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THE IMPACT OF THE GREEN TRANSITION ON THE PRODUCTION OF CEREALS IN THE EUROPEAN UNION. NEW INSIGHTS BASED ON THE FGLS PANEL DATA MODEL

Błażej Supron[1]

ABSTRACT

Aim: The aim of this study is to econometrically assess the long-term impact of Green Deal-related regulatory areas on cereal crop production in European Union countries. **Methods:** The study is based on an analysis of panel data for 21 European Union countries for the period 1995-2021. The FGLS, PCSE and CCEMG models, which are robust to heteroskedasticity and cross-sectional dependence, were used to determine the impact of agricultural CO_2 emissions, agricultural area, food production volumes and fertiliser consumption on cereal production. In addition, a robust test of the Westerlund ECM panel test model was applied to confirm cointegration. All models were bootstrapped to strengthen the results. **Results:** The results show that, in the long run, a 10% increase in CO_2 emissions from agriculture leads to an average decrease in cereal production of 0.5%. A 1% increase in cultivated area leads to a 1.1% positive change in the value of cereal production, and a 1% increase in fertiliser use per hectare leads to a 0.38% increase in cereal production. The value of the food production index also shows a positive effect on cereal production. If the index increases by 1 p.p., cereal production increases by 1.13% in the long run. The study also found a positive relationship between an increase in the share of renewable energy and the volume of cereal production. If the share of renewable energy increases by 1%, the volume of cereal production in the EU countries increases by 0.11%. **Conclusions:** Overall, it can be concluded that the green transformation brings both negative and positive aspects of change to agriculture. The decrease in cultivated land and

reduced use of artificial fertilisers may negatively impact farm productivity in crop production areas. On the other hand, the improvement of climatic conditions and the development of renewable energies could be beneficial for agriculture in the long term. The study is original in the sense that it fills an empirical and theoretical gap related to the verification of the impact of the Green Deal on the cereal production sector and thus on agriculture in the European Union.

Keywords: Cereal production, Agriculture, FGLS, Green transformation, European Union

JEL codes: C23, O47, O13, Q15, Q54

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INTRODUCTION

Crop production is a very important sector of the European economy and a pillar of food security. Cereals provide almost 60% of calories for European consumers, forming the basis of nutrition and ensuring food security in the European Union [Laskowski et al. 2019]. Cereals are used both for direct consumption, in the form of raw and processed products, and as an important component of animal feeds and oils, influencing animal production [Iji et al. 2011]. In addition, the evolution of dietary habits in recent years, combined with the change in preferences of a large group of consumers towards vegetarian, vegan and organic food, whose production is based on cereals, further increases the importance of cereal production in the European economy [Dorgbetor et al. 2022, Macdiarmid 2022].

Cereal production is one of the most sensitive agricultural activities to climate change [Wang et al. 2018]. Rising global temperatures are influencing the instability of weather conditions and the occurrence of many extreme events, creating uncertainty for producers and markets [Neupane et al. 2022]. Climate variability has significant implications for agriculture, including increased crop damage, low productivity, and high production costs [Malhi et al. 2021]. This can cause a decrease in farmers' income, leading to a shift in production or even the complete abandonment of farming [Karaczun and Kozyra 2020].

Due to global warming, the European Union aims to reduce CO_2 emissions. To achieve this, two strategies have been developed that affect agriculture: the European Green Deal with the Field-to-Fork (F2F) part and REPowerEU. These programmes aim to transition European agriculture, including crop production, towards a greener and more sustainable energy model [Grochowska and Staszczak 2021]. As part of the transition to environmentally friendly agriculture, the members of the European Union plan to implement the following measures [Parlińska et al. 2020]:

- 55% reduction in greenhouse gas emissions by 2030 compared to 1990, while considering that agriculture is one of the sectors that needs to reduce emissions significantly,
- 50% reduction in pesticide use and a 20% reduction in fertiliser use by 2030,
- restoring at least 10% of the agricultural area to natural ecosystems by 2030,
- increasing the share of renewable energy in the EU to 45% in 2030,
- reduction in meat consumption and production and an increase in the consumption of plant and organic foods.

The implementation of all regulations, according to European Commission (EC) estimates, could result in a 10% decrease in total European Union (EU) food production by 2030.

Meanwhile, the Food and Agriculture Organisation (FAO) predicts that the European Green Deal could lead to a 2-4% reduction in total EU food production by 2030 [The European Green Deal, 2019].

The European Community has set climate objectives for agriculture, which present both opportunities and challenges. This study aims to assess the impact of regulatory areas related to the broader Green Deal on cereal crop production in the EU. The study establishes the following research hypotheses:

H1 - The implementation of the European Green Deal strategy, which involves reducing cultivated areas and fertiliser use, is expected to have a negative impact on cereal production in the long term.

H2 - Increased use of renewable energy can indirectly increase cereal production in the European Union.

H3 - Food production is a significant factor in determining cereal production in European Union countries.

A panel feasible generalized least squares (FGLS) model based on bootstrap estimation was used to achieve the stated objective and to test the research hypotheses. This method was chosen to provide consistent and robust results for long-term data characterised by heteroskedasticity and cross-sectional dependencies (CSD). The FGLS model, along with robust estimation of confidence intervals and standard errors, produces highly reliable results [Bai et al. 2021]. The study uses data for the period 1995-2021 for 21 European Union countries. The article tries to fill both the theoretical and empirical gap in the impact of the European Green Deal on cereal crop production.

The study selected variables based on the work of Kibria et al. [2023], who examined the impact of CO2 emissions and FPI on cereal food production in South Asia. Fertiliser use and sown area were also added to the variable sets based on a study by Koondhar et al. [2021], which estimated the impact of sown area and fertiliser use on CO2 emissions and cereal production in China. The choice of renewable energy as a variable was supported by the work of Liu et al. [2017], who estimated the impact of renewable energy on agricultural value added and CO2 emissions in their model for BRICS countries.

Assessing the impact of the European Green Deal on EU cereal production is a complex task with limitations. The long-term effects of the strategy are still unknown, and a comprehensive analysis of the impacts requires access to detailed data. Additionally, cereal production is influenced by various factors, including climate change and market trends. Therefore, it is essential to interpret the conclusions and recommendations in this text with these limitations in mind. The provisions of the Green Deal also could change as a result of various factors, including pressure from trade unions, agricultural producers and social tensions.

The article is divided into four sections. The first section is the introduction, followed by a review of the existing literature. The third section provides a detailed description of the variables, the model specification, and the econometric method. The final section presents the empirical results and discussions. Conclusions and practical implications are also presented in this section.

LITERATURE REVIEW

The theories and concepts related to cereal production include the necessity of increasing cereal yield to ensure food security [Oishi 2021]. There is a gap in cereal production between developing and developed countries due to the lack of capital, technology and human resource skills in developing countries [Zhang and Long 2013]. The relationship between population undernourished and cereal production has been analysed using grey system theory, and it has been found that promoting cereal production can help reduce undernourishment [Wood and Lenné 2018]. Factors affecting cereal production are diverse and their relative importance may change in the future [Adviento-Borbe 2020].

The Green Deal proposes the establishment of a green economy with zero emissions, based on renewable energy sources. It also aims to promote sustainable agriculture [Fayet et al. 2022], which meets current food and material needs without compromising the ability of future generations to do the same [Prandecki et al. 2021]. The Green New Deal for agriculture focuses on combating environmental degradation, social inequality, and improving crop efficiency [Selwyn 2022]. These actions aim to enhance the resilience of food systems, ensuring their capacity to provide sufficient, adequate, and accessible food in the face of environmental challenges [Blake 2020].

The implementation of green transformation in agriculture involves various measures, including the reorientation of state subsidies, attention to the rights of agricultural workers, reform of agricultural relations, decommodification of food, agroecology, and the application of new technologies in agricultural production [Adamowicz 2021]. The European Green Deal strategy aims to achieve ambitious climate and environmental goals. To achieve this, a complex, multi-pronged approach to agricultural policy is required, which includes greater consideration of non-productive aspects such as environmental protection [Wrzaszcz and Prandecki 2020]. The Common Agricultural Policy (CAP) in the European Union places increasing emphasis on developing environmentally friendly forms of agriculture, as reflected in subsequent standards and measures [Rudnicki et al. 2021].

The green transformation in agriculture has both positive and negative aspects. The positive aspects include the drive to transform agricultural practices towards environmentally friendly activities. This transformation will require substantial investment and research, which could increase labour demand, accelerate structural transformation, and offset the adverse effects of climate change [Nico and Christiaensen 2023]. Conversely, increasing the proportion of organic farming could enhance the quality and characteristics of agricultural products and food, thereby positively impacting human health [Li et al. 2022].

There are concerns among consumers and agricultural producers regarding the potential negative consequences of implementing green agriculture as part of the 'Farm to Fork' strategy proposed by the European Commission. This strategy, which is part of the European Green Deal, aims to establish sustainable agri-food production and distribution processes [Poczta et al. 2023, Szajner and Szczepaniak 2023]. To implement the strategy's objectives, it is necessary to reduce the use of pesticides and fertilisers, reclaim arable land, increase the share of organic farming, reduce CO_2 emissions from agriculture, and increase the use of renewable energy [Szubska-Włodarczyk 2023].

Wesseler [2022] highlights that the proposed solutions may negatively impact agricultural production, the availability of agricultural products to consumers, and global food prices. Beckman et al. [2020] conducted an economic assessment of the Green Deal assumptions in agriculture and found that there is potential for a decline in EU agricultural production, a net loss of welfare, and transition costs for consumers.

The energy transition targets as well as the CO_2 reduction from agriculture set by EU countries should be regarded as ambitious. To date, however, there have been few econometric studies analysing the effects of the proposed regulations. Köprücü and Acaroğlu [2023] and Xiang and Solaymani [2022] note that there is a scarcity of scientific papers that concentrate on the ecological-environmental impact of climate change on agricultural production, particularly cereals, using advanced econometrics.

Chandio et al. [2022] demonstrated, using the Autoregressive distributed lag (ARDL) model, that CO_2 has a significant negative impact on cereal production in both the short and long term in Bangladesh. Similarly, Abbasi [2021] found, using a combination of ARDL and vector error correction model (VECM) models, that an increase in CO_2 emissions in agriculture leads to a decrease in cereal production productivity in China. Simionescu et al. [2019], used 2000-2016 data for the European Union and applied the FGLS model and the generalized method of moments. They found a positive effect of GHG emissions on cereal production. Kumar et al. [2021] used a combination of FGLS and fully modified ordinary least squares (FMOLS) models for lower- and middle-income countries and indicated a positive impact of increased CO_2 on cereal production. In contrast, Demirhan [2020] analysed global data and found that rising temperatures lead to a decrease in wheat yields. The study also highlights the negative impact of climatic instability on agriculture as a whole. Furthermore, individual studies have been conducted on the effects of climate change on cereal yields in specific countries such as Pakistan [Ahsan et al. 2020], India [Baig et al. 2020] and Turkey [Chandio et al. 2020], indicating a long-term relationship with varying impacts.

Additionally, several studies have examined the impact of changes in arable land on cereal production. Abbasi et al. [2021] confirmed that an increase in arable land devoted to cereals has a positive effect on crop productivity in China, using the ARDL model. Similarly, Ahsan et al. (2020) found that an increase in arable land in Pakistan has a positive impact on cereal production using the same model. Abdullahi et al. [2023] also reported similar estimates for Nigeria. Research conducted by Köprücü and Acaroğlu [2023] has shown a positive correlation between fertiliser consumption and yields of wheat, barley, and maize in Turkey. Similarly, Zwane et al. [2022] found similar results for selected African countries using the FMOLS methodology.

There is a scarcity of recent econometric studies on the correlation between food production and cereal production. Kibria et al. [2023] used the FMOLS model to demonstrate that increases in the food production index (FPI) and land use lead to an increase in cereal production in South Asia. Kibria et al. [2023] and Abbasi et al. [2021] have confirmed that the increase in cereal production in China is induced by an increase in the food production index.

Currently, there are no large-scale studies using econometric modelling on the relationship between renewable energy and crop production. However, Koondhar et al. [2021] have determined that there is a positive relationship between overall energy use and agricultural production in Pakistan. The study by Rahman et al. [2020] confirmed the same conclusion for Bangladesh.

In spite of the problem's relevance, there is a significant research gap in the area under investigation. The literature review clearly indicates that no empirical studies using panel econometric models have been conducted on the impact of green transformation on agriculture and cereal production in the European Union. Therefore, this study fills the identified gap and provides new scientific evidence.

METHODS

Data sources and variables

The model development process utilized panel data, encompassing both time series and cross-sectional data. The empirical study analysed data from the World Bank's database (World Development Indicators), the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Framework Convention on Climate Change (UNFCCC) for 21 European Union countries from 1995 to 2021. From research group excluded Belgium, Cyprus, Luxembourg, Malta, and Slovenia due to incomplete or lack of data for the studied variables.

The literature review was conducted using the Scopus and Web of Science databases. Based on a thorough literature study and the clearly stated aim of the study, the selection of variables was made. Table 1 presents all variables used in the study and their sources.

Table 1: Variables and Sources

Variables	Symbol	Measure	Dataset source
Cereal production	CP	tons	FAO
Carbon dioxide emission from agriculture	ACO2	kilotons	UNFCC
Land under cereal production	CLS	hectares	WDI
Food production index	FPI	2014-2016 = 100	WDI
Fertilizer consumption	FZ	kilograms per hectare of arable land	WDI
Renewable energy consumption	REW	% of total energy consumption	WDI

Source: Author's own research.

The econometric framework

The research procedure involves conducting preliminary data analysis and selecting the best model based on the data properties. The first stage of the study was the identification of the presence of cross-sectional dependence in the panel data under study, which is a common problem in economic aggregates [Wooldridge 2010]. Cross-sectional dependence tests using the Breusch-Pagan Lagrange Multiplier (LM) are recommended when T>N and N is not asymptotic [Baltagi et al. 2012]. Serial correlation and group heteroskedasticity were analyzed in the panel data under study. Heteroskedasticity was tested using White's [1980] test, while autocorrelation was tested using the Wooldridge [2001] approach. Robust estimators must be used if these properties are present, making testing for them crucial.

The study utilized the Dumitrescu-Hurlin [2012] panel causality test to establish causality between the variables. This test is appropriate for time series where T>N and accounts for panel data heterogeneity. The results confirm the existence of a causal relationship between the variables. A bootstrap is employed to enhance test outcomes when dealing with CSD.

To test for stationarity, this study uses two second-generation unit root tests that are robust to the presence of CSD: the Dickey-Fuller extended cross-section (CADF) test and the CIPS test - Im, Pesaran and Shin [Im et al. 2003]. The lags were determined according to the AIC criterion. Variables were tested at both levels and transformations to first differences.

To identify long-run dependencies, the study uses robust cointegration tests suitable for cross-sectional dependencies, as proposed by Westerlund [2007]. The test confirms the presence of cointegration by detecting error correction for individual panel members or for the panel as a whole. The bootstrapping method can be used to obtain reliable results when cross sectional units are suspected to be dependent.

In this study, the long-term impact of the climate strategy of the European Union on the agricultural sector was determined using the FGLS model. This model was chosen due to its suitability for large data sets (where T>N) that exhibit problems with heteroskedasticity, serial correlation, and cross-sectional dependence [Bai et al. 2021]. The following formula represents the precise form of the FGLS model [Fomby et al. 1984]:

$$\hat{\beta}_{FGLS} = (X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y$$
$$Var(\hat{\beta}) = (X'\hat{\Omega}^{-1}X)^{-1}$$

The model under study is presented in the following initial form:

$$CP = f(ACO2, CLS, FPI, FZ, REW) \tag{1}$$

The following equation can be derived from the above:

$$CP_{2,it} = \alpha + \beta_1 ACO2_{it} + \beta_2 CLS_{it} + \beta_3 FPI_{it} + \beta_4 FZ_{it} + \beta_5 REW_{it} + \varepsilon_{it} \tag{2}$$

where α is the intercept, i and t represents countries and time individually, β1... β5 are the coefficients of the independent variables and ε is the error term. After logarithmic transformation, the analytical form of the model was determined as follows:

$$lnCP_{2,it} = \alpha + \beta_1 lnACO2_{it} + \beta_2 lnCLS_{it} + \beta_3 lnFPI_{it} + \beta_4 lnFZ_{it} + \beta_5 lnREW_{it} + \varepsilon_{it} \quad (3)$$

A robustness check was carried out using alternative methods to ensure a stable and consistent model. A regression model with panel-corrected standard errors (PCSE) was estimated. PCSE is similar to linear regression but is more robust to heteroskedasticity, CSD and autocorrelation [Beck and Katz 2011]. Furthermore, the model's robustness was tested using a second-generation panel model based on the Common Correlated Effects Mean Group (CCEMG) estimator. This estimator is known to be robust to cross-sectional dependence and heteroskedasticity [Pesaran 2006].

RESULTS

Descriptive analysis

During the initial phase of the study, a preliminary analysis of the data was carried out. Descriptive statistics and correlations were examined. Table 2 presents the descriptive statistics, which clearly demonstrate the mean, median, maximum, minimum, and standard deviation.

Table 1. Descriptive statistics.

Variable	Obs	Mean	Min	Max	Std. dev.
lnCP	567	15.705	12.903	18.107	1.170
lnACO2	567	9.754	7.882	11.810	1.021
lnCLS	567	14.230	12.251	16.089	1.073
lnFPI	567	4.556	4.113	4.906	0.119
lnFZ	567	4.885	3.089	7.542	0.686
lnREW	567	2.679	0.647	4.067	0.735

Source: Author's own research.

Table 3 presents the results of the correlation analysis. The study variables demonstrate moderate to low correlation. Notably, lnCP exhibits a moderate and positive correlation with lnACO2 (0.624), lnCLS (0.651), and lnFPI (0.354). Additionally, lnACO2 has a moderate positive correlation with lnCLS (0.710). However, lnFPI only shows a weak positive correlation with lnFZ (0.166). The Variance Inflation Factor (VIF) value of 1.860 confirms the absence of any multicollinearity issue.

Table 2. Pairwise correlations

Variable	lnCP	lnACO2	lnCLS	lnFPI	lnFZ	lnREW
lnCP	1.000					
lnACO2	0.624	1.000				
lnCLS	0.651	0.710	1.000			
lnFPI	0.354	0.231	0.221	1.000		
lnFZ	0.088	0.217	-0.118	0.166	1.000	
lnREW	-0.329	-0.270	-0.310	-0.163	-0.338	1.000

Source: Author's own research.

Table 4 presents the results of the Pairwise Dumitrescu-Hurlin Panel Causality Tests, which are suitable for panel data when T>N. To strengthen the findings regarding the presence of CSD, a bootstrap with 800 replications was also used. The results demonstrate bidirectional and unidirectional causality between the variables. The results identify predictive relationships based on statistical patterns in the data. The time-series studied can be used in the econometric modelling process.

Table 3. Pairwise Dumitrescu Hurlin Panel Causality Tests

Causality	Zbar-Stat.	Causality	Zbar-Stat.
ACO2 → CP	12.429 ***	ACO2 → FZ	4.856 *
CP → ACO2	0.8587	FPI → ACO2	2.173
CLS → CP	7.3440 ***	ACO2 → FPI	10.714 ***
CP → CLS	6.3832 ***	REW → CLS	12.398 ***
REW → CP	3.2634 **	CLS → REW	2.534
CP → REW	2.3898 *	FZ → CLS	5.308 **
FZ → CP	8.9655 ***	CLS → FZ	2.476
CP → FZ	1.352	FPI → CLS	4.257 **
FPI → CP	2.713 **	CLS → FPI	9.052 ***
CP → FPI	7.772 ***	FZ → REW	5.392 *
CLS → ACO2	3.568	REW → FZ	4.882
ACO2 → CLS	8.363 ***	FPI → REW	6.695 ***
REW → ACO2	8.906 **	REW → FPI	7.121 **
ACO2 → REW	13.599 ***	FPI → FZ	1.922

FZ → ACO2	6.883 **	FZ → FPI	5.441 **

Note: The significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denotes 10%, 5%, and 1% significance level, respectively. Source: Author's own research.

Preliminary analysis included performing the Wooldridge autocorrelation (AR1) test using the F statistic, which confirmed the absence of first-order autocorrelation. To test for homoskedasticity of the study variables, the White test based on the chi-square test statistic was used, and it confirmed the presence of heteroskedasticity.

Prior to estimation, cross-sectional dependence tests were also conducted between variables. Table 5 presents the results of these tests. The variables in the panel have T>N, and tests based on a Lagrange Multiplier Breusch-Pagan were applied to determine their characteristics. The results of the test indicate that the variables used exhibit cross-sectional dependence for all countries. Therefore, the models must be estimated using estimators that are robust to cross-sectional dependence.

Table 5. Results of cross-sectional dependence test

Variable	Statistic (χ^2)	p-value
lnCP	780.080	0.000
lnACO2	1140.726	0.000
lnCLS	1189.964	0.000
lnFPI	997.287	0.000
lnFZ	1079.128	0.000
lnREW	1540.556	0.000

Source: Author's own research.

The study tested the stationarity of variables using the IPS and CADF tests, which are robust to cross-sectional dependence. Lag determination was based on the Akaike information criterion (AIC). Table 6 shows the results of the two-unit root tests applied, indicating that all variables are stationary at I (1) and none are stationary at I (2). The results of the CIPS test confirm that the variables lnCP, lnACO2, lnFPI, lnCLS, and lnREW are stationary in both I(0) and I(1). Additionally, the CADF test confirms that lnCP and lnREW are stationary at both the level and first difference.

Table 6. Results of the unit ring test

Variable	CIPS		CADF	
	Level	1st Difference	Level	1st Difference
lnCP	-4.390 ***	-6.096 ***	-2.531 ***	-4.662 ***
lnACO2	-1.708 **	-4.655 ***	-1.944	--3.529 ***
lnCLS	-2.295 **	-5.542 ***	-1.835	-3.921 ***
lnFPI	-3.002 ***	-5.987 ***	-1.967	-4.475 ***
lnFZ	-1.802	-5.575 ***	1.400	-3.297 ***
lnREW	-2.726 ***	-5.247 ***	-2.293 ***	-3.694 ***

Note: CIPS and CADF critical values: -2.07 for 10%, -2.15 for 5% and -2.3 for 1%. Source: Author's own research.

Table 7 presents the results of the Westerlund cointegration test based on the Error correction model (ECM). For data with cross-sectional dependence, these tests are appropriate. To ensure robust results under CSD conditions, test with a bootstrap with 800 replications was performed. The probability results for all G and P parameters reject the H0 hypothesis of no cointegration and confirm strong cointegration between the selected variables. Therefore, estimation methods such as FGLS, CCE, and PCSE can be applied.

Table 7. Westerlund ECM panel cointegration tests

Statistic	Value	Z-value	P-value	Robust P-value
Gt	-4.091	-8.523	0.000	0.000
Ga	-12.819	-0.654	0.257	0.000
Pt	-18.427	-8.023	0.000	0.000
Ba	-13.563	-3.188	0.001	0.000

Source: Author's own research.

Model estimation and disccusion

The FGLS model, which is robustness to cross-sectional dependence and heteroskedasticity, was used to achieve the study's objectives and to account for the characteristics of the variables [Fomby et al. 1984]. In addition, a bootstrap-based method of standard error estimation with 800 replications was used to further strengthen the results. Additionally, a control estimation was performed using the PCSE and CCEMG models to verify the robustness of the results. Both control estimations utilized a bootstrap. The results of the long-run estimation of the FGLS model are presented in Table 8.

Table 8. Result of FGLS estimation

Variable	Coefficient	Standard errors	z -statistic	p-value
lnACO2	-0.048	0.016	-2.980	0.003
lnCLS	1.102	0.018	61.630	0.000
lnFPI	1.135	0.081	13.960	0.000
lnFZ	0.375	0.014	25.920	0.000
lnREW	0.109	0.017	6.510	0.000
Constant	-6.796	0.329	-20.650	0.000

Note: The significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denotes 10%, 5%, and 1% significance level, respectively. Wald Chi^2 21137.18, prob. 0.000.

Source: Author's own research.

The results obtained for CO_2 emissions from agriculture indicate that they have a statistically significant and negative impact on the volume of cereal production in the European Union. A 10% increase in CO_2 emissions from agriculture leads to a 0.5% decrease in cereal production on average over the long term. These results therefore suggest that it is in the interest of both Member States and farmers themselves to limit the growth of CO_2 emissions from agriculture. Indeed, excessive carbon dioxide emissions can cause adverse weather events and unstable climatic conditions, which will contribute to lower crop yields.

These results are not in line with the study by Simionescu et al. [2019], which shows a positive impact of CO_2 on cereal production in the European Union, using data for the period 2000-2016. This difference may be due to the fact that this study uses a longer time series, allowing more robust conclusions to be drawn for a longer time horizon. However, the results of this study confirm the observations of Ben Mariem et al. [2021] and Wang and Liu [2021] hat while CO_2 may provide some short-term benefits for cereal production under controlled conditions, these benefits are not sustainable in the long term. Addressing the broader challenge of climate change and its impact on agriculture is critical to ensuring long-term food security.

The estimation results suggest that there is a positive relationship between the size of the area sown and the yield. Specifically, the data indicate that a 1% increase in the area sown leads to a 1.1% increase in the volume of cereal production. These results are consistent with Abbasi et al. [2021] and Abdullahi et al. [2023]. According to Yu et al. [2019], the multiplicity of cultivated areas is a significant factor in promoting production growth and influencing food security. The authors suggest that optimizing productivity, including the better utilization of cultivated land, is imperative within the context of sustainable development. The results indicate that the implementation of the European Green Deal in agriculture, which aims to reduce arable land by 10%, may have a significant impact on cereal production across the EU. To ensure food security and maintain current cereal production levels, it may be necessary to explore options to increase crop productivity. One potential solution that could be considered is organic farming. However, as suggested by Röös et al. [2018] in order for organic farming to make a greater contribution to sustainability in the food system, it may be necessary to explore and accept new sources of plant nutrients. This could involve greater nutrient recycling within society, the use of mineral nitrogen fertilisers from renewable sources in certain circumstances, and the adoption of alternative livestock production systems.

The EU's climate targets do not explicitly address the matter of food production volumes. Nevertheless, they do have an impact on agricultural practices and policies, which in turn affect food security. According to the study's findings, an increase in the food production index results in a corresponding increase in cereal production. Specifically, if the index increases by 1 percentage point, cereal production will increase by 1.13% in the long run.

These findings are consistent with Abbasi et al.'s [2021] study, which showed that an increase in FPI affects CO_2 emissions, with a greater impact observed in the European Union than in China. Likewise, Kibria et al. [2023] verified that an increase in FPI can result in increased cereal production in Southeast Asian countries. According to Bernabéu et al. [2023], the implementation of the European Green Deal may result in an increase in agricultural and food prices due to the rise in production and supply costs. As per Green et al.'s [2013] research, a 1% increase in cereal prices can lead to a 0.61% decrease in consumption, which could have a direct and negative impact on the volume of cereals produced in EU countries.

The model suggests that a 1% increase in fertiliser use per hectare of crop leads to a 0.38% increase in cereal production. These findings are in line with Simionescu et al.'s [2019] study, albeit indicating a slightly smaller impact of fertilisers on cereal crops. The parameters obtained in this study are comparable to the results of the model estimated by Köprücü and Acaroğlu [2023] for Turkey.

Taking into account the climate policy objective of reducing mineral fertiliser use by 20% by 2030 and the evidence from models and literature, it is possible that cereal yields in EU countries may experience a decrease. Considering the presented results and references to other studies, hypotheses H1 and H3 are confirmed.

The final variable analysed in relation to agricultural transformation in the surveyed European Union countries was the rise in the proportion of renewable energy. It is recommended by the REPowerEU programme that member states should aim for 45%

renewable energy usage by 2030. According to the model, a 1% increase in renewable energy usage results in a 0.11% increase in cereal production volume.

The positivistic relationship between renewable energy and cereal production corresponds with the study of Monforti et al. [2013] who indicate that cereal crop residues can generate significant bioenergy resources in the European Union. Thus, an increase in the share of renewable energy may represent an opportunity for cereal producers, by providing a raw material for biomass gasification [Centi et al. 2019].

This approach not only offers a source of renewable energy but also aids in the management of waste from cereal production. The increase in the share of renewable energy sources can contribute to the reduction of environmental degradation, as suggested by Dogana and Sekera [2016] and Jebli and Youssef [2017]. According to Kumar et al. [2021], enhancing the quality of the environment can stabilize weather patterns and rainfall, leading to increased crop production. Therefore, the results confirm hypothesis H2.

Appendix (Fig. 1 – 5) presents average marginal effects plots, which graphically represent the obtained results. These plots show how the dependent variable is affected by the marginal increase in the independent variable, assuming the ceteris paribus principle. To test the robustness of the results, estimations were made using the PCSE and CCEMG methods, which are known for their robustness to heteroskedasticity and cross-sectional dependence. Table 9 presents the results of the control models.

Table 9. Robust check

Variable	PCSE	CCEMG
lnACO2	-0.050 * [0.014]	-0.082 *** [0.026]
lnCLS	1.090 * [0.015]	0.630 * [0.140]
lnFPI	1.148 * [0.077]	1.640 * [0.210]
lnFZ	0.369 * [0.014]	0.212 *** [0.042]
lnREW	0.099 * [0.014]	0.100 *** [0.06]
Constant	-6.628 * [0.342]	2.49 * [0.126]
R2	0.959	0.910

F-statistic		4.41 *
Chisq	12455.96 *	

Note: The significance of the coefficients is indicated by an asterisk in the tables, where *, **, *** denotes 10%, 5%, and 1% significance level, respectively. [] are standard errors.

Source: Author's own research.

The results confirm the robustness of the estimation carried out with the FGLS model, as both the PCSE and CCEMG models have significant coefficients with values similar to the FGLS model. However, it should be noted that the coefficients for the CCEMG model exhibit more variability due to the different estimation technique used. Both models confirm the robustness of the model used and its ability to make inferences about the studied phenomena. It is important to acknowledge the validity of these findings and consider them in future research.

CONCLUSIONS

This article explores the effects of the European Union's climate policy and strategy on cereal production in 21 member countries from 1995 to 2021. The study employed various models, including FGLS to account for heteroscedasticity and cross-sectional dependence, and PCSE and CCEMG as controls to validate the findings. The study suggests that the impact of the green transition on agriculture in EU countries is intricate and diverse. Nevertheless, the study provides significant new insights that can guide policy decisions and future Green Deal implementation efforts.

The results of the study show that the areas which are regulated by the European Union's climate policy have a significant impact on cereal production in the countries studied. Changes in the size of cultivated areas and in the number of fertilisers used can have a significant impact on reducing the volume of cereal crop production. Changes in food production volumes also have a significant impact on the yields of European agriculture. These areas require the creation of appropriate regulations which will provide protective measures for farmers in European Union countries, and which will not lead to a decrease in food availability.

The energy transition presents opportunities for agricultural producers. One such opportunity is the use of waste from cereal and crop production to produce biogas. This not only improves climatic conditions but also provides green energy for agriculture to increase production efficiency. In the long term, it is believed that reducing CO_2 emissions from agriculture and economic activities could potentially improve climatic stability, increase crop production volume, and reduce the risk of anomalies.

With regards to the policy implications of the results obtained, it is worth noting that supporting farms during the green transition in agriculture can help to minimize negative effects. Furthermore, it is crucial to educate and inform the public about the positive aspects of these activities. It is recommended that policy makers provide tax and legal incentives for investments in organic crop production and energy production in biogas plants.

This study has some limitations, such as the relatively short time period for which the data was collected. It is possible that more precise results could be obtained with a longer time series. Furthermore, the study focuses on the European Union countries as a whole, and it may be beneficial for future analyses to consider a regional or income-based breakdown of these countries. This will facilitate a more precise examination of the issue, considering regional disparities and enabling the proposal of customized solutions on a more localized level.

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Appendix - FGLS model average marginal effects

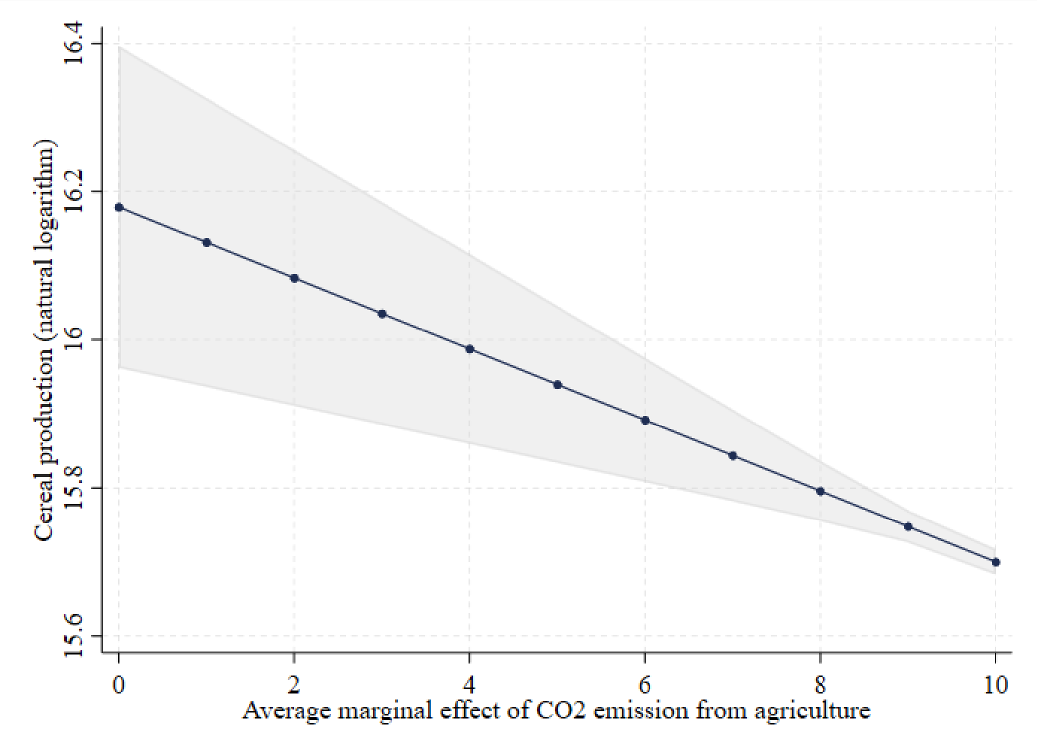

Fig. 1. Average marginal effect of CO_2 emissions from agriculture on cereals production

Source: Author's own research

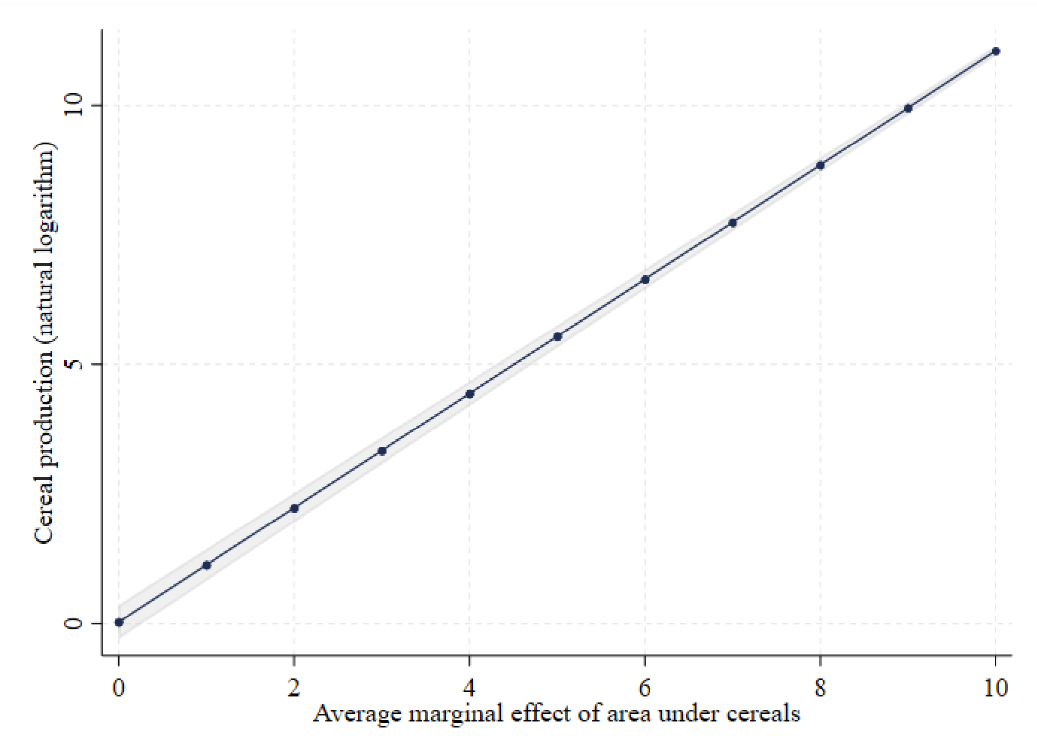

Fig. 2. Average marginal effect of land under cereal production on cereal production

Source: Author's own research

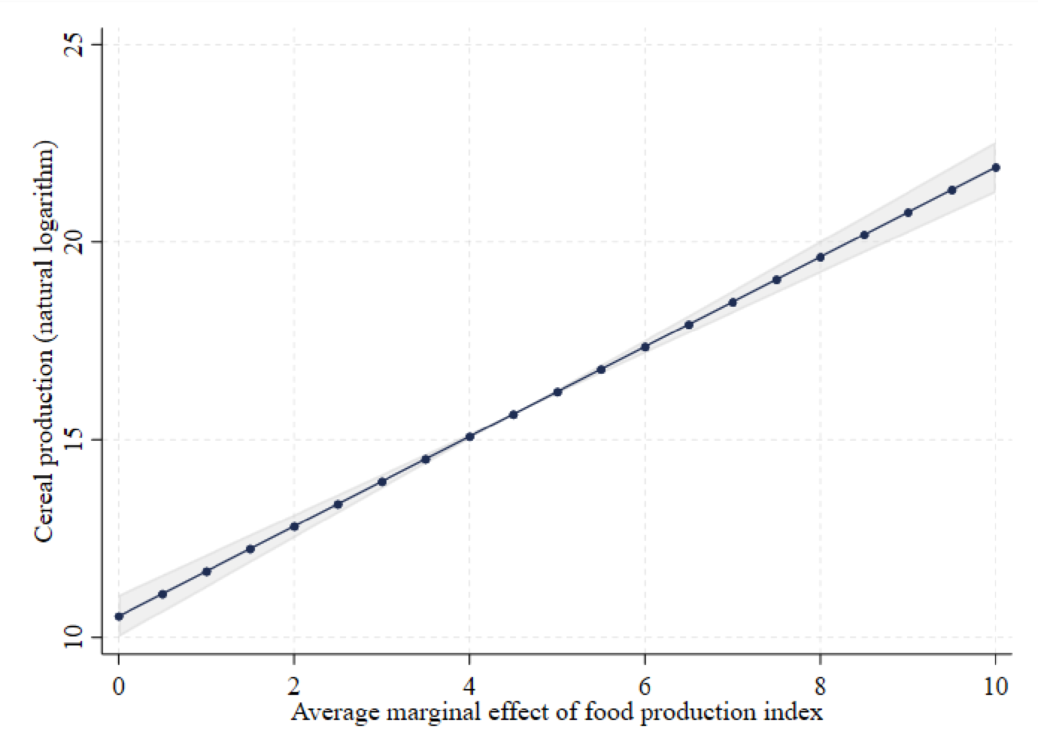

Fig. 3. Average marginal effect of food production index on cereals production

Source: Author's own research

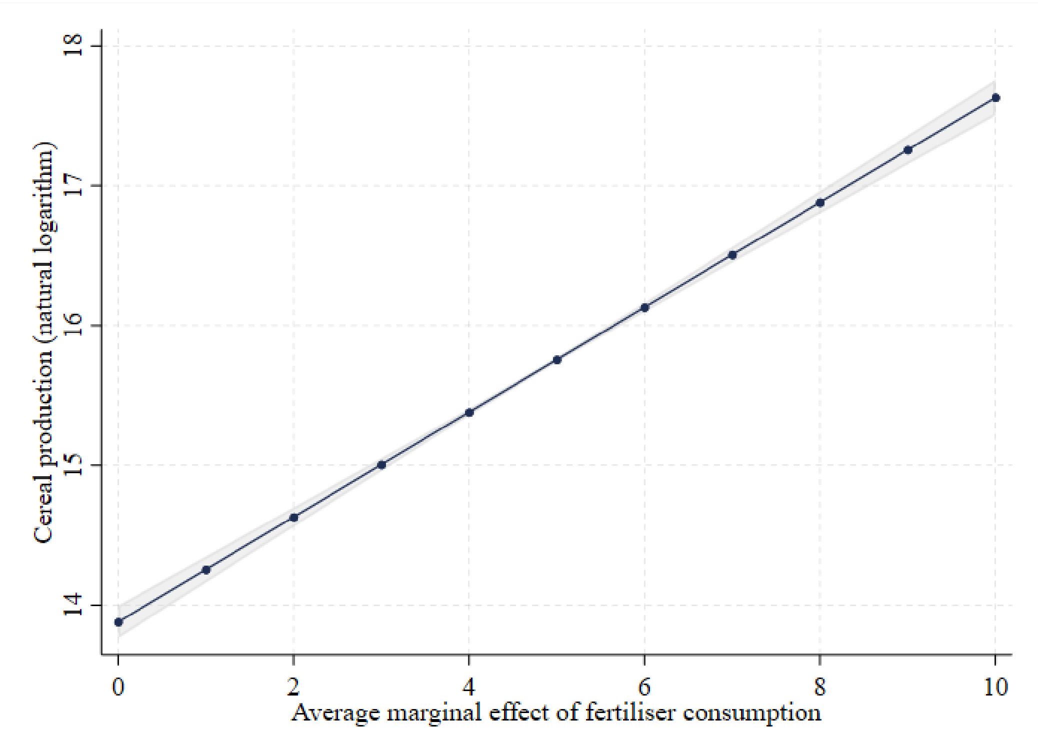

Fig. 4. Average marginal effect of fertilizer consumption on cereals production

Source: Author's own research

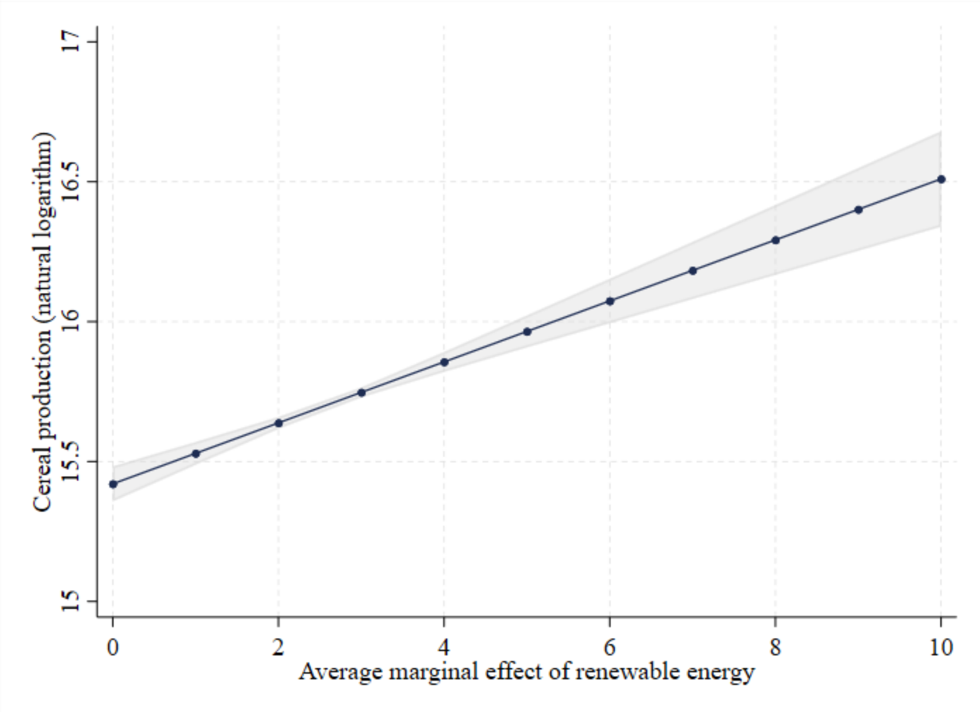

Fig. 5. Average marginal effect of renewable energy share on cereals production

Source: Author's own research