AIC: Akaike information criterion, and FPE: Final prediction error.

The Johansen cointegration test, created by Johansen, is used to determine whether long-run cointegration exists (1988). It was done to determine whether the series are linearly connected. If short-term shocks in this environment frequently impact the different sequences, they may converge in the long run. In the case of non-cointegrated series, only the Vector Auto-Regressive (VAR) model is estimated.

In the Johansen cointegration test, the null hypothesis denotes the absence of a cointegrating equation, and the 5% significance level is used to determine the outcome. The null hypothesis is rejected if the trace and maximum statistics have values higher than the 5% critical value. Otherwise, we are unable to rule out the null hypothesis.

The Johansen unrestricted integrated rank test is shown in Tables 3 and 4. Given that the values of the trace statistic (trace) and the maximum eigenvalue (max) are higher than the threshold of 5%, we reject the null hypothesis that there is no cointegrating equation. We get to the conclusion that a long-run cointegration equation exists.

The long-run equation may be estimated in the Vector Error Correction (VEC) Model framework since all the variables are cointegrated in Trace and Max-Eigen statistics. According to our estimation, Table 5 shows the normalized Johansen cointegration results.

Table 3. Johansen Unrestricted Cointegration Rank Test (Trace).

Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.7628	62.434	47.856	0.0012
At most 1 *	0.7031	32.211	29.797	0.0259
At most 2	0.2720	6.706	15.494	0.6120
At most 3	0.0018	0.0384	3.8414	0.8445

* Denotes rejection of the hypothesis at the 0.05 level. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table 4. Johansen Unrestricted Cointegration Rank Test (Maximum Eigenvalue).

Hypothesized No. of CE (s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob
None *	0.7528	30.222	27.584	0.0224
At most 1 *	0.7031	25.505	21.131	0.0113
At most 2	0.2720	6.667	14.264	0.5291
At most 3	0.0018	0.0384	3.8414	0.8445

* Denotes rejection of the hypothesis at the 0.05 level. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table 5. Long-run equilibrium.

Variable	Coefficient	Std. Error	t-Statistic
LCO_2	1.0000		
LGDP	−0.373	0.0235	−15.848
LAGR	−0.618	0.0648	−9.549
LPEC	−0.874	0.1037	−8.43
C	−9.123		

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

The following is the equation for the Johansen long-run cointegration:

$$\text{LnCO}_2 = 9.123 + 0.373\text{LnGDP} + 0618\text{LnAGR} + 0.872\text{LnPEC} \quad (13)$$

Economic growth as measured by GDP, agricultural, and energy consumption output are all positively correlated with CO_2 emissions, according to Equation (13). Table A5 in the Appendix A shows that services and industry are negatively correlated with a negative impact on CO_2 emissions.

Ceteris paribus, a rise of 1% in GDP, energy use, and agricultural output tends to result in corresponding increases in CO_2 emissions of 0.373%, 0.618%, and 0.872% respectively.

In light of the alternative, a cointegrating relationship in the model, we conclude that the null hypothesis of no cointegration is rejected.

4.3. Granger Causality

A Pairwise granger causality test was performed to fulfill the paper goals and check the direction of causality among the variables. Table 6 shows the direction between each two variables.

Table 6 shows the correlation trend between the variables by applying Granger's causal models. Table 6 summarizes the results as follows:

❖ There is a unidirectional Granger Causality for the following variables:
  - Economic growth towards carbon dioxide emissions.
  - Agriculture towards CO_2 emissions.

❖ There is a unidirectional Granger Causality agriculture towards economic growth, and energy consumption.

❖ There is no Granger Causality between energy consumption and each of CO_2 emissions, and economic growth.

Table 6. Pairwise Granger causality tests.

Null Hypothesis	F-Statistics	*p*-Value	Decision
LGDP does not Granger Cause LCO_2	3.76610	0.0665 ***	Fail to reject the null hypothesis
LCO_2 does not Granger Cause GDP	0.41243	0.5280	Reject the null hypothesis
LAGR does not Granger Cause LCO_2	6.12765	0.0224 ***	Fail to reject the null hypothesis
LCO_2 does not Granger Cause LAGR	0.14733	0.7052	Reject the null hypothesis
LPEC does not Granger Cause LCO_2	2.14132	0.1589	Reject the null hypothesis
LCO_2 does not Granger Cause LPEC	0.30516	0.5868	Reject the null hypothesis
LAGR does not Granger Cause LGDP	16.2111	0.0007 ***	Fail to reject the null hypothesis
LGDP does not Granger Cause LAGR	0.04508	0.8340	Reject the null hypothesis
LPEC does not Granger Cause LGDP	0.00017	0.9896	Reject the null hypothesis
LGDP does not Granger Cause LPEC	0.35443	0.5583	Reject the null hypothesis
LPEC does not Granger Cause LAGR	0.07417	0.7881	Reject the null hypothesis
LAGR does not Granger Cause LPEC	5.69660	0.0270 ***	Fail to reject the null hypothesis

*** indicates statistical significance at 10%. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table A6 in the Appendix A shows the correlation trend between the variables by applying Granger's causal models. Table A6 summarizes the results as follows:

- ❖ There is a unidirectional Granger Causality for the following variables:
  - Industry towards CO_2 emissions.
  - Services towards CO_2 emissions.
- ❖ There is a unidirectional Granger Causality service toward economic growth.
- ❖ There is a unidirectional Granger Causality agriculture towards economic growth, industry, and services.
- ❖ There is a bidirectional Granger Causality between industry and economic growth, as well as industry and services.
- ❖ There is no Granger Causality between energy consumption and each of industry, and services.

4.4. Diagnostic Tests

The heteroskedasticity, Autocorrelation, and normality post-estimation diagnostic tests were applied, and the results are shown in Table 7.

Table 7. Diagnostic tests.

Variable	Test	*p*-Value
Heteroskedasticity	Breusch-Godfrey LM Test	0.2048
Autocorrelation	Breusch-Godfrey LM Test	0.2313
Normality	Histogram (Jarque-Bera) Test	0.2947

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

The results of Autocorrelation, heteroskedasticity, and normality are shown in Table 5. The tests provide *p*-values of 0.2313, 0.2048, and 0.2947, all of which are larger than 5%, indicating that the N0 is rejected. Therefore, the model selection was accurate for the interpretation and analysis.

5. Discussion

5.1. Contextualization with Previous Research

Johansen's cointegration model was used in many previous studies, which provide various perspectives on the current scientific issue. The studies which discussed CO_2 emissions using the Johansen cointegration model were in different regions such as Asia [23,24], Africa [18,21,22], and Europe [17]. However, this was not the only technique to understand how energy and economy affect the environment represented by CO_2 emissions, as some studies used the ARDL technique to reach their goals [15,19,20,27].

Some research was conducted on a single country to focus on and give detailed discussions which evaluate the current policies and help policymakers in their upcoming actions [17,18,23,24].

Some authors simultaneously studied numerous countries. Where they could make a comparison in the results as well as discuss different policies in general [45–47].

The practical results provided a clear relationship between the studied variables and how they affected each other and gave us a clearer picture to determine the direction of effect for the variables.

The results of the Johansen test (Tables 3 and 4) demonstrated the existence of a long-run cointegration equation. Table 5 explained the form of the long-term relationship between each of the variables, and Table 6 gave us the direction of the effect.

Economic growth in the Czech Republic, agriculture, and primary energy consumption positively correlates with carbon dioxide emissions. It has not been discussed previously in previous studies.

Several studies, including [48–53], have found that energy consumption positively affects carbon dioxide emissions. The economic growth's impact on the environment is similar to those related to energy consumption [52,54–56]. The same applies to agriculture [20,21]. This happens as the Czech Republic and other countries are still not committed to using alternative energy. Belgium, Bulgaria, Romania, and Poland share with the Czechs limited or no progress in transitioning to a green energy sector over the next decade. The six countries are responsible for 40% of energy sector emissions for 2030. The Czech Republic has the worst commitment to green energy. The country plans to convert less than 5% of its energy production to solar and wind power by 2030. Hungary and Slovakia are distinguished from their Czech neighbors regarding their integration into the EU's national energy and climate plans and not having to change their energy and electricity use practices according to their current situation [57].

The Netherlands, Spain, and Denmark will lead in deploying solar and wind energy over the next decade, while the Czech Republic is the last in the European Union in this regard. The Czech Republic, Slovakia, Bulgaria, Hungary, and Romania are still far from switching to wind and solar energy compared to all other European Union countries. The matter is not limited to wind and solar power. Speaking of bioenergy, we see that Poland, Spain, Finland, and Sweden have developed more extensive plans for generating energy and electricity from bioenergy. The Czechs do not plan to use this type until 2030. We notice a clear gap between the countries of Eastern Europe and the Scandinavian countries in terms of shifting to the use of renewable energy due to their high share of hydro and bioenergy [57].

In Europe, the reduction in emissions has ceased to be as large as before. In 2019, for example, emissions circulating in the European Union were 24% lower than in 2005. Greenhouse gas emissions from agriculture continue to increase. This can be attributed to several things in the Czech Republic, like the destruction of the country's fir tree forests owing to the bark beetle catastrophe and the change in the distribution of rain over the seasons, which is the primary source of water in the country. The rise in average temperatures in the winter months causes a shortage of the usual water supply in the form of snow. It results in less water supply in the soil or groundwater reserves. Agriculture is still the most important source of ammonia, produced mainly in animal production and using fertilizers, which is considered one of the most significant negative impacts on the environment in the Czech Republic. There have already been around 6 million tons of CO_2-equivalent emissions from the forestry and land use sectors [58,59].

The Czech government has tightened environmental legislation within the industry sector and has introduced BAT and emerging technologies. Where the government has defined basic measures to reduce emissions of fugitive dust and to develop operating conditions per Decree No. 415/2012 Coll.23. Where the regional authorities grant operating permits after applying these conditions, this is consistent with the results of our study, which confirmed that the development in the industry has a negative relationship with carbon dioxide emissions [58,59].

In theory, there is a relationship between services and industry, as the increase in demand for exports leads to the acceleration of the industry [60]. The composition effect of the service and industry sectors which are parts of economic growth corresponds to the reality in the Czech Republic, where the strict laws of the Czech government have achieved the characteristic environmental impact of these two sectors on carbon dioxide emissions (Table A5 in the Appendix A). In addition to the interdependence of these two sectors by the influence of one on the other (Table A6 in the Appendix A) [61].

According to the findings of this study, the Czech Republic's scenario is perfectly consistent with the Kuznets curve in the second stage. There are three steps to the model. In the first stage, governments try to boost economic growth, accompanied by increased energy consumption, resulting in increased carbon dioxide emissions. Even when countries achieve a certain degree of economic growth, non-environmental practices that result in a considerable increase in carbon dioxide remain in the second stage. In the last step, governments aim to increase carbon-diminished economic growth [8,62].

Reduced use of fossil fuels, raw materials, and environmentally unfavorable energy sources can be ascribed to the consequences of energy usage on the environment in the Czech Republic in the form of carbon emissions. The findings showed that energy consumption in the Czech Republic causes an increase in emissions and, as a result, has an impact on the environment, which is consistent with the Czech government's strategy. Where the Czech Ministry of Environment authorized a policy to lower dangerous material and greenhouse gas emissions as a top priority, the procedure is outlined in the State Environmental Policy 2030 (SPŽP 2030), which outlines the country's environmental goals for 2050. Over the next ten years, the Czech Republic will invest a record 300 billion CZK in environmental and climatic protection. As one of the signatories to the Paris Agreement, the Czech Republic aspires to limit rising raw material and energy consumption, as well as work to transition away from fossil fuels and find new sources of energy, as evidenced by the findings of the current study [58,59].

5.2. Future Research Guidelines

The data used in the study dates back to 1995 due to the use of many variables to give an integrated picture of the Czech Republic, achieving the study's goal. At the same time, other researchers used one country or group of countries, with a link between them, long-term data with fewer variables for more extended periods, which gave them greater flexibility in choosing standard economic models in the case of studying one country or making a comparison between countries in the multi-country study. Accordingly, the researchers recommend conducting research for the countries of Central and Eastern Europe to compare practically the results and link these results with the government's medium and long-term policies and how they will affect the joint European environmental plan and the Paris Agreement. Moreover, the researchers recommend a deeper study of the impact of agriculture on greenhouse gas emissions individually and practical recommendations from an agricultural technical point of view on the best possible ways to mitigate emissions in the Czech Republic.

5.3. Policies and Recommendations

According to both the results of the study on the one hand and the above technical discussion, on the other hand, it was found that the Czech Republic needs to reduce the use of fossil fuels and non-environmental energy sources, which are considered significant causes of carbon emissions. In addition, the development of sustainable agricultural practices, the safe use of pesticides, the preservation of forests, and the management of water resources should be necessary.

The Czech government has included within its strategy giving priority to the environment where the Czech Ministry of Environment has authorized a policy to reduce emissions of hazardous substances and greenhouse gas emissions as a top priority; the policy is set out in the State Environmental Policy 2030 (SPŽP 2030), which sets out the country's environmental goals for the year 2050. Over the next ten years, the Czech Republic will invest 300 billion CZK in ecological and climate protection. As one of the signatories to the Paris Agreement, the Czech Republic aspires to reduce the rise in consumption of raw materials and energy, as well as work on the transition away from fossil fuels and finding new energy sources [58,59].

In addition, the Czech government presented a set of action plans such as the National Action Plan for the Safe Use of Pesticides in the Czech Republic 2018–2022 and National Plans for River Basin Management in the Czech Republic in close cooperation with both Ministry of Environment, and Ministry of Agriculture, Administrative Strategy of the Ministry of Agriculture in the Czech Republic with an outlook to 2030, work program according to Government Regulation No. 262/2012 Coll., 13 that define the procedures required for nitrate (MoA) processing. Finally, the Action Plan for the Development of Ecological Agriculture in the Czech Republic 2020–2025 (MoA) is under preparation. [58,59].

And we cannot forget the Czech Republic's National Energy and Climate Plan based on the requirements of the European Parliament and Council (EU) Regulation (EU) 1999/2018 on the management of the Union for Energy and Climate Action (despite the timid participation of the Czech Republic compared to other EU countries) which aims to convert nearly 59% From electricity demand in the EU27 by 2030 to renewable energy sources [57].

6. Conclusions

The primary goal of this research was to assess the impact of economic growth, agriculture, and energy consumption on the Czech environment, which was quantified using CO_2 emissions. Johansen, Vector Error Correction (VEC) Model, and granger causality were used to determine cointegration, long-run relationship and the direction of effect of the aforementioned variables.

The results showed that all studied variables are cointegrated (Tables 3 and 4). Economic growth, agricultural, and energy consumption output are all positively correlated with CO_2 emissions (Table 5).

There is a unidirectional Granger Causality between economic growth, and Agriculture towards carbon dioxide emissions. A unidirectional Granger Causality agriculture towards economic growth, and energy consumption. In addition, there is no Granger Causality between energy consumption and CO_2 emissions, and economic growth (Table 6).

The Czech Republic lags behind European countries in general and its neighbors in particular in terms of the appropriate and planned transition to renewable energy. The Czech Republic is still suffering agriculturally from the consequences of some pests that caused them natural problems. It is vital to discover environmentally friendly energy sources and adequately implement the announced government support plan to support the environment to accomplish the aims of sustainable development and the Czech commitment to international agreements to safeguard the environment.

The Czech Republic should commit to, or make a plan, a green energy transition, which currently in the 2030 European Agreement has not benefited at least from the experiences of its neighbors such as Hungary in the development of wind energy. Observe Poland's experience and make use of it to generate energy and electricity from bioenergy. Finding early response plans for agricultural pests to avoid a disaster similar to the bark beetle disaster. Due to the lack of normal water supply for agriculture, saving agricultural irrigation methods must be used. Finding alternatives to the use of ammonia through the use of less environmentally harmful fertilizers.

To achieve the goal of the research, all the studied variables were added, so the authors faced a problem in obtaining data for longer periods of time. This made the research focus on studying the period of the nineties of the last century until 2018. For subsequent studies, the authors recommend taking each of agriculture, industry, and services independently and studying their impact on CO_2 emissions, which gives a big picture of each of them with deeper technical discussions for long periods of time and contributes to offering solutions to the problems that can be found in that research.

This is the first study to use the most recent data to empirically evaluate the environmental impact of economic growth, agriculture, and energy use in the Czech Republic. This study includes pertinent advice for reducing emissions and supporting the environment by increasing renewable energy sources and adhering to the Czech Ministry of Environment's strategy.

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Appendix A

Table A1. Descriptive analysis.

	CO_2	GDP	Agriculture	Industry	Services	Energy Consumption
Mean	1.20	1.57	4.04	5.15	8.21	490.51
Median	1.23	1.66	4.01	5.56	9.33	485.14
Maximum	1.35	2.09	4.94	7.00	1.40	527.019
Minimum	1.04	1.16	3.41	3.62	3.09	447.625
Std Dev		2.91	3.86	1.19	3.88	21.659
Skewness	−0.30	0.02	0.54	−0.04	−014	0.0576
Kurtosis	1.66	1.72	2.68	1.42	1.39	2.1617
Jarque-Bera	2.14	1.64	1.28	2.47	2.64	0.7159
Probability	0.34	0.44	0.52	0.28	0.26	0.6990
Sum	2.87	3.77	9.70	1.24	1.97	11,772.25
Sum Sq Dev	2.21	1.95	3.43	3.25	3.45	10,790.5
Observations	24	24	24	24	24	24

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table A2. Optimal lag selection criteria.

Lag	FPO	AIC	SC	HQ
0	1.37	−19.49	−19.20	−19.42
1	3.79	−25.52	−23.44	−25.03
2	−1.27 *	−27.53 *	−23.67 *	−26.62 *

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021). * Indicates lag order selected by the criterion. HQ: Hannan-Quinn information criterion, SC: Schwarz information criterion, AIC: Akaike information criterion, and FPE: Final prediction error. Note: the lag selection was conducted again for all variables after adding services, and industry.

Table A3. Johansen Unrestricted Cointegration Rank Test (Trace).

Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob
None *	0.927187	150.3263	95.75366	0.0000
At most 1 *	0.881062	92.68919	69.81889	0.0003
At most 2	0.612774	45.84774	47.85613	0.0763
At most 3	0.504459	24.97533	29.79707	0.1623
At most 4	0.350008	9.529000	15.49471	0.3187
At most 5	0.002339	0.051516	3.841465	0.8204

* Denotes rejection of the hypothesis at the 0.05 level. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table A4. Johansen Unrestricted Cointegration Rank Test (Maximum Eigenvalue).

Hypothesized No. of CE (s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob
None *	0. 927187	57.63707	40.07757	0.0000
At most 1 *	0. 881062	46.84145	33.87687	0.0003
At most 2	0. 612774	20.87241	27.58434	0.0000
At most 3	0. 504459	15.44633	21.13162	0.2589
At most 4	0. 350008	9.477484	14.26460	0.2486
At most 5	0. 002339	0. 051516	3.841465	0.8204

* Denotes rejection of the hypothesis at the 0.05 level. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table A5. Long-run equilibrium.

Variable	Coefficient	Std. Error	t-Statistic
LCO_2	1.0000		
LSERV	1.5341	0.91503	1.676571
LPEC	−1.1212	0.09585	−11.6984

Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

Table A6. Pairwise Granger causality tests.

Null Hypothesis	F-Statistics	*p*-Value	Decision
LIND does not Granger Cause LCO_2	4.72001	0.0420 ***	Fail to reject the null hypothesis
LCO_2 does not Granger Cause LIND	0.13820	0.7140	Reject the null hypothesis
LSERV does not Granger Cause LCO_2	3.31465	0.0837 ***	Fail to reject the null hypothesis
LCO_2 does not Granger Cause LSERV	1.14124	0.2981	Reject the null hypothesis
LIND does not Granger Cause LGDP	8.89900	0.0073 ***	Fail to reject the null hypothesis
LGDP does not Granger Cause LIND	9.38584	0.0061 ***	Fail to reject the null hypothesis
LSERV does not Granger Cause LGDP	4.57251	0.0450 ***	Fail to reject the null hypothesis
LGDP does not Granger Cause LSERV	2.29109	0.1458	Reject the null hypothesis
LIND does not Granger Cause LAGR	0.00152	0.9693	Reject the null hypothesis
LAGR does not Granger Cause LIND	14.9650	0.0010 ***	Fail to reject the null hypothesis
LSERV does not Granger Cause LAGR	0.15749	0.6957	Reject the null hypothesis
LAGR does not Granger Cause LSERV	10.5364	0.0040 ***	Fail to reject the null hypothesis
LSERV does not Granger Cause LIND	6.87078	0.0164 ***	Fail to reject the null hypothesis
LIND does not Granger Cause LSE RV	3.60704	0.0721 ***	Fail to reject the null hypothesis
LPEC does not Granger Cause LIND	0.44338	0.5131	Reject the null hypothesis
LIND does not Granger Cause LPE C	0.70352	0.4115	Reject the null hypothesis
LPEC does not Granger Cause LSERV	0.51048	0.4832	Reject the null hypothesis
LSERV does not Granger Cause LPEC	0.22466	0.6406	Reject the null hypothesis

*** indicates statistical significance at 10%. Source: Own calculations based on (World bank 2022, Our world in data 2022, and Global Carbon Project 2021).

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