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Environmental Degradation by Energy–Economic Growth Interlinkages in EU Agriculture

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Abstract: Energy has the most significant input to agricultural production. The EU's effort to produce a carbon-neutral economic entity necessitates changes in the energy mix used for agricultural production. Therefore, we employ different variables, in particular, the emissions generated by energy sources, namely coal, natural gas, and diesel gas and their interlinkages with the GDP share generated from agriculture. The data are annual and refer to the period 1970–2020. The ARDL methodology is the econometric tool employed. The year 1990 is identified as a statistically significant break point for all variables, while for the cointegrating equation, the year 2009 appears to play a significant role. Emissions generated by coal appear to play a vital role in the GDP share generated by agriculture and, therefore, should be the main focus of the policy measures taken. Coal should be replaced by other renewable sources or the use of technologies by farmers that improve energy efficiency in order to make the agricultural income stable and to achieve the objective of carbon-neutral agriculture in the EU.

Keywords: agricultural income; energy; EU; ARDL

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1. Introduction

1.1. Environmental Degradation in EU Agriculture

The issue of environmental degradation has been extensively studied within the last two decades. The major focus is on climate change mitigation, the extent of which may be based not only on the appearance of environmental problems but also on the socioeconomic drivers for the mitigation impacts which, in most cases, are not incorporated [1–3]. Environmental degradation is mainly caused by the combustion of energy used as well as by land use, the structure of which is related to water availability and forestry formatted mainly by international demand [1,4]. Especially for the sector of agriculture, energy is more than vital, because the mechanization of all activities presents a significant impediment that limits energy use in the sector. Technology may provide the answer to the efficient use of energy, along with renewable energy use.

In terms of EU agriculture, the role of energy cannot be limited, despite the fact that energy data are of low quality due to errors or incomplete time series. These issues may affect the efficacy of a study to unveil the trends in energy consumption over time and by fuel type used [1–3].

An event that has had a significant impact on energy consumption as well as in agriculture is COVID-19. More specifically, home restrictions led to a reduction in total energy consumption by 6% in 2020 compared to 2019 in the EU. In terms of individual countries, a decrease in total energy consumption in 2020 compared with 2019 was recorded.

More analytically, Luxembourg (−14%), Spain (−11%), and Italy (−9%) had the greatest decreases. On the other hand, the smallest rates of change were recorded for Romania (−1%), Hungary, and Bulgaria (both −2%). The only exception was Sweden with an increase of +1% [3].

In contrast, the use of energy in agriculture was characterized by a slight increase (+1%). Furthermore, the energy consumed in agriculture and forestry in the EU for the year 2020 corresponded to 3.2% of the total energy use recorded. More specifically, in terms of individual countries, sharp rates of increase were recorded in the period 2019–2020, namely for Malta (+10%), Portugal (+8%), and Croatia (+6%). The only countries for which a decrease was recorded were Belgium (−11%), Sweden (−6%), and Romania (−5%) [3].

In terms of the share of total energy consumption in agriculture and for the case of the EU, the Netherlands (9%), Poland, and Latvia (both 6%) are the pioneers. Especially for the Netherlands, the value unveils the significance of greenhouse gas emissions in the production of fruit, vegetables, and horticultural plants. On the other pole stand Luxembourg, Slovakia, and Malta (all 1%). Another problem related to the consumption by agriculture is that it may be overestimated in countries with a significant forestry sector [3].

The carbon-neutral economy target for the EU was incorporated into the energy consumption policy measures. To be more specific, the Energy Efficiency Directive (2012/27/EU) announced a target of reducing, by 2020, energy consumption in the EU by 20% compared to projections with an amendment of an increased target of 32.5% by 2030 to be set in 2018 (EU 2018/2002). All of the above are included within the effort of Europe to be first climate-neutral continent by 2050. Thus, energy efficiency has become a high-priority target, focusing on an increase of 36–39% by 2030 [3,4].

Having all of these issues in mind, the present work tries to explore the impact of environmental degradation as synopsized in carbon emissions generated by different types of energy sources for the sector of agriculture on the EU share of the GDP generated by agriculture for the EU.

The next part of the introduction outlines the features of energy use in the European Union, the policies adopted, as well as the spatial distribution of energy use in the entity studied.

1.2. The Role of Energy in EU Agriculture

The sector of agriculture in the EU, as mentioned above, consumes different types of energy for different objectives in agricultural production. The distribution of the use of different energy sources in agriculture is recorded as follows: crude oil use corresponds to 60% of the total energy used in agriculture, electricity and natural gas represent 12%, and renewable energy represents 10%. In almost all EU countries, for the time period studied, the dominant importance of crude oil is evident. However, the distribution for the others was differentiated. Renewable energy use has expanded within the last decade, while in 2018, energy sources of this type corresponded to more than 20% of the energy used in agriculture. In most developed EU countries, this type of technology has become widely used, and in countries such as Slovakia, the production and energy use from renewable sources have evolved in parallel. Italy and Spain are two countries with limited consumption of renewable energy. The trend in the EU is that fossil and gaseous fuels are gradually being replaced by liquid fuels, while the significance of electricity and renewable energy has been steadily growing. There is high volatility in consumption involving fossil fuels, while energy sources with stabilized consumption are electricity and crude oil. The total energy used in agriculture is stale with oscillations recorded for different energy sources, with the exception of the steadily growing trend for renewable energy sources.

The use of energy may involve the production of fertilizers and pesticides or seeds and on-farm diesel use. More analytically, in the production of fertilizers, 31% of the total energy input is used, while for pesticides and seeds, 5% of the total energy input is required. Regarding other uses, irrigation, storage, and others require 8% of the total energy input. Fossil fuels represent the majority of the energy used, and therefore, the present work studies emissions generated by coal, natural gas, and gas–diesel energy sources in order to unveil their impacts on agricultural income and to provide policymakers with an assessment of the existing situation and how this can be reversed in order to secure ecoefficiency [5].

The impact of the economic situation on conventional energy consumption in agriculture is evident in all EU countries, although this is not the case for renewables. More specifically, the increase in the consumption of renewable energy in agriculture is closely related to individual economic parameters. Furthermore, the energy issue is a requirement for the protection of the natural environment, leaving economic factors behind in terms of repercussions [5–7].

Interlinkages among parameters of agricultural production related to land resources and energy have been established and empirically validated. In agriculture, energy consumption has expanded due to the expanded use of mechanical devices. A stylized fact is that the speed of mechanization is higher than the improvement of energy-consuming technologies. The only means of achieving mechanization in agriculture without environmental degradation is through the expansion of the use of renewable energy sources. The introduction of renewable energy sources has occurred in all countries with the level of economic development not being a prerequisite. In the following years, increasing consumption of energy from renewable sources should be observed. Modern agriculture in the European Union should move in the zero-carbon direction, an objective that could be achieved if energy efficiency is improved with the use of technology [5]. The fossil fuel variables employed involve carbon emissions generated by coal (CEMEU), natural gas–diesel (GAMEU), natural gas (NATGAS), and motor gas (MOTGAS), factors that were not used in the model. More specifically, based on FAOSTAT, the emission factors for CO_2 require conversion factors that are net caloric values. More specifically, the fuel amounts are turned into energy contents based on IPCC (2006) values, as follows: gas–diesel oil, 43 TJ/Gg; motor gasoline, 44.3 TJ/Gg; and hard coal, 25.8 TJ/Gg [8,9].

The Figure 1 illustrates the emissions generated by different energy types.

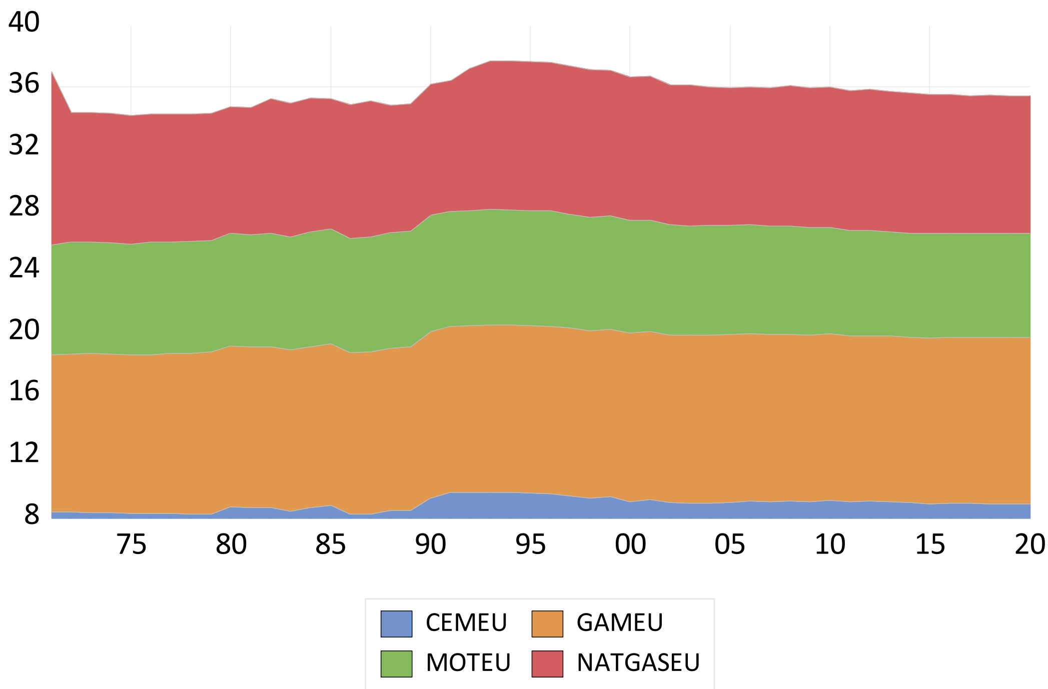

Figure 1. Emissions generated by different energy sources.

Within this framework, the present work explores the interlinkages of carbon emission generated by energy sources for agriculture with the GDP share generated by agriculture, although renewables are not incorporated due to a lack of sufficient data.

The structure of the paper is as follows: The next section provides an insight into the existing literature, Section 3 describes the data and methodology employed, Section 4 presents the results, and Section 5 discusses the results and concludes the paper.

2. Literature Review

The existing literature mainly focuses on the environmental degradation–income linkages, as synopsized in the Environmental Kuznets curve [8–15]. For the case of agriculture, this issue has been studied by Coderoni and Esposti [10] as well as by Burakov [11], Zafeiriou and Azam [12], Zafeiriou et al. [13], Zafeiriou et al. [14], and Zafeiriou et al. [15]. Significant work on agriculture was conducted by Bennetzen et al. [16]. In their work, the intensity of GHG emissions generated from global agricultural production and land-use change was estimated, and an analysis on past and future trends of the same variable was conducted.

Furthermore, the role of energy in economic growth was initially studied by Kraft and Kraft [17], a topic that, in following years, became popular. The majority of the existing literature confirmed a positive relationship between those two variables, namely energy consumption and economic growth [18–22].

An abundance of studies has focused on the impact of climate change on agricultural output and production [14,15,23] The bidirectional relationship appears to be affected by energy use, which is considered to have a significant input into agricultural production as well as an effect on the total output. Actually, limited energy resources are limiting households' and producers' abilities to meet their ultimate energy demands, even in advanced economies, for all types of needs, causing energy poverty [24,25].

Therefore, the issue of energy was the initial subject of study in the Environmental Kuznets curve, since it is considered to be a significant source of carbon emissions and, subsequently, climate change, while it is also the major means for economic growth. More specifically, 90% of carbon dioxide emissions are related to fossil fuels. This means that we have to limit the negative effects of climate change, and the use of renewable energy sources could provide a perfect solution. Therefore, renewables are becoming a rapidly expanding energy source that is expected to account for 14% of the total energy consumption by 2035 [26]. Actually, for the time period 1990 to 2017, more than 160 countries incorporated renewable sources into their energy mix, including solar, wind, geothermal, and hydroelectricity, in order to limit their environmental problems [19,20,26,27]. Furthermore, the target to mitigate the negative effects of climate change has turned renewable energy resources into an expanding energy source that is aimed to reach 14% of the total energy consumption in global terms by the year 2035 [28,29].

Thus, another strand of literature focuses on either fossil fuels or renewable energy sources and their impacts on economic growth [29–44]. More specifically, Paris et al. [5] studied the existence of interlinkages among urbanization, economic growth, nonrenewable energy, renewable energy, and carbon emissions in the common markets and found connections, whereby the role of renewable energy sources appears to affect environmental degradation, and the type and proportion of renewables added to the energy mix appear to significantly affect environmental degradation. Along the same vein, this framework has become a subject of study with different methodologies and conflicting results. General Equilibrium Linear Models, linear or nonlinear cointegration time series, or panel data are econometric tools employed for this specific issue [33–44].

Concerning agriculture, especially in the EU, a significant effort is being made to expand the use of renewable energy or to advance the technology employed when nonrenewable energy is used in order to limit the environmental degradation caused by agriculture without causing shrinkages to agricultural income and promoting ecoefficiency within the objective of sustainable agriculture. In the existing literature, sustainable agriculture entails the features of ecological, low-input, regenerative, permaculture, prudent use, and others, as mentioned in [44,45]. In terms of practices, sustainability in agriculture asks for the minimization of the usage of nonrenewable resources, along with turning agriculture into an economically viable and profitable sector. Last, but not least, the ecological viewpoint of preserving the natural environment and its resources in a sustainable way serves as means of securing the implementation of the SDGs suggested by Agenda 2020. The 17 goals to be achieved by 2030 represent a major commitment for the EU, while for agriculture, SDG13 and SDG15 are the major goals [46,47]. The former refers to climate change, and the latter to land degradation cessation.

Energy consumption has served as a linkage between economic growth and the sustainable environment of agriculture according to the findings of Mirza and Kanwal [39]. Most studies have focused on linkages among carbon emissions, agriculture, and energy use involving different areas and different methodologies with conflicting results [45]. In many cases, the bidirectional causalities between economic growth, energy consumption, and CO_2 emissions have been validated [29–44].

Within this framework, the present work makes an effort to unveil the impact of carbon emissions generated by different energy sources used in agriculture on the GDP share generated by agriculture and, therefore, to validate whether the measures aimed at achieving carbon-neutral agriculture as well as the efforts made to advance the technology used to upgrade energy efficiency are the appropriate means to achieve the SDGs concerning agriculture [46–49]. The autoregressive distributed lag (ARDL) model is the econometric tool employed in the present work. The scientific value of the present work is to provide policymakers with information on interlinkages between environmental degradation by fossil fuels and growth in agriculture and how this could become a tool for ecoefficiency.

3. Data–Methodology

3.1. Data

The energy data employed are annual, derived by FAOSTAT (2022) [50] and refer to carbon emissions generated by coal, natural gas, and gas–diesel sources used in the sector of agriculture. The GDP share per capita generated by agriculture serves as a proxy for sectoral economic growth. The data collected involve the European Union as an entity. The reason that we did not use data for individual countries, but for EU as an entity, is related to the lack of data. Furthermore, the objective of this study was to unveil the efficacy of the EU's effort as a whole in terms of agroenvironmental policies aimed at carbon-neutral agriculture. Furthermore, we used disaggregated data in terms of energy used in agriculture and the carbon emissions generated by each and how they affect growth in agriculture. This can serve as a tool to detect how efficient the technology is in upgrading energy productivity and limiting carbon emissions without impeding economic growth in agriculture.

3.2. ARDL Methodology

The present work employs the ARDL bounds cointegration technique. This particular methodology allows us to estimate associations for data with a time period span of less than 25 years. The ARDL model to be estimated has the following form:

$$\begin{aligned}\Delta LnGDP_t = {} & \alpha_0 + \alpha_1 T + \sum_{i=1}^{p-1} \alpha_{1i} \Delta lnGDPshar_{t-i} + \sum_{i=0}^{p-1} \alpha_{2i} \Delta lnEC_{coalat-i} + \sum_{i=0}^{p-1} \alpha_{3i} \Delta lnECgas_{t-i} \\ & + \sum_{i=0}^{p-1} \alpha_{4i} \Delta ln\text{ECdiesgas}_{t-i} + \phi_1 lnGECcoal_{t-1} + \phi_2 lnGECgas_{t-1} \\ & + \phi_3 lnGECdiesgas_{t-1} + \epsilon_t \end{aligned} \quad (1)$$

where EC_t denotes carbon emissions generated by different energy types (natural gas, diesel gas, and coal); GDP_{shar} denotes the share of GDP per capita generated by agriculture; T denotes the time trend; α_0 is a constant; $\phi_{1,2,3}$ denotes the long-term coefficients; α_{1i}, α_{2i}, α_{3i}, and $\alpha_{4\text{i}}$ denote the short-term parameters; Δ denotes the first difference operator of the variable employed; and p denotes the lags determined by the lag length optimization criteria, namely the Akaike Information Criterion (AIC).

The carbon emissions are presented in kilotons/he, and the GDP share per capita generated by agriculture is used to illustrate economic growth in EU agriculture. The general model may suffer from stability problems that can be solved with the selection of a modified model in which the time trend T and the constant coefficient are not included.

The model employed in our study includes both long-term and short-term parameters. More specifically, φ_1, φ_2, φ_3, φ_4 denote the long-term parameters. The null hypothesis, $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$ (no cointegration), against the alternate (that is $\varphi_1, \varphi_2, \varphi_3 \neq 0$) is tested. Rejecting the null confirms that the variables are cointegrated. The test described above is based on the computed F-statistic. The comparison of the test compared to the critical values provided for small-sized data by Giannone et al. [51] provides the test result. The alternative results of the particular test are provided in Table 1.

Table 1. F-statistic test potential results.

Condition	Result
F > Upper Critical Bound (UCB)	Long-Term Relationship (Cointegration)
F ≤ Lower Critical Bound (LCB)	No Long-Term Relationship (No cointegration)
LCB ≤ F-statistic ≤ UCB	Uncertain Result (Dependancy on the lagged ECT for cointegraton)

The major advantage of the particular methodology is that it is efficient for variables of different orders of integration, under the condition that the order is less than or equal to one [52,53]. This condition necessitates the exploration of the order of integration for the variables used in the model, prior to the model estimation employed to test the existence of cointegration. Implicitly, the authors examined the existence of a unit root for all variables with the assistance of the ADF break point test. This particular test incorporates the structural breaks on the stationarity test employed.

The particular test involves a two-step procedure. The first step aims to descend the series with the proper trend and break variables, and the estimation is based on the ordinary least squares (OLS) methodology. The second step involves a modified Dickey–Fuller regression implemented into the modified series in order to test the nonstationarity [48]. An intercept break or trend break may be included in the model, and therefore, the model employed may include the trend, intercept, or both.

A lack of appropriate tests may well lead to mis-specifications. Thus, the procedure suggested by Shrestha and Chowdhury [54] and Hlouskova and Wagner [55] was the one employed for the selection of the appropriate model for conducting the unit root test.

Having confirmed that the variables employed are either I(0) or I(1), ARDL cointegration approach may well be implemented. We also conducted tests to detect whether the model suffers from residual serial correlation and endogeneity problems [56,57]. Having validated that the ARDL model is free from those problems, the model selected was based on the general-to-specific modeling framework [56,58]. Furthermore, the estimated dynamic error correction model (ECM) [59] reflects the short-term dynamics with the long-term equilibrium while at the same time problems resulting from nonstationary time series data are minimized [58].

Prior to the model estimation, and according to the methodology suggested by Pesaran and Shin [59], the authors chose the lags for the optimum model. The selection of the best model was based on the lowest prediction error. In the next step, the existence of a long-term relationship was confirmed with the assistance of the bounds test and the error correction model.

The long-term relationship to be surveyed is based on the following model:

$$lnGDPshare_{it} = \varphi_1 lnECTgas + \varphi_2 lnECTcoal + \varphi_3 lnECTdesgas + \mu + \lambda 3D_t + \delta_t \quad (2)$$

where $lnGDP_{it}$ denotes the share of GDP generated by agriculture for the EU to be surveyed, $lnECT$ denotes the carbon emissions generated by gas and coal, respectively, and D_t is a dummy variable that captures a structural break in the interlinkages among the variables studied for the EU. This is the case when the particular variable is found to be statistically significant. When the parameters λ_1 and λ_2 are found to be positive and negative, this could validate the environmental impact of the EKC pattern on the GDP share generated by agriculture.

The last step of the analysis involves a test to examine the parameter stability and goodness of fit. More specifically, we employed the cumulative sum of squares of the recursive residuals (CUSUM test). In this test, the parameter stability is validated when the graphs lie within the bounds [58,59].

The error correction model is provided by Equation (3).

$$(1-L)\begin{bmatrix} lnGDP \\ ln(ECTgas)_t \\ ln(\text{ECTcoal})_t \\ \text{n}(\text{ECTdiesgas})_t \end{bmatrix} = \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix} \alpha_{11i} & a_{12i} & a_{13i} \\ b_{21i} & b_{22i} & b_{23i} \\ \delta_{31i} & \delta_{32i} & \delta_{33i} \\ c_{41i} & c_{41i} & c_{41i} \end{bmatrix} + \begin{bmatrix} \beta \\ \gamma \\ \vartheta \\ h \end{bmatrix} ECM_{t-1} + \begin{bmatrix} v_{1i} \\ v_{2i} \\ v_{3i} \\ v_{4ii} \end{bmatrix} \quad (3)$$

where $(1-L)$ denotes the lag operator, and ECM_{t-1} denotes the lagged error correction term generated by the cointegrating equation while the η terms are white noises. The validation of the short-term interlinkages is achieved when the parameters are found to be statistically significant, whereas the long-term causality is validated when the error correction term is validated as being statistically significant.

4. Results

The present section describes the results of the methodology described in the previous section. As mentioned above, the first test conducted in our analysis involved unit root tests and, more specifically, the break point unit root test, a methodology that incorporates the structural breaks. Based on our findings, we confirmed that the variables were I(1), a result that is illustrated in Table 2. The major advantage of the particular test is that it provides the potential structural breaks of the time series studied. For the structural breaks identified, we provide plausible and reasonable explanations. The year 1990 was identified as a structural break for all time series studied, which is significant, given that it was used as a benchmark for all policy measures aimed at climate change mitigation, while the breaks identified for the years 1982 and 1986 illustrate two time points related to significant events in the global economy.

Table 2. Break unit root test. Minimized Dickey–Fuller t-statistic.

	t-Statistic	*p*-Value	Structural Break
lnECTcoal	−3.35	0.4733	1986
lnGDPshare	−2.00	0.7855	1990
lnECTdiegas	−4.15	0.1101	1988
lnECTnatgas	−28.56 ***	<0.01	1990
D(lnCitcoal)	−7.26 ***	<0.01	1991
D(lnECTdiegas)	−7.55 ***	<0.01	2006
D(GDPshare)	−6.675 ***	<0.01	1982

*** Rejection of the null hypothesis at the 5% level of significance. Critical value for 5% level of significance is 4.443649. Source, own calculations.

More specifically, for the year 1982, the behavior of macroeconomic variables, such as unemployment, declines in demand, investment, and income, and rising trade protectionism, accompanied by a significant rise in the value of external debt along with growth in military expenditures, are features that signal a recession which, in turn, has in direct effects on farmers and sectors related to agriculture. Subsequently, all international monetary and credit problems have had significant impacts on farmers' expectations and their ability to acquire fertilizer, feed supplements, and other inputs needed for increased production. Over a time period of 30 years, the world's fertilizer production and consumption have been going through a declining trendm while immediate economic pressures have postponed improvements in farming, marketing, and input supply systems [48].

Taking into consideration that all time series employed in this study are I(1) and I(0), we were able to implement the ARDL methodology. The ARDL model selected was ARDL (5, 7, 7, 7). Having estimated the ARDL model, we also estimated the explanatory ability of the model with the assistance of the F-statistic. The F-statistic is a tool to test the null hypothesis according to which no level relationships exist or not. In our case, the null hypothesis cannot be accepted, and therefore, the existence of a long-term relationship among the variables studied is confirmed. The F-test estimation results are provided in Table 3.

Table 3. F-test estimation results.

F-Bounds Test		Null Hypothesis: No Level Relationships		
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	8.6248	10%	2.97	3.74
k	3	5%	3.38	4.23
		2.5%	3.8	4.68
		1%	4.3	5.23

Source, own calculations.

The estimated cointegrating relationship, that is, the long-term relationship estimated, is illustrated in Table 4.

$$EC = SHAREGDP - (-2.55 \times 10^{-5} \times GASDESEMEU - 7.27 \times 10^{-6} \times NATGASEMSEU + 0.0018 \times COALEMISLCD - 0.1281 \times TREND)$$

Table 4. Long-term form.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
NATGASEMSEU	-7.27×10^{-6}	1.12×10^{-5}	−0.648673	0.5288
GASDESEMEU	-2.55×10^{-5} **	8.83×10^{-6}	−2.886229	0.0137
COALEMISLCD	0.0018 ***	0.000215	8.481849	0.0000
@TREND	−0.128 ***	0.009012	−14.21530	0.0000

***, ** rejection of the null hypothesis for 1 and 5% levels of significance. Source, own calculations.

The coefficients of the long-term relation were found to be statistically significant with the exception of natural gas, a result that confirms the limited impact of natural gas emissions on the GDP share generated by agriculture. Our results are in line with the majority of previous studies, since energy use, carbon emissions, and agriculture are interlinked [39–41]. Furthermore, our findings are in line with those of Zhang et al. [49], who confirmed economic growth–carbon emission–energy consumption interlinkages for the sector of agriculture in China. Though in our study, we examined the impact of emissions generated by agriculture on sectoral economic growth for the EU, an entity that is making a significant effort to mitigate climate change.

The cointegration graph is illustrated in Figure 2. The great recession in the EU that occurred in the year 2009 is evident, illustrating how the specific incident affected the variables' interlinkages, while oscillations are evident for the rest of the time period studied.

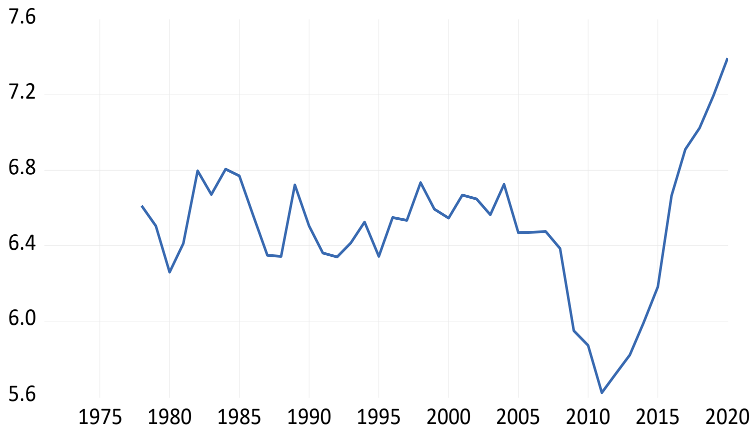

Figure 2. Cointegration relationship graph.

An estimation of the error correction model is provided in Table 5. The negative coefficient of ECT_{t-1} (error correction term) validates the convergence to the steady state. Moreover, the speed of the steady state is quite high, namely 123% per year. More specifically, the ECT coefficient reflects the speed of convergence from the short-term disequilibrium to the long-term equilibrium. The negative (positive) coefficients of $DGDP_{t-1}$ ($DGDP_{t-12}$) show the emission contributions from different energy sources to economic growth. A significant result is the statistical significance of the terms in the short-term, unveiling the intervention requirements in the short- as well as the long-term. Once again, the necessity of this analysis is to assess the existing situation and to suggest to policymakers measures or technology advances that could assist in climate change mitigation without having a negative impact on growth by agriculture, given the significant role of fossil fuels in the economic growth of agriculture. Furthermore, coal appears to be the most significant energy source, while the short-term coefficients do not appear to change in different time lags.

Table 5. Error Correction Model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	8.241179	1.095397	7.523462	0.0000
D(GDPSHARE(−1))	0.366255	0.114097	3.210036	0.0075
D(GDPSHAR(−2))	0.404211	0.117414	3.442606	0.0049
D(GDPSHAR(−3))	0.596291	0.101039	5.901568	0.0001
D(GDPSHAR(−4))	0.477527	0.136888	3.488440	0.0045
D(GDPSHAR)	-8.00×10^{-6}	7.41×10^{-6}	−1.080117	0.3013
D(GASDESEMEU(−1))	1.69×10^{-5}	8.27×10^{-6}	2.041752	0.0638
D(GASDESEMEU(−2))	-2.45×10^{-5}	7.94×10^{-6}	−3.082171	0.0095
D(GASDESEMEU(−3))	-4.09×10^{-6}	1.18×10^{-5}	−0.346623	0.7349
D(GASDESEMEU(−4))	6.68×10^{-5}	1.07×10^{-5}	6.249464	0.0000
D(GASDESEMEU(−5))	4.76×10^{-5}	1.31×10^{-5}	3.635013	0.0034
D(GASDESEMEU(−6))	3.01×10^{-5}	1.10×10^{-5}	2.745058	0.0178
D(ECTNATGAS(−1))	-6.20×10^{-5}	1.03×10^{-5}	−6.038494	0.0001
D(NATGASEMSEU(−2))	-2.84×10^{-5}	1.29×10^{-5}	−2.195736	0.0485
D(NATGASEMSEU(−4))	-2.30×10^{-5}	8.61×10^{-6}	−2.668061	0.0205
D(NATGASEMSEU(−5))	-2.78×10^{-5}	9.45×10^{-6}	−2.942226	0.0123
D(NATGASEMSEU(−6))	-4.03×10^{-6}	1.25×10^{-6}	−3.214874	0.0074
D(COALEMISLCD(−1))	−0.001671	0.000358	−4.663924	0.0005
D(COALEMISLCD(−2))	−0.000695	0.000266	−2.613063	0.0227
D(COALEMISLCD(−3))	−0.001359	0.000247	−5.491612	0.0001
D(COALEMISLCD(−4))	−0.001998	0.000301	−6.645472	0.0000
D(COALEMISLCD(−5))	−0.001303	0.000321	−4.059302	0.0016
D(COALEMISLCD(−6))	−0.001017	0.000307	−3.312484	0.0062
CointEq(−1) ***	−1.235758	0.162968	−7.582812	0.0000
R-squared	0.914			

***, rejection of the null hypothesis for 5% levels of significance Source; Own calculations.

The next step involved the implementation of the residual diagnostic tests. Based on our findings, as illustrated on Table 6, both the Breusch–Godfrey autocorrelation test and the ARCH heteroscedasticity of the estimated model did not detect problems of heteroscedasticity or autocorrelation in the estimated model.

Table 6. Residual diagnostic tests.

	F-Statistic	*p*-Value
Breusch–Godfrey autocorrelation test	2.606182	0.106
ARCH Heteroscedasticity test	2.06	0.357

Source, own calculations.

The last diagnostic test in the model involved the study of the parameter's stability with the Cumulative CUSUM square (CUSUMsq) tests, the results of which are illustrated in Figure 3. To be more specific, the plot shown in Figure 3 lies within the critical bounds at the 5% significance level, which indicates that the estimated model is stable in the research period.

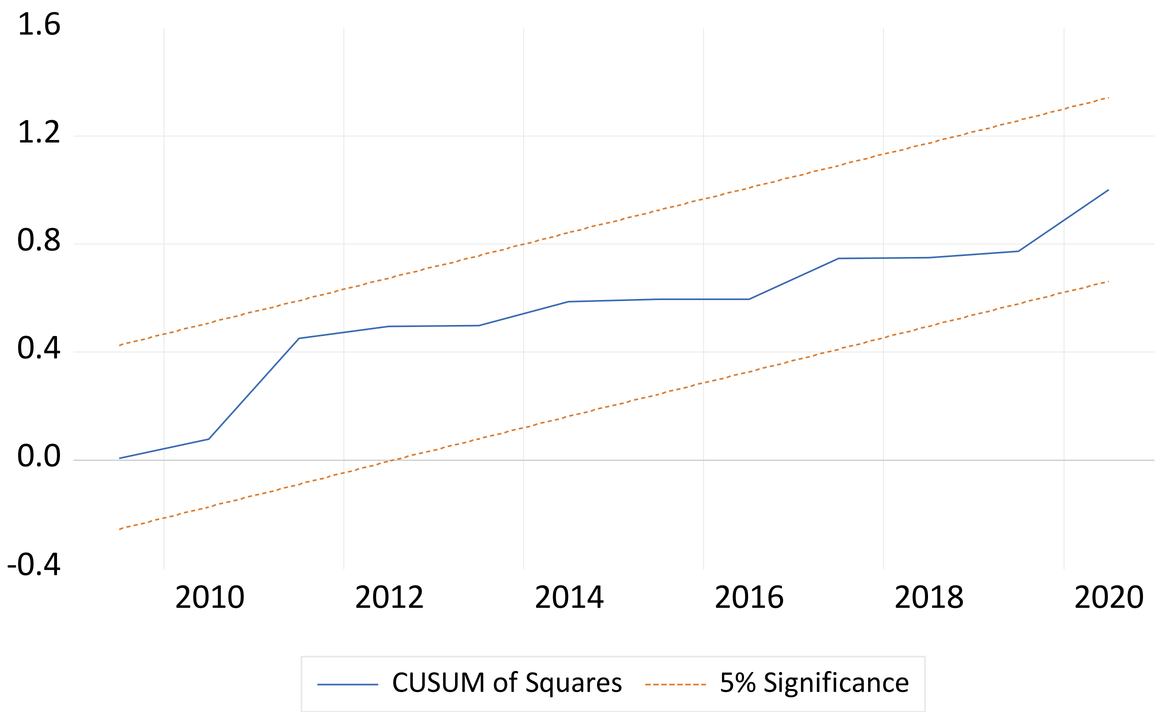

Figure 3. Graphical illustration of CUSUM of the squares stability test.

The last step in our analysis is related to the impulse response analysis of the impact of ECT by different energy types on economic growth, as synopsized by the GDP share generated by agriculture. The Figure 4 presents the graphical result of the specific analysis.

Evidently, the response of the growth generated by agriculture to the emissions generated by coal initially decreased for the first ten periods and then increased for the rest of the time periods. The turning point in the response, thus, was detected in the tenth period. Furthermore, the response of the growth to innovation in the emissions generated by diesel–gas decreased within all the time periods studied. Lastly, an innovation to the emissions generated by natural gas caused a decrease in agricultural growth for the first two periods, which increased with a declining trend and then stabilized after the 15th period. Based on the above, the interlinkages between the emissions and growth in agriculture are confirmed.

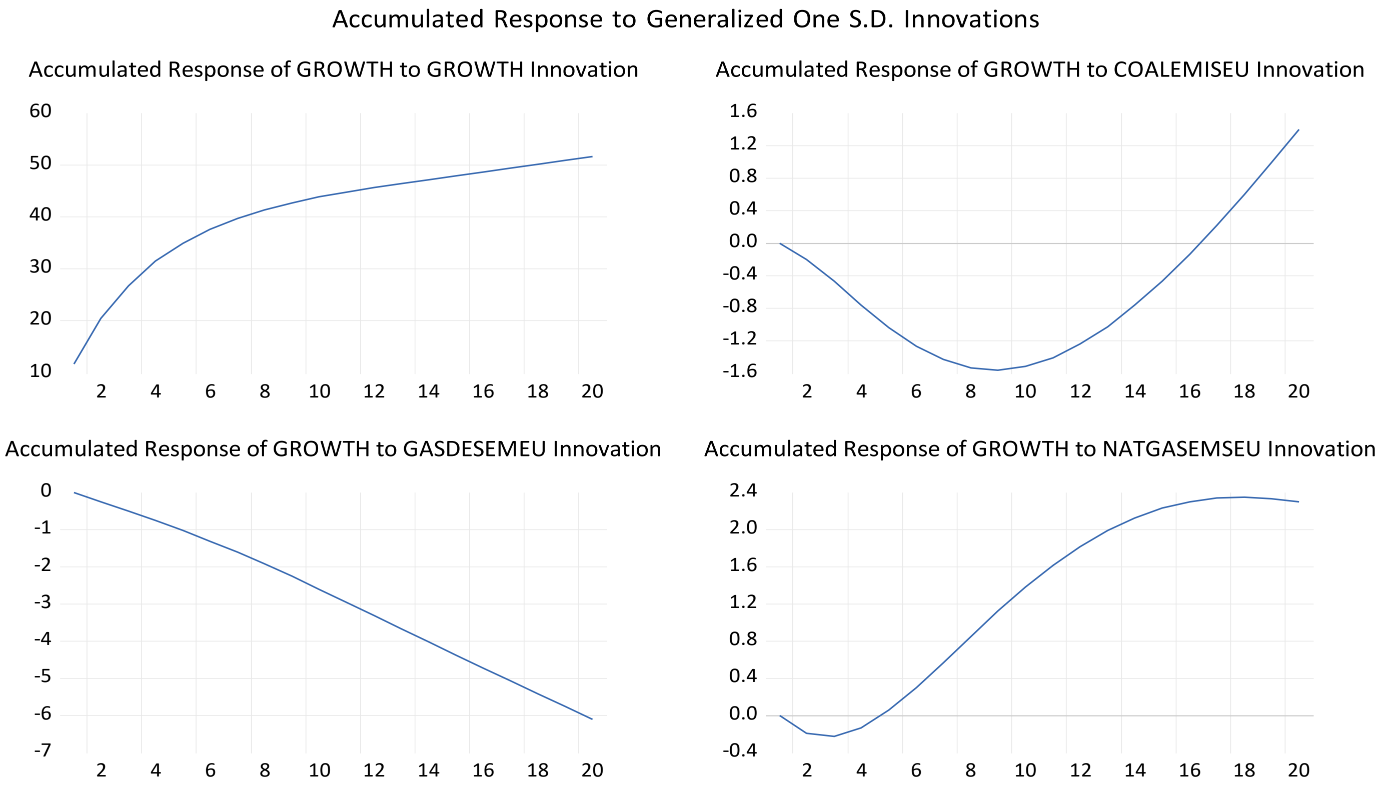

Figure 4. Impulse response analysis of the impact of ECT.

5. Discussion and Conclusions

The present work aimed to unveil the effect of emissions generated by different energy sources of agriculture on the GDP share generated by agriculture. The long reference period allowed us to unveil the evolution of the interlinkages, since this model may well assist in the adoption of practices to improve energy efficiency. The common method is to link energy consumption to the output produced. This is a direct approach. However, we chose to employ an indirect approach with the assistance of carbon emissions generated by different energy sources in the sector of agriculture.

The model estimated and validated the significance of coal emissions in agricultural income and, therefore, the use of coal should be assisted by technology in order to improve energy efficiency and to limit the emissions, while its substitution with natural gas that is less pollutant may not be such an effective solution.

In the short-term, the other types of energy appear to play significant roles in agricultural economic growth, while the negative coefficients of ECT_{t-1} that express the speed of convergence from the short-term disequilibrium to the long-term equilibrium showed a significant result.

The impulse response analysis was another econometric tool that was implemented to quantify the impacts of emissions generated by different fossil fuels on economic growth to provide policymakers with tools for efficient energy use in different agro-production sectors with significant implications for economic growth. Coal and natural gas appear to affect economic growth in a positive way, although with different patterns: inversed U and inversed N, respectively. These results stress the role of nonrenewable energy sources in the economic growth of EU agriculture [60]. However, more steps should be taken in order to change the impact of GHG emissions on agricultural income, and this will only be feasible through the use of technology. Furthermore, within the framework set by the Green Deal and Farm to Fork strategy, energy efficiency and the adoption and further development of non fossil energy sources is a necessity. More specifically, the policies should aim to achieve a sufficient energy supply from sources with more significant contributions to the development of agriculture. The significant role of conventional fuels is in line with the majority of the existing literature, as provided in recent review papers [5,61]. However, renewable sources represent an investment that should be promoted in the sector of agriculture in order for a carbon-neutral economy to be achieved, as intended and synopsized in agro environmental policy measures and ESG targets.

A subject for future research could be the implementation of a modified nonlinear ARDL methodology or novel ARDL on our data in order to provide more concise and accurate results, as well as the implementation of a panel data analysis that could generate more specific results in terms of individual countries regarding energy efficiency or progress on the way to zero-carbon agriculture. Furthermore, regarding the expansion of renewables in EU agriculture, when sufficient and accurate data are available, their processing would have a significant contribution to the puzzle related to the energy mix used for the parallel expansion of economic growth in agriculture.

Author Contributions: E.Z., S.T. organized this study, conducted the study design, analyzed the data, and contributed to the conclusions. E.Z., S.G. and G.A. contributed to the interpretation of the analysis, the revision of the manuscript by modifying and polishing the written English, and the formulation of conclusions. E.Z., S.G., A.B., G.A. and S.T. contributed to the deployment of the literature review and to the conclusions of the analysis. All authors have read and agreed to the published version of the manuscript.

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