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Exploring the Dynamic Relationships between Agricultural Production and Environmental Pollution: Evidence from a GMM-SYS Model in the Three Seas Initiative (3SI)

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Abstract: Three Seas Initiative (3SI) is still an underresearched area and is particularly important due to historical circumstances and economic backwardness. A study was carried out to assess the impact of renewable energy and production generated by the agricultural sector on CO2 emissions in 3SI countries between 2008 and 2020. The study used panel data analysis based on the two-step system generalised method of moments (GMM) and the Dumitrescu-Hurlin panel causality test. The results show that a 1% increase in the value-added generated by agriculture increases CO2 emissions in the countries studied by 0.11%. In contrast, a 1% increase in GDP leads to a 0.29% increase in CO2 emissions. Conversely, when renewable energy consumption increases by 1%, CO2 emissions fall by 0.25% in the countries studied. One way to reduce CO2 emissions from agricultural production in the short term is to increase the share of renewables, which, incidentally, is in line with EU action.

Keywords: agricultural production; agriculture; gmm system; renewable energy; three seas initiative

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1. Introduction

Climate change is one of the most important challenges facing the European and global economy today. Especially in times of constant change and geopolitical tensions, volatile energy and food prices are a major source of instability for global economic growth [1]. Energy, food production, agriculture and climate change are closely related concepts that need to be considered together, especially in a globalised environment [2].

The global challenges of combating global warming while maintaining economic growth are prompting many countries to take joint initiatives. The Three Seas Initiative (3SI) is a platform for regional cooperation established in 2016 by representatives of twelve European Union Member States: Austria, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. The area encompassed by the 3SI accounts for almost one-third of the total area of the European Union, and the population is more than 112 million people.

The 3SI is intended to lead to deeper European integration and strengthen EU cohesion, including by developing communication infrastructure, strengthening energy security and supporting the digital economy in Central Europe [3]. Undoubtedly, increasing energy security through a common, well-functioning energy market and diversifying energy sources and suppliers for all member countries are among the main challenges of 3SI member countries [4].

The energy sector is one of the primary sources of greenhouse gas emissions, including CO_2; therefore, significant investment is needed to ensure climate protection and the implementation of sustainable development policies. Therefore, the choice between renewable and nonrenewable energy sources has become a critical decision for all countries worldwide [5,6]. In turn, agricultural production plays a crucial role in food security, but agricultural activities are also associated with the emission of significant amounts of N_2O and methane (CH_4) into the atmosphere [7,8].

There is a two-way relationship between the broader agricultural sector and climate [9]. On the one hand, agriculture requires the right climatic conditions (temperature, sunshine, precipitation and other aspects of climate that affect agricultural productivity); on the other hand, agricultural production is responsible for at least 9% of GHC emissions [10]. The main causes of these emissions are gases from soil management practices, livestock production and fossil fuel consumption [11].

The adoption of stringent standards by European Union countries to reduce greenhouse gas emissions by 2050 could pose a significant challenge for the agricultural sector. Moreover, the agricultural sector can seize the opportunity to arise from the energy transition through participation in renewable energy generation and the use of low-carbon agricultural production techniques [12].

With these aspects in mind, this study aimed to assess the impact of renewable energy and production generated by the agricultural sector on CO_2 emissions in 3SI countries for the 2008–2020 period. The following research hypotheses were established for the study:

H1: Agricultural production and economic growth both contribute to the release of CO_2 emissions in the short term in the Three Seas Initiative region.

H2: An increase in the use of renewable energy in 3SI countries is linked to a reduction in CO_2 emissions in the short term.

To achieve the stated objective and verify the research hypotheses, the two-step system generalised method of moments (GMM) was proposed by Arellano and Bover [13] and Blundell and Bond [14], as this method provides consistent and robust results for short-term panel data. The two-step GMM procedure allows the results to be highly reliable, even in the presence of endogenous regressors. In addition, a causality analysis based on the Dumitrescu-Hurlin panel test was applied [15] to classify variables and select instruments properly. The study used data for the 2008–2020 period.

The novel aspects of this study can be summarised as follows. First, the study analyses the countries of the 3SI initiative, which is a new venture in Europe, and examines aspects of the group’s functioning that have not been analysed before. At the same time, the study is intended to stimulate discussion on the subject of this initiative and to contribute to future research. We also analyse the links between agriculture and economic emissions for European countries, providing new evidence in this area. To date, much of the research on agriculture, energy and the environment has focused on countries in Asia and Africa. However, agriculture plays an important role in European countries, and the challenges facing the sector in the context of energy transition are an important political and economic issue.

Second, the model used in the study, the two-stage panel GMM, has an advantage over other approaches used so far in that it allows not only the study of causality, but also the study of the absolute impact of factors in the short term. This is an important extension, as causality studies in the Granger sense alone do not necessarily provide information on the direction of the relationship. The GMM approach is complemented by the identification of the interaction between agricultural activity and CO_2 emissions.

Finally, to the best of our knowledge, no previous studies have considered the impact of renewable energy and agricultural production on CO_2 emissions in the Three Seas Initiative countries.

The article is structured in four sections. A review of the literature follows the introduction. The third section describes the variables in detail, the model specification, and the description of the econometric method. The empirical results and discussion are presented in the final fourth section. Conclusions and practical implications are presented in the fourth section.

2. Literature Review

Over the past decade, researchers have increasingly focused on the relationship between pollution and broad economic categories. The scientific community’s collective work is expected to contribute to the development of emission reduction strategies. The literature focuses on many aspects of the relationship between CO_2 emissions and human economic activity. Carbon dioxide has been identified in most studies as the main cause of global warming [16,17].

The relationship between economic development and environmental degradation or quality can be broken down into three effects: scale effects, composition effects, and technical effects. As production increases, environmental pressures also increase, but these pressures can be counteracted by the other two effects [18,19]. Most studies use the environmental Kuznets curve (EKC), which depicts the relationship between CO_2 emissions and economic growth [20].

Research on EKC is twofold. The first section focuses on the causal relationships between economic development and environmental pollution, using a high level of generalization due to the data aggregates [21]. The second aspect focuses on the relationship between economic parameters and energy consumption, as greenhouse gas emissions are mainly caused by the economic use of natural resources, including fuels [22].

Numerous works have been created in this area, with increasingly detailed analyses. Their common feature is the focus on the Environmental Kuznets Curve (EKC) as the main cause of environmental degradation in various aspects of human activity. To date, the impact of macroeconomic determinants such as globalisation on CO_2 emissions has been analysed and determined by econometric methods [22], population growth [23], urbanisation [24], and investment [25]. The last strand of research, based on global trends related to the energy transition, addresses the impact of renewable energy sources and sustainable production practices on environmental pollution [26]. Some researchers have combined economic growth, CO_2 emissions, and the use of conventional and renewable energy[25,26].

The research concludes that in developing economies, there is a positive relationship between GDP and CO_2 emissions [29]. In contrast, developed countries experience a negative impact of economic growth on pollution, as shown by the U-shaped EKC curve [30]. The use of modern econometric techniques, such as NARDL, confirmed the non-linear and asymmetric effects of economic growth and economic variables on CO_2 emissions [31,32]. The researchers noted that technological progress, education, and globalization can mitigate the negative effects of pollution resulting from economic development [33–35].

Most studies also agree that non-renewable energy has a positive impact on the growth of emissions from human economic activity [27,36]. The answer to ensuring both economic growth and adequate energy supplies, researchers say, lies in renewable energy [26,37,38]. To gain a deeper understanding of the impact of renewable energy on CO_2 emissions, studies are continuously being conducted using updated data resources and modern econometric methods. However, contradictory results are often found, and specific conclusions depend on the region analysed and the econometric method used [39].

Recent research has also examined the impact of individual industries on CO_2 emissions and the development of applied economic policies. Moreover, studies on the impact of agricultural activities on CO_2 emissions have also emerged. Global warming may have a negative impact on farm operations and agricultural production [40,41], while agriculture contributes to greenhouse gas emissions [42]. In view of the above, most studies conclude that there is a bidirectional causality between agriculture and CO_2 emissions [33]. Jebli and Youssef [43], based on African countries, indicated that increased production in agriculture reduces CO_2 emissions in the long term. Using Pakistan as an example, Waheed et al. [9] indicated that an increase in agricultural production leads to an increase in CO_2 emissions. Using the example of CEE countries, Florea et al. [44] confirmed this relationship; Zafeiriou and Azam [45] for Mediterranean countries; Yan et al. [46] for European Union countries; and Jeremiás for large non-EU countries [47].

Farming also influences soil degradation by increasing the surface area of agricultural land at the expense of forested areas and grasslands [48]. Mu et al. [49] indicated from the U.S. that there are bidirectional relationships between CO_2 emissions and agricultural land area. [23]Using China as an example, Pachiyappan et al. showed that an increase in agricultural land area has a positive effect on the increase in GHC emissions. Similar conclusions were also obtained in studies of European countries [50].

Moreover, it should be emphasised that the vast majority of scientific studies see an opportunity for sustainable and low-carbon agriculture in terms of renewable energy sources [51]. Previous studies have shown that renewable energy has an impact on CO_2 reduction and has a positive impact on the volume of agricultural production [9,43,44]. Numerous studies have found causal relationships between the agricultural sector's production volume and the share of renewable energy in total energy consumption. For example, in Tunisia, bidirectional causal links have been observed between agricultural production volumes, renewable energy use and per capita carbon dioxide emissions [52]. Similarly, a sample of BRICS countries (Brazil, Russia, India, China and South Africa) found unidirectional causal links running from renewable energy to CO_2 emissions [53]. Numerous research findings highlight the importance of integrating renewable energy into agricultural practices to address environmental concerns, promote sustainability and counter the effects of climate change [54].

Previous studies on the linkage between agricultural production, renewable energy and environmental pollution have used a wide range of panel econometric methods, such as ARDL, GMM and FMOLS [55]. However, an analysis of the literature reveals that comprehensive econometric studies in this area for European countries, including those in Central Europe, are still lacking. This study, therefore, contributes to the literature in three ways. First, to the best of our knowledge, there have been no studies on the relationships between agricultural sector activities, renewable energy production, economic development and environmental pollution in 3SI countries. Second, this is the first study in which a two-stage system GMM was used for the identified countries. Third, this study adopts a novel approach with instrumental variables and examines impacts in the short term.

An additional motivation for the authors was the realisation that some of the 3SI countries are among the top European countries with the worst air quality, while at the same time, the agricultural sector occupies a unique economic and social position there. Renewable energy, on the other hand, is still not widely used within the available possibilities; hence, it is essential to examine the factors discussed and to present relevant conclusions and policy implications for the future.

3. Materials and Methods

The empirical study used data obtained from the World Bank's database (World Development Indicators) on the 13 countries comprising the Tri-Seas Initiative countries for the period 2008–2020. Panel data covering both time series and cross-sectional data were used in the process of developing the model. The study used CO_2 emissions as the dependent variable and economic growth, renewable energy consumption, agricultural land area, agricultural growth and value added as explanatory variables. The variables were log-transformed to ensure normal distribution and stability. All variables used in the study, together with their sources, are presented in Table 1.

Table 1. Variables and sources.

Variables	Symbol	Measure	Dataset source
Carbon dioxide emissions	CO_2	per capita metric tons	WDI
Agriculture value-added	AGDP	% of GDP	WDI
Gross Domestic Product	GDP	per capita USD const. 2015	WDI
Renewable energy consumption	REW	% of total energy consumption	WDI
Agricultural land share	ALS	% of land area	WDI

Source: Authors's research.

This This study uses the GMM model developed by Arellano and Bover [13] and Blundell and Bond [14]. The choice of the GMM method was dictated by its robustness to endogeneity and heterogeneity. The model estimation framework uses lagged instrumental variables in the model for endogenous variables.

Instruments are variables that are used to improve parameter estimation in models, especially in the case of endogeneity or other problems associated with an incomplete set of independent variables. Instruments are used to eliminate correlations between independent variables and model errors. Instruments can also be variables that are lagged appropriately. These instruments thus make it possible to test the effect of the independent variables on the dependent variable.

The GMM model is particularly applicable to the estimation of panel data, where the number of cross-sectional units is larger than the number of periods, and there are autocorrelation and heteroscedasticity problems. According to the theoretical and empirical evidence, it is not possible to apply panel data models with fixed effects or random effects when the abovementioned time series imperfections are present.

The study uses a systematic two-stage GMM model. The system GMM is more efficient and robust to heteroskedasticity and autocorrelation than the single-stage model [56]. A dynamic panel model using a system-GMM has an advantage over a difference-GMM model in the case of *random walk* type variables, which often occur when describing macroeconomic phenomena. In addition, to counteract the situation where past levels convey little information about future changes, orthogonal moment conditions are used. Thus, the GMM-SYS technique, together with the transformation of forward orthogonal deviations instead of differentials, produces more efficient and precise estimates than does the difference GMM method. Moreover, dynamic GMM solutions produce better estimates than OLS models [57]. The general form of the model under study can be presented as follows:

$$CO_2 = f(GDP, AGDP, ALS, REW) \quad (1)$$

The following equation can be derived from the above:

$$CO_{2,it} = \alpha + \beta_1 GDP_{it} + \beta_2 AGDP_{it} + \beta_3 ALS_{it} + \beta_4 REW_{it} + \varepsilon_{it} \quad (2)$$

where α is the intercept, i and t represent countries and time, respectively; β_1… and β_4 are the coefficients of the independent variables, and ε is the error term.

After a logarithmic transformation to eliminate multicollinearity, the analytical form of the model was determined as follows:

$$lnCO_{2,it} = \alpha + \beta_1 lnGDP_{it} + \beta_2 lnAGDP_{it} + \beta_3 lnALS_{it} + \beta_4 lnREW_{it} + \varepsilon_{it} \quad (3)$$

A two-stage GMM system was used to analyse the relationships between the selected variables empirically. A dynamic panel model using the system-GMM. The analytical form of the model is as follows:

$$lnCO_{2_{i,t}} = \alpha + \Phi_1 lnCO_{2i,t-1} + \beta_1 lnGDP + \beta_2 lnAGDP + \beta_3 lnALS + \beta_4 lnREW + \eta_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

α and β and Φ are the coefficients of the model, λ is the time-invariant country effect, η is an unobservable time effect, ε is a residual term, and t is a time interval.

Following the estimation, verification was carried out using the Hansen test and the Diff-in-Hansen test to check the robustness of the results obtained and the validity of the instruments used [58]. In addition, an Arellano–Bond test for serial correlation was also performed [59].

To ensure a consistent and stable model, a robustness check was carried out according to the methodology proposed by Bond and Windmeijer [60]. This check consists of verifying that the estimated coefficient of the Φ of the lagged variable is between the values obtained by estimating the pooled ordinary (OLS) model as the upper bound and the fixed effect (FE) model as the lower bound. In addition, a control estimation of the random effects (RE) model and the Diff-GMM was also performed.

The present study aims to estimate the model parameters and capture the causal relationships between variables. To achieve this objective, Dumitrescu and Hurlin's [15] causality test was used, which is appropriate for heterogeneous panel data models and based on Granger causality tests [61]. The Dumitrescu and Hurlin test assume the null hypothesis of homogeneous non-causality and estimates the parameters using an individual Wald statistic. This statistic converges sequentially to a standard normal distribution and a semi-asymptotic distribution of the mean statistic, which is characterized for a fixed sample T. The results of the causality test for the GMM method can also be used to group the variables of the model appropriately in terms of their exogeneity and endogeneity [62].

4. Results and Discussion

Table 2 presents the summary descriptive statistics for the study variables. Additionally, tests of normality, including skewness, probability, kurtosis, and Jarque-Bera, were conducted, along with an analysis of the correlation between variables. The dataset consists of 237 observations of time series data from 2008-2020 for Tri-Seas Initiative countries. The skewness values suggest that the variables' distributions lack symmetry, while kurtosis indicates a slight flattening of the tail compared to a normal distribution. However, the kurtosis values for all variables are less than the deviation from normality, which is confirmed by the Jarque-Bera test statistic and low p-values.

Table 2. Descriptive statistics.

Variable	$\ln CO_2$	lnAGDP	lnALS	lnGDP	lnREW
Mean	1.824	1.133	3.682	9.517	2.826
Median	1.826	1.178	3.818	9.487	2.883
Maximum	2.691	2.576	4.192	10.750	3.779
Minimum	1.074	0.051	2.802	8.222	1.316
Std. Dev.	0.387	0.464	0.347	0.506	0.549
Skewness	0.144	0.253	-0.421	0.327	-0.409
Kurtosis	2.087	3.768	2.041	3.449	2.318
Jarque-Bera	10.434	9.628	18.517	7.169	12.891
Probability	0.005	0.008	0.000	0.028	0.002
Observations	273	273	273	273	273

Source: Authors's research.

The correlation analysis is presented in Table 3. The correlation results revealed moderate correlations between REW and ALS, between AGDP and GDP and between AGDP and CO_2. This result thus indicates that agricultural production has an impact on CO_2 emissions in the Triangle countries. Furthermore, there is a strong correlation between lnGDP and lnAGDP, indicating that when one variable increases, the other tends to decrease, and vice versa.

Table 3. Correlation matrix.

Variable	$\ln CO_2$	lnAGDP	lnALS	lnGDP	lnREW
$\ln CO_2$	1.000	-0.442	-0.139	0.420	-0.388
lnAGDP	-0.442	1.000	0.306	-0.798	-0.108
lnALS	-0.139	0.306	1.000	-0.291	-0.599
lnGDP	0.420	-0.798	-0.291	1.000	0.293
lnREW	-0.388	-0.108	-0.599	0.293	1.000

Source: Authors's research.

In the first stage of the study, causality between the study variables was determined to obtain information on the possibility of endogeneity. For this purpose, a test based on the Dumitrescu-Hurlin panel data test was applied, the results of which are presented in Table 4. The results obtained indicate that there is bidirectional causality between the variables: $CO_2 \leftrightarrow$ GDP, $CO_2 \leftrightarrow$ ALS and REW

↔ GDP. In contrast, unidirectional causality occurs between the variables CO_2 → AGDP, CO_2 → REW, ALS → GDP, GDP → AGDP, GDP → REW and ALS → REW.

Table 4. Pairwise Dumitrescu Hurlin Panel Causality Tests.

Causality	W-Stat.	Zbar-Stat.	Prob.
GDP ® CO_2	3.558	3.563	0.000
CO_2 ® GDP	2.511	1.920	0.055
ALS ® CO_2	2.404	1.753	0.080
CO_2 ® ALS	2.807	2.386	0.017
AGDP ® CO_2	0.671	-0.964	0.335
CO_2 ® AGDP	3.868	4.049	0.000
REW ® CO_2	1.274	-0.019	0.985
CO_2 ® REW	2.483	1.877	0.061
ALS ® GDP	7.891	10.354	0.000
GDP ® ALS	2.030	1.168	0.243
AGDP ® GDP	1.647	0.567	0.571
GDP ® AGDP	2.900	2.531	0.011
REW ® GDP	12.183	17.083	0.000
GDP ® REW	3.109	2.859	0.004
AGDP ® ALS	1.440	0.242	0.809
ALS ® AGDP	2.076	1.239	0.215
REW ® ALS	1.121	-0.258	0.796
ALS ® REW	2.772	2.330	0.020
REW ® AGDP	1.962	1.061	0.289
AGDP ® REW	0.626	-1.034	0.301

Source: Authors's research.

To select an appropriate generalised method of moments model estimation, two models were estimated: OLS with fixed effects and pooled OLS. The results of both models are presented in Table 5, and an estimation of the random effects model was also carried out to confirm robustness. The F-test statistic for the fixed effects test was estimated at 2.52 and was found to be statistically significant at the 1% level. It means that the fixed effects are nonzero, thus rejecting the pooled model in favour of the fixed effects model. Furthermore, the results of the Hausman test indicate that at the 1% significance level, the fixed effect model should be preferred over the random effect model in the estimation. Therefore, the fixed effects model was used to assess the robustness of the GMM estimation results, and the error component was not correlated with the independent variables.

Table 5. Random and fixed effect OLS estimation (robustness check).

Variable	Fixed Effect		Random Effects		Pooled	
	Coeff.	**Prob.**	**Coeff.**	**Prob.**	**Coeff.**	**Prob.**
$CO_{2\ t-1}$	0.608	0.000	0.920	0.000	0.920	0.000
GDP	0.153	0.040	0.026	0.381	0.026	0.383
REW	-0.282	0.000	-0.036	0.042	-0.055	0.043
ALS	0.058	0.729	0.005	0.280	-0.036	0.282
AGDP	0.145	0.008	-0.055	0.867	0.005	0.867
Const.	-0.303	0.702	0.167	0.569	0.167	0.570

R2	0.826		0.958	0.958
Husman cross-section	24.570	0.02		

Source: Authors's research.

According to the results obtained for the fixed effect model, a 1% increase in GDP causes a 0.15% increase in CO_2 emissions in the countries studied, while a 1% increase in renewable energy consumption causes a 0.28% decrease in CO_2 emissions. The added value of agricultural production also has a significant impact on CO_2 emissions among the variables studied, with an increase of 1%, which translates into a 0.14% increase in CO_2 emissions.

It should be noted, however, that ordinary OLS models are not without flaws and may fail to control for unobserved heterogeneity over time. Furthermore, many economic panel data do not meet the assumptions of the OLS method, such as a lack of autocorrelation and heteroskedasticity, leading to biased estimation results. Moreover, the use of GMM provides more consistent estimation results.

To select an appropriate estimation method, according to Arellano–Bond (2001), it is necessary to compare the coefficient ϕ for the dependent variable ($CO_{2\ t-1}$) for the estimation results of the OLS models. When the Diff GMM model ϕ is equal to or less than that estimated by the fixed effect method, the GMM model estimation should be chosen as the systematic method. In view of the above, the final GMM was estimated using the two-step system method, and the results are presented in Table 6. In addition, to confirm the robustness of the results obtained, the Diff model is presented in the table.

Table 6. Two-step difference and system generalised method of moments estimation.

Variable	System			Difference		
	Coeff.	**Std. err.**	**Prob.**	**Coeff.**	**Std. err.**	**Prob.**
$CO_{2\ t-1}$	0.678	0.182	0.006	0.453	0.201	0.042
GDP	0.297	0.070	0.004	0.261	0.113	0.038
REW	-0.247	0.155	0.097	-0.387	0.150	0.023
ALS	0.482	0.395	0.037	0.417	0.475	0.397
AGDP	0.107	0.096	0.149	0.208	0.116	0.097
Const.	-3.436	1.314	0.006			
AR(1)	0.092			0.078		
AR(2)	0.206			0.196		
Hansen p value	0.678	0.182	0.006	0.453	0.201	0.042
Sargan	0.297	0.070	0.004	0.261	0.113	0.038

Source: Authors's research.

According to the results, a 1% increase in the value-added generated by agriculture leads to a 0.11% increase in CO_2 emissions in the countries studied, *ceteris paribus*. Given that a 1% increase in GDP, on the other hand, leads to a 0.29% increase in CO_2 emissions, this result indicates that higher agricultural production has a more negligible impact on CO_2 emissions than other sectors of the economy. Moreover, the model obtained does not confirm that the change in agricultural land shares in the countries studied had a significant impact on CO_2 emissions in the short term. Moreover, these results are similar to those obtained using the OLS method with the fixed effect and difference GMM, which further confirms the robustness of the estimated model. Thus, the results obtained allow positive verification of hypothesis H1 and are similar to those obtained in earlier studies by Dauda et al. [63] for African countries, by Waheed et al. [9] for Pakistan and Doğan [64] for China.

According to the results, an increase in renewable energy consumption leads to lower CO_2 emissions in the TSI countries studied. If renewable energy consumption increases by 1%, CO_2

emissions fall by 0.25%, *ceteris paribus*. The results obtained, therefore, indicate that reducing CO_2 emissions in a relatively short time involves increasing the share of renewables. The results obtained, therefore, allow a positive verification of hypothesis H2. These results are also in line with those obtained by Naseem and Guang Ji [52] for SAARC countries and Liu et al. [53] for BRICS countries.

Considering the diagnostic parameters of the model obtained, such as the Arellano–Bond autocorrelation test, it should be noted that the null hypothesis of no first-order serial correlation in first differences AR(1) was rejected. However, the null hypothesis of no higher-order serial correlation AR(2) in the first differences was not rejected. Therefore, the GMM estimator used should be considered consistent.

The second type of test was the J Hansen test, which was used to determine whether the instruments used were exogenous and whether the resulting GMM-SYS model estimates were correct. The results of the Sargan test of overid indicate that all the instruments are correct. In summary, according to the results of the Hansen test and the difference-in-Hansen test, it should be assumed that both the GMM instruments for levels and the IV instruments are valid and significant for the outcome variable.

5. Conclusions

The Three Seas Initiative is an essential premise for strengthening cooperation and further integration with the European Communities. The vast majority of the member states were in the Soviet sphere of influence after World War II, which affected both the functioning of their societies and their economic policies. This study analyses the relationships between renewable energy consumption, economic growth, agricultural production, agricultural area, and CO_2 emissions in the countries of the Three Seas Initiative from 2008 to 2020. The study used the OLS technique and the two-step system generalised method of moments (GMM).

The results of the study indicate that the consumption of renewable energy sources reduces carbon dioxide emissions, while economic growth and agricultural production have a positive impact on CO_2 emissions in the countries studied. These findings indicate that it is necessary to increase the use of renewable energy production and reduce energy dependence on fossil fuels. The energy transition will, therefore, be crucial in promoting a sustainable economy and achieving fit for 55.

The study recommends that agricultural and environmental policies in the Tri-Sea Initiative countries consider preserving economic growth and agricultural production while reducing CO_2 emissions. To achieve this, individual governments should establish a strong and coordinated legal framework that contributes to improving air quality and developing technological innovations in the long term. Therefore, it would be logical to establish collaborative funds for research and development, coordinate cooperation between research centres, and establish international research consortia to create and implement low-carbon innovations in the agricultural sector. It is important to note that technological progress and the development of renewable energy are the only ways to achieve the energy transition without a significant decline in agricultural production in the countries under study.

The governments of the 3SI countries should aim to introduce well-considered fiscal measures to promote low-carbon and renewable agriculture. Modern agriculture in the initiative countries should be based on efficient and sustainable production, rather than the exploitation of natural resources. This approach will enable meeting growing consumption needs while minimizing negative environmental impacts.

Therefore, it is crucial to implement measures to enhance the added value in agriculture. This can be accomplished by introducing modern agrarian technologies based on renewable energy sources (RES) and better seed varieties, which will lead to an increase in agricultural productivity. Additionally, educating farmers is essential to provide them with the knowledge required for farm development. The countries involved in the initiative should strive to attract more funding from the European Union and transition their farms to organic farming. According to the study results, organic farming can reduce emissions, including CO_2.

The Tri-SI countries should coordinate their efforts in developing renewable energy and utilize the agricultural sector as a crucial component of the energy transition process. Due to its large geographical area and diverse climatic conditions, the Three Seas Initiative offers an opportunity for cooperation in the production and sale of renewable energy, which can improve air quality. The countries involved should also aim to establish joint funds for the development of renewable energy sources and advocate for increased financial support from the European Union and the World Bank.

To enable organic farming, it is crucial to increase the use of renewable energy. This not only adds value to agriculture but also helps combat global warming and climate change. However, developing renewable energy sources in agriculture requires investment in energy infrastructure. It is important to connect individual countries as they have different natural resources. These measures can ensure the exchange of affordable energy and support the development of agriculture in individual countries.

As part of an initiative to develop low-carbon agriculture, other measures that can be taken include abandoning traditional farming techniques, switching to no-till, reducing the use of organic fertilisers, and decreasing the amount of pesticides used. These measures can all aid in reducing CO_2 emissions without compromising economic growth and agricultural production. Agriculture can have a significant positive impact on the environment in the countries of the Intermarium. Stimulating investment and technological progress through international cooperation would help to reduce emissions while increasing the added value from agriculture.

The countries involved in the initiative should coordinate their efforts. It should be noted that the energy transition has had a negative impact on economic development, particularly in the agricultural sector. Policies should therefore be pursued to provide transitional protection for agricultural producers.

This study has limitations that can be addressed in future research. The focus is on the short-term relationship between economic growth, renewable energy, fertiliser consumption, and CO_2 emissions from agriculture. Future studies could establish long-term relationships using modern estimation techniques such as ARDL and QARDL. The NARDL model could provide interesting evidence by examining the analysed relationships asymmetrically. To use the indicated estimation techniques, longer time series would be required.

Future research could also consider other determinants, such as trade openness, financial development, foreign direct investment, and organic farming. Further research could also utilise other gases emitted by agricultural activities, such as nitrous oxide or methane, as the dependent variable. Additionally, agricultural activities could be categorised into crop and livestock production. This type of research would complement the results obtained in this study, strengthening the scientific discussion on the energy transition of the agricultural sector.

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