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Dynamic relationship among agriculture-renewable energy-forestry and carbon dioxide (CO_2) emissions: empirical evidence from GUAM countries

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Abstract
Nowadays with the climate change the environmental degradation has became the crucial issue in the World. This study empirically investigates the impact of agriculture value-added, forest area, and renewable energy on CO_2 emissions in GUAM union countries from 1996 to 2019. The independent variables in this study are agriculture value-added, forest, renewable energy and the dependent variable is CO_2 emissions. The statistical methods as the Panel unit root test, Pedroni and Kao panel co-integration test and OLS, FMOLS, and DOLS long-run tests were employed for the empirical part of the paper. The independent variables in this study are agriculture value-added, forest, renewable energy and the dependent variable is CO_2 emissions. The statistical methods as the Panel unit root test, Pedroni and Kao panel co-integration test and OLS, FMOLS, and DOLS long-run tests were employed for the empirical part of the paper. The outputs of the Pedroni and Kao panel co-integration tests confirmed that there is a long-term relationship between the analyzed series. The findings of the OLS, FMOLS, and DOLS tests indicate a negative relationship between the analyzed variables. According to the the results of empirical analyzes it was confirmed that there is a statistically significant and negative relationship between agriculture value-added, forest, renewable energy and CO_2 emissions which means that an increase of agricultural production, forest areas and renewable energy consumption decreased the CO_2 emissions in GUAM countries for the time span 1996-2019.

Keywords
GUAM, agriculture; renewable energy; forest; sustainable; Panel unit root test; Pedroni and Kao panel co-integration test; OLS, FMOLS, and DOLS

Introduction

With a significant increase in population in the World, the countries started to increase their agricultural production to feed the population. Thus, both developed and developing countries with an increase in agricultural production started to increase the usage of fossil fuels which in turn carried out several severe environmental problems (Chandio et al., 2020).

Nowadays, Global Warming is one of the most crucial problems which are faced by human beings. According to the report of the Intergovernmental Panel on Climat Change (IPCC, 2021), the temperature increase due to anthropogenic activities was registered as 1.07 °C from 1850–1900 to 2010–2019. Hence, to prevent the global environmental crisis and decrease greenhouse gases (GHGs), the Kyoto protocol was signed by 150 countries (Karimov, 2019). At the current time, there

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are several options for reduction of the carbon dioxide emissions: (1) Decrease carbon dioxide emissions and (2) grow the carbon dioxide absorbent. In response to option 1, the countries should increase the consumption of renewable energy in comparison with non-renewable energy. In response to option 2, to countries should increase the forest areas to decrease the carbon dioxide emissions. The reason for this is that the forest areas have a huge carbon sequestration capacity, they play a role as a natural absorbent (Chandio et al., 2020; Harris & Feriz, 2011). The GUAM countries were chosen as research objects for this study. The main goal in selecting the GUAM countries as a research object; during the literature review, the studies conducted by researchers are mostly conducted on a single country basis and there is a limited number of studies conducted using panel data analyzes on groups of countries. Additionally, the other reason for choosing the GUAM countries as a research object is the lack of research on environmental pollution in the countries included in this union.We assume that this research will make an important contribution to the current literature. Because, to the best of our knowledge, this is the first empirical study that investigates the relathionship between CO_2 emissions per capita, agriculture value-added, renewable energy consumption, and forest areas in GUAM countries. The GUAM (The Organization for Democracy and Economic Development) association was established on October 10, 1997, with the signing of a joint agreement by the presidents of Georgia, Ukraine, Azerbaijan, and Moldova in Strasbourg. In the agreement, the heads of state emphasized doing business in all areas for the growth and development of the union based on the principles of sovereignty, territorial integrity, inviolability of borders, democracy, rule of law, and respect for human rights. In April 1999, the state of Uzbekistan also became a member of the union, but its membership was suspended in 2002 and then left completely in 2005. When Uzbekistan became a member of the union, the name of the union was changed to GUUAM (Katarzyna & Agnieszka, 2017). When we take a look at Graph 1 the mixed trendlines can be observed. For instance, in the case of Ukraine, there is a continuous decrease in CO_2 emissions. Contrary to the other member of GUAM countries, in Georgia, the CO_2 emissions dropped down until 2002 and afterward start to increase until 2019. When we take a look to Azerbaijan it can bee seen that there is a fluctuation in trendline until 2019. Additionally, in the case of Moldova there is a drop in CO_2 emissions until 2000 and afterward a constant significant increase until 2019 (Fig. 1). Hence, the negative effects of the energy obtained from fossil fuels on the environment and its depletion have led countries to find alternative energy sources (Gurbuz et al., 2021). Solar, wind, geothermal, and biofuel hydropower energy is considered renewable energy. When we take a glance at the renewable energy consumption of the GUAM countries we can see different trendlines. For instance, in the case of Georgia, there is a continuous decrease in renewable energy consumption. In the case of Ukraine, the usage of renewable energy grew continuously until 2019. In the case of Azerbaijan, there are fluctuations in the trendli-

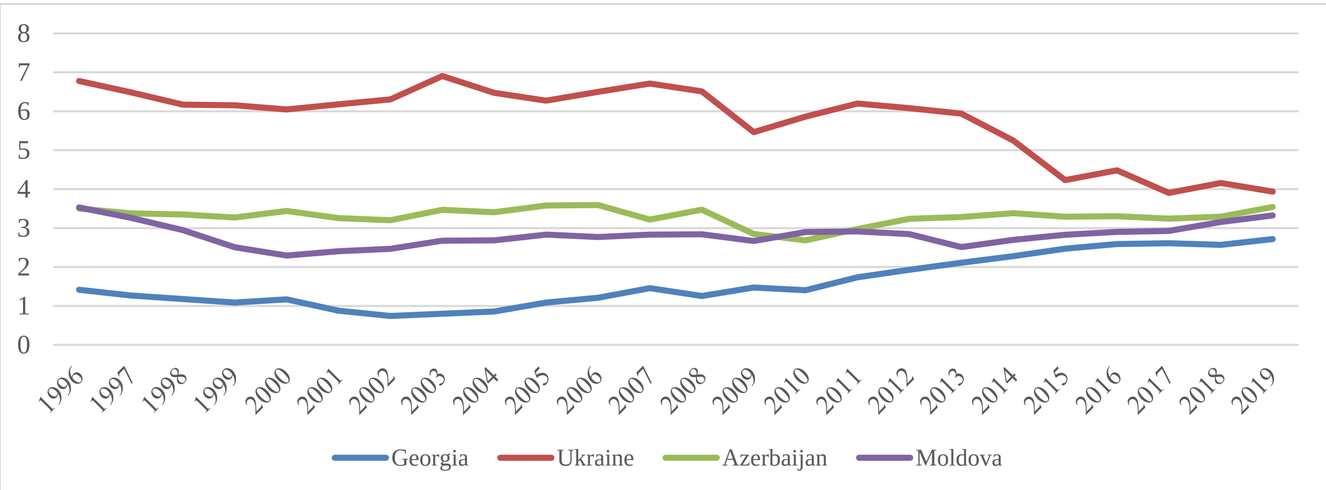

Figure 1. *CO2 emissions (metric tons per capita) in GUAM countries from 1996 to 2019. Source: authors` own invention based on World Bank Database (https://data.worldbank.org/indicator/EN.ATM.CO2E.PC)*

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ne but mostly renewable energy consumption was decreased in 2019. In the case of the last member of GUAM, Moldova, the renewable energy consumption constantly increased and we can observe a boom in the increase of it from 0209 (Fig. 2). In recent times, the increase in the price of natural gas, especially as a result of the energy crisis that arose in the context of the recent economic-political, including military conflict between Russia and Ukraine, increases the potential of using renewable energy sources.

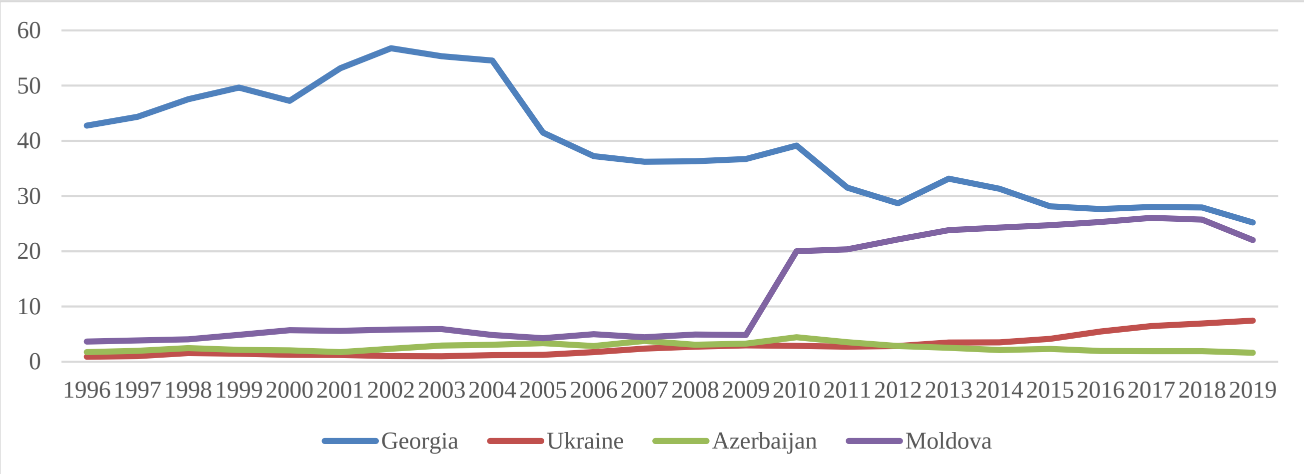

Figure 2. *Renewable energy consumption (% of total final energy consumption) in GUAM countries from 1996 to 2019*
Source: authors` invention based on World Bank Database (https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS?locations=GE)

Therefore, as another significant indicator, the agricultural footprint on the environment should be considered. Due to its extensive utilization of fossil-sourced energy, the agriculture sector is considered to be accountable for about 14 and 30 percent of global greenhouse gas (GHG) emissions (Ben Jebli and Ben Youssef, 2017). Furthermore, the significant greenhouse gasses from agriculture are due to the usage of fuel-powered agricultural equipment, pumping irrigation water, rearing livestock on farm premises, and applying nitrogen - rich fertilizers (Okumuş, 2020). Another report of the Intergovernmental Panel on Climat Change (IPCC, 2014) states that the CO_2 emissions which come from agriculture production might be decreased to 80% by 2030 . According to Figure 3, we can observe that there is a negative trend line in all of the GUAM countries (Fig. 3). The reason why there is a decrease in agricultural production is that the Soviet Union has collapsed and after this process, the focus has changed from the agricultural sector to entrepreneurship.

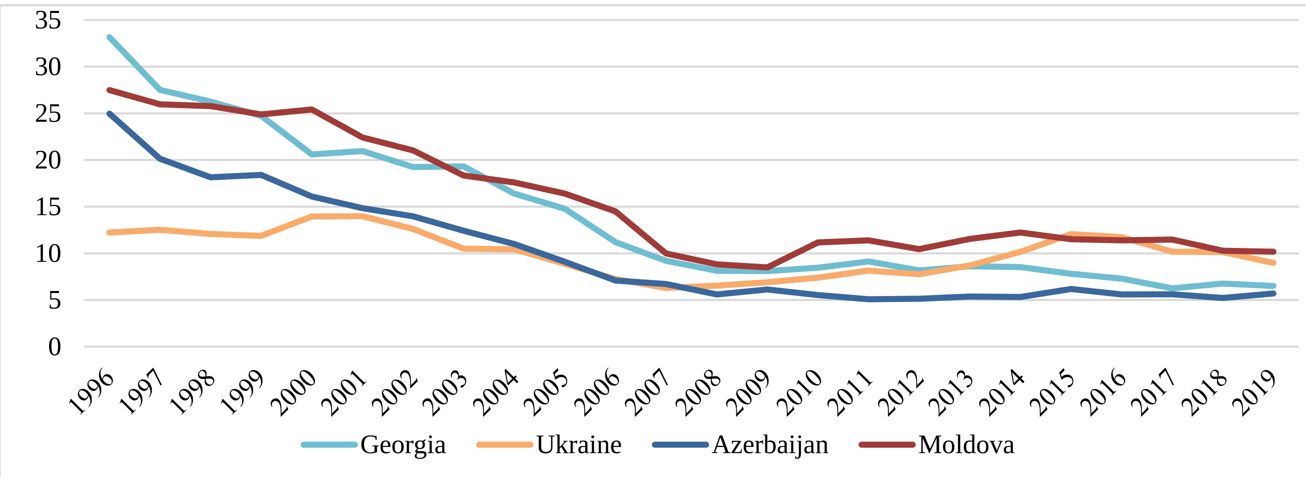

Figure 3. *Agriculture value-added (% of GDP) in GUAM countries from 1996 to 2018*
Source: authors` invention based on World Bank Database (https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS)

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Although economic progress benefits the community, it causes suffering to the ecosystem. Non-renewable resources, like forests, are particularly vulnerable to economic growth (Parajuli et al., 2019). The transformation of forestry areas to agricultural land is one of the major impacts of anthropogenic actions of human beings to increase CO_2 emissions. When we take a look at the trendline of the forest areas in GUAM countries, we can see that forest areas in all countries are constantly increasing by a small amount (Fig. 4).
In this study, a 3-step procedure has been tried to be applied to investigate the long-term effects of agriculture value-added, renewable energy consumption , and forest areas on CO_2 emissions. In the first step, the stationarity level of the series was tested through the Panel Unit Root test developed by Levin-Lin-Chu (Levin et al., 2002), Im-Pesaran-Shin (Im et al., 2003), and ADF- Fisher (Maddala and Wu, 1999). In the second step, the long-run relationship between the analyzed series was investigated by utilizing the panel co-integration test which was developed by Pedroni (Pedroni, 1999, 2004) and Kao (Kao, 1999). OLS, FMOLS (fully modified ordinary least squares), and DOLS (dynamic ordinary least squares) tests were utilized to estimate the long-term coefficients (Phillips & Hansen, 1990) (Stock & Watson, 1993).

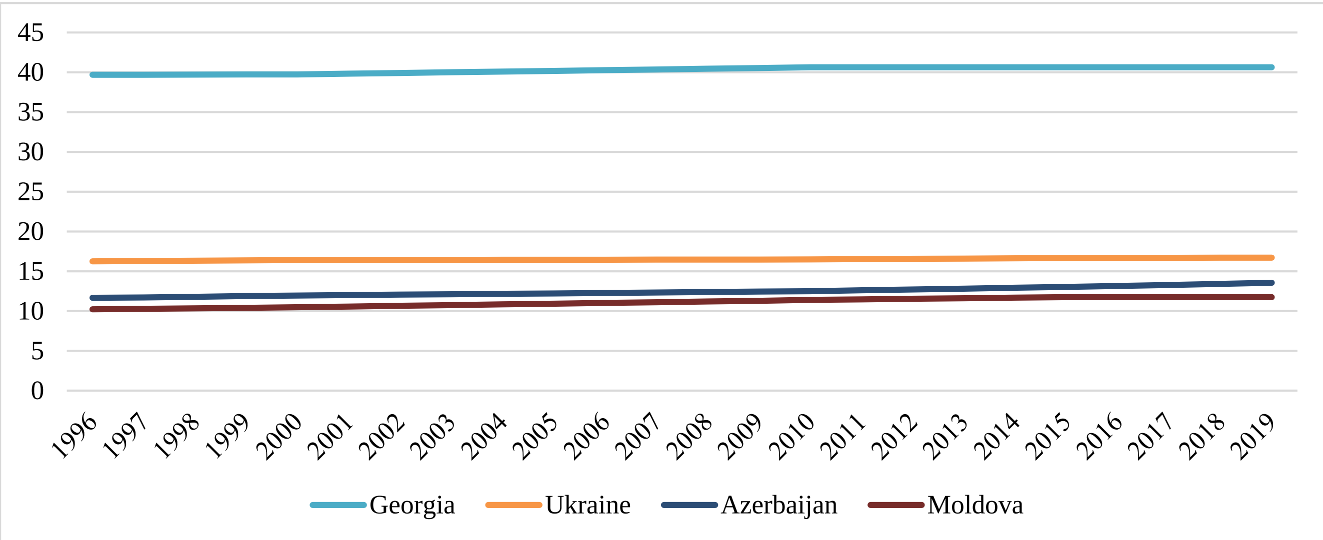

Figure 4. *Forest area (% of land area) in GUAM countries from 1996 to 2018*
Source: authors` invention based on World Bank Database (https://data.worldbank.org/indicator/AG.LND.FRST.ZS)

Literature review
In this study, dynamic relationships between agriculture value-added, forest, renewable energy, and CO_2 emissions in GUAM union countries were empirically investigated. When the previous researches related to the subject of this study were examined, a large number of studies conducted in different countries for the different time intervals were detected. Based on the results of the empirical literature research, it was revealed that there are both positive and negative relationships between the analyzed variables depending on the object of the research, the selected time period and the applied empirical methods. Below is a summary of the results of empirical studies conducted by various researchers on this topic. In their studies, Ben Jebli and Ben Youssef (2017) examined the links between GDP, renewable energy consumption, stratified agriculture value-added, and carbon dioxide (CO_2) emissions for the five countries in North Africa for the period from 1980 to 2011. In their research, they utilized Panel Verification techniques and the Granger causality test. According to the results of the Granger causality test, there is a short-term and long-term bidirectional causality relationship between the agriculture value-added and CO_2 emissions. Therefore, it also reduces CO_2 emissions for each of the five countries that have been the subject of increased research in the long run. Another finding is that economic growth and renewable energy consumption increase CO_2 emissions. Liu et al. (2017a) examined the relationship between CO_2 emissions and renewable and non-renewable energy consumption for the

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selected 4 ASEAN countries (Indonesia, Malaysia, the Philippines, and Thailand) for the span from 1970 to 2013. Pedroni and Kao co-integration tests were employed for the correlation relationship between the variables, and panel OLS, FMOLS, and DOLS methods were utilized for long-term estimates. The results show that increases in agriculture value-added and renewable energy, in the long run, he long run reduce CO_2 emissions, while non-renewable energy consumption has a positive relationship with CO_2 emissions. Moreover, the EKC hypothesis is not valid for 4 ASEAN countries over a period that is the subject of research.

Liu et al. (2017b) examined the link between agriculture, renewable and non-renewable energy, and CO_2 emissions for BRICS countries. The period of 1992-2013 was chosen as the time interval in their research. The Pedroni and Kao co-integration tests, panel OLS, FMOLS, DOLS methods, and panel VECM Granger causality test were utilized in the study. The results show that agriculture and non-renewable energy has a positive effect on CO_2 emissions, while renewable energy negatively effects emissions.

Khan et al. (2018) investigated the link between agriculture value-added, forest area, renewable energy, coal electricity, hydropower, vegetable area, and greenhouse gas emissions in Pakistan for the period 1981-2015. FMOLS and CCR tests, which take into account their long-term dynamic relationships, show that agriculture value-added, forest areas and renewable energy have negative and significant effects on greenhouse gas emissions.

Waheed et al. (2018) investigated the impact of renewable energy consumption and forest on carbon dioxide (CO_2) emissions in Pakistan for the span from 1990 to 2014. In the study, the short and long-term relationships between the variables were estimated by utilizing the ARDL model. The findings of the study show that forest and renewable energy consumption has negative and significant effects on CO_2 emissions in the long term. However, agricultural production affects CO_2 emissions positively and significantly in the long run. These results show that carbon dioxide (CO_2) emissions can be reduced by increasing both forest area and renewable energy consumption. Therefore, forest area was found to be more effective in reducing CO_2 emissions than renewable energy consumption.

Qiao et al. (2019) examined the relationship between economic growth, agriculture, and renewable energy and carbon dioxide (CO_2) emissions for a group of 19 G20 (Group of twenty countries) countries for a period from 1990 to 2014. As a result, they found that agriculture significantly increased CO_2 emissions in all countries, while renewable energy reduced carbon dioxide (CO_2) emissions for all countries.

Parajuli et al. (2019) investigated the effect of forest, farmland, and energy consumption on CO_2 emissions using panel data for 86 different countries between 1990 and 2014. As a result, they found that forests are an important determinant in reducing CO_2 emissions. However, this result varies by region. Another result shows that with energy consumption, agricultural lands contribute positively to CO_2 emissions.

Yufang et al. (2019), investigated the impact of the forest, agriculture, and renewable energy on carbon emissions in China and India for the period from 1989 to 2015. The ARDL bound test and Granger causality analysis were employed in the study. The empirical results show that the use of forest areas and renewable energy negatively effects carbon emissions in both countries. Agriculture has a negative but non-significant impact on carbon emissions in China in both the short and long term. In India, it has been found that agriculture has a negative and significant effect on CO_2 emissions in the short term and a negative and insignificant effect in the long term.

Mehman Karimov (2020) analysed the relationship between GDP per capita, CO_2 emission, Renewable Energy Contribution (REC) and Foreign Direct Investment (FDI) regarding Turkey from 1970 to 2014. The ADF Unit Root, Philips–Perron, Johansen co-integration, and the Granger Causality tests were employed for the empirical part of the paper. According to the empirical findings, it was determined that the EKC hypothesis was not present in the Turkish economy. However, statistical data confirmed the existence of the PHH concept in the Turkish economy, implying that FDI has a detrimental influence on the Turkish economy's long-term growth.

Aydoğan and Vardar (2020), examined the relationship between economic growth, agricultural added value, renewable, and non-renewable energy consumption, and CO_2 emissions for E7 countries

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utilizing annual data covering the period 1990-to 2014 in their research. Pedroni and Kao panel co-integration tests were utilized for the co-integration relationship between the series, and OLS, FMOLS (fully modified ordinary least squares), and DOLS (dynamic ordinary least squares) methods were employed to estimate the long-term coefficients. As a result, they defined that renewable energy negatively effects CO2 emissions, while agricultural added value and non-renewable energy consumption have a positive effect.

Eyuboglu and Uzar (2020), investigated the effect of agriculture and renewable energy on CO_2 emissions for seven lucky-seven countries (Malaysia, Indonesia, India, Kenya, Mexico, Colombia, and Poland) in their research for the period from 1995 to 2014. The findings show that agriculture, economic growth, and energy consumption increase CO_2 emissions, while renewable energy is an important factor in reducing CO_2 emissions.

Anwar et al. (2021), analyzed the linkage between renewable energy consumption, forest area, and carbon dioxide emissions among 33 partner economies of BRI for the time from 1986 to 2018. The cointegration and heterogeneous Granger causality tests have been employed for the empirical part of the paper. The statistical findings have revealed that the expansion in renewable energy consumption and increase in forestation will support reducing the carbon dioxide emissions among the economies of BRI.

Yasmeen et al. (2022), examined the impact of agriculture and forestry on carbon emissions at global and five regional levels from 1996 to 2015. The Cross-sectional tests, panel unit root tests, cointegration tests, Driscoll & Kraay, and fully modified ordinary least square regressions and causality tests have been utilized for the empirical part of the paper. According to the findings of the statistical test, agricultural production has a positive impact on carbon dioxide emissions, and forestry negatively effects CO_2 emissions. Therefore, this research indicated that renewable energy consumption plays a vital role in improving the quality of the environment.

Table 1 summarizes the studies examining the relationship between agriculture value-added, forest, renewable energy, and CO2 emissions. In this context, agriculture value-added increases CO2 emissions in seven out of eleven studies, and agriculture value-added reduces CO2 emissions in the remaining four studies. It was found that 5 out of 6 studies indicate that forestry decreases the CO2 emissions and the remaining 1 on the contrary increases the carbon dioxide emissions. Renewable energy consumption reduces CO2 emissions in eight out of eleven studies and it increases the CO2 emissions in the remaining 3 research. Additionally, two of the studies focused on one country, while theother ten focused on country groups.

Table 1. *Researches on AGRI, FOR, REN, and CO_2 relationship Source: Authors` own invention*

Authors	Countries	Period	AGRI-CO_2	FOR-CO_2	REN-CO_2
B. Jebli and B.Youssef 2017	North Africa countries	1980-2011	(−)		(+)
Liu et al. (2017)	4 ASEAN countries	1970-2013	(−)		(−)
Liu et al. (2017a)	BRICS country	1992-2013	(+)		(−)
Khan et al. (2018)	Pakistan	1981-2015	(−)	(−)	(−)
Waheed et al. (2018)	Pakistan	1990-2014	(+)	(−)	(−)
Qiao et al. (2019)	G20 country	1990-2014	(+)		(−)
Parajuli et al. (2019)	86 different countries	1990-2014	(+)	(−)	
Peng et al. (2019)	China and India	1989-2015	(−)	(−)	(−)
Aydogan and Vardar (2020)	E7 countries	1990-2014	(+)		(−)
Eyuboglu and Uzar (2020)	lucky-seven country	1995-2014	(+)		(−)
Anwar et al., 2021	BRI countries	1986-2018		(+)	(+)
Yasmeen et al., 2022	at global and five regional levels	1996-2015	(+)	(−)	(+)

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Data and Methodology

Data

The main purpose of the research is to empirically investigate the relationship between the agricultural value added, forest area, renewable energy and CO2 emissions in GUAM countries by the panel data set covering the period from 1996 to 2019. In the selection of the time period, the availability of data for GUAM countries was taken into account and the time period was limited to the years 1996-2019. The econometric model [1] considered in the study is as follows:

$$CO_{2it} = f\,(AGRI_{it}, FOR_{it}, REN_{it})\dots\dots \quad [1]$$

The analyzed series of our model (2) were transformed into logarithmic forms in order to reduce the heterogeneity of the data.

$$CO_{2it} = \beta_0 + \beta_1 + \beta_2 lnAGRI_{it} + \beta_3 lnFOR_{it} + \beta_4 lnREN_{it} + \varepsilon_{it} \dots\dots \quad [2]$$

Where is, $lnCO_2$ is the natural logarithm of Carbon dioxide emissions per capita, lnAGRI is the natural logorithm of agricultural value-added (% of GDP), lnFOR is the natural logorithm of forestry area (% of land area), lnREN is the natural logarithm of renewable energy consumption (% of total final energy consumption). In the model β indicates the rate of effect of independent series on the dependent series and ε_{it} attributes to the error term.

Table 2 demonstrates the number of the variables which have been utilized in our model, abbreviation of the variables, units of the data, and the sources of the data. In order to accomplish the next step of the research the summary statistics of variables were described in the Table 3.

Variables	Abbreviation	Unit	Sources
Carbon dioxide emissions	CO_2	metric tons per capita	World Bank Database
Agricultural value-added	AGRI	% of GDP	
Forest areas	FOR	% of land area	
Renewable energy consumption	REN	% of total final energy consumption	

Table 2 *Data description. Source: Authors` own calculations*

Countries	Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Average annual growth (%)
Georgia	CO_2	1.4993	1.3463	2.6302	0.8517	0.5603	0.065
	AGRI	15.5119	12.9844	33.1524	7.8138	7.9741	-0.069
	FOR	40.1192	39.9696	40.6159	39.6788	0.3947	0.001
	REN	41.7095	40.3151	56.7580	28.6625	9.0000	-0.015
Ukraine	CO_2	6.5267	6.6269	8.0759	4.3470	0.8114	-0.028
	AGRI	10.1871	10.4662	14.4905	6.5486	2.5546	0.006
	FOR	16.4775	16.4954	16.6704	16.2520	0.1055	0.001
	REN	2.0652	1.6560	4.1443	0.8979	1.0186	0.098
Azerbaijan	CO_2	3.8059	3.7863	4.6163	3.3882	0.2732	0.002
	AGRI	10.8512	8.1193	24.9616	5.0762	6.1273	-0.066
	FOR	11.4413	10.7723	13.7837	10.3801	1.1507	0.015
	REN	2.7359	2.6858	4.4497	1.7389	0.7197	0.033
Moldova	CO_2	1.7815	1.7087	3.9104	1.2015	0.5676	-0.032
	AGRI	16.7664	15.4493	27.4843	8.4975	6.6213	-0.038
	FOR	11.0010	11.1067	12.4392	9.7783	0.9387	0.013
	REN	6.8566	5.2888	14.2737	3.6604	3.4022	0.088
World	CO_2	0.0045	0.0046	0.0050	0.0040	0.0004	0.010
	AGRI	4.3940	3.93429	7.5174	3.5178	0.9938	-0.037
	FOR	31.0156	30.9837	31.4016	30.7443	0.1933	0.001
	REN	17.5198	17.5566	18.1298	16.9083	0.3695	0.001

Table 3 *The summary statistics of variables. Source: Authors` own calculations*

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According to the growth rate of CO_2 emissions, Georgia (0.065%) is above both the other three countries and the global average (0.010%). Azerbaijan (0.002%) comes in second place, but its growth rate is below the global average. The annual growth rate of CO_2 emissions in Ukraine (-0.028%) and Moldova (-0.032%) is negative. But historically, Ukraine has the highest emissions per capita (8.08 metric tons). The annual average growth rate of agriculture value-added is negative in the other three countries, excluding Ukraine (0.006%). While Georgia is the country with the largest forest areas (40.12) on average, it ranks last in terms of growth rate. Azerbaijan ranks first in terms of the annual average growth rate of forest areas (0.015%). The same is true for renewable energy consumption. Georgia has the largest consumption of renewable energy on average (41.71), while the growth rate is negative (-0.015%). Ukraine (0.098%) comes first in terms of growth rate in renewable energy consumption, followed by Moldova (0.088%) and Azerbaijan (0.033%) (See Table 3).

Panel unit root test

Firstly, in time series data applied research it should be tested whether the data has a stationary structure. Because spurious regression results when non-stationary time series are used in the research. In such a case, the results obtained from the study do not reflect the real relationship between the variables (C. Granger & Newbold, 1974). In studies utilizing panel datasets, panel unit root tests are used to determine the stationarity between the series. Levin-Lin-Chu (Levin et al., 2002), Im-Pesaran-Shin (Im et al., 2003), and ADF- Fisher (Maddala and Wu, 1999) panel unit root tests, which are first-generation unit root tests, were employed in the research. Appropriate lag length, which eliminates the problem of autocorrelation between errors, was chosen according to the Schwarz information criterion. One of the panel unit root tests, LLC (Levin et al., 2002) is one of the first tests prepared for use in panel data analysis and is used to analyze whether each group in the panel contains a unit root. Therefore, the IPS (Im et al., 2003) test is an extended version of the LLC (Levin et al., 2002) test. For all three tests, the null hypothesis states that the series has a unit root, and the alternative hypothesis states that the series is stationary at the first difference.

Panel co-integration test

Pedroni (Pedroni, 1999, 2004) and Kao (Kao, 1999) are frequently used co-integration tests for panel co-integration analyses in the literature. Both of these tests were utilized in the empirical application of the study. Pedroni's (Pedroni, 2004) co-integration test consists of seven statistics distributed over two parts of the co-integration test. The first part covers four-panel statistics and includes v-statistics, rho-statistics, PP-statistics, and ADF-statistics and is classified as within groups. The second part includes three group statistics and these statistics include rho-statistics, PP-statistics, and ADF-statistics, and these tests are classified between groups. The null hypothesis indicates that there is no co-integration, while the alternative hypothesis indicates that there is co-integration between the variables.

The other co-integration test to be used in the study is the Kao co-integration test. Kao presented a co-integration test for panel data analysis using DF and ADF tests in 1999 (Baltagi and Kao, 2001).

As a result of determining the long-term co-integration relationship between the variables, the long-term coefficient estimation phase was started. For this, FMOLS (Full Modified Ordinary Least Square) method was developed by Pedroni (Pedroni, 2000, 2001) and DOLS (Dynamic Ordinary Least Square) method developed by Mark and Sul (Mark and Sul, 2003) was employed. These estimators follow the I(1) process to analyze the relationship between the co-integrated series. In general, although it is accepted that DOLS estimation results are more reliable than FMOLS results, the lack of consensus on this issue is the reason for making a comparison between the results of both estimators in the study.

Empirical results and discussion

According to Granger and Newbold (Granger and Newbold, 1974), econometric analysis with non-stationary data is not reliable. Therefore, before proceeding to the regression analysis, the data to be used in the model should be stationary. To ensure stationarity, unit root tests should be run (See Table 4). The results of the unit root test showed that while each of the four variables utilized in the research was not stationary at their levels, they became stationary in I(1). This result makes it possible to apply panel co-integration analysis to the variables.

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Table 4. Panel unit root test. *Source:* Authors` own invention

Variables	LLC		IPS		Fisher-ADF	
	level	1st difference	level	1st difference	level	1st difference
CO_2	1.854(0.96)	-5.547***(0.00)	0.725(0.76)	-5.632***(0.00)	5.689(0.682)	40.280***(0.000)
AGRI	2.464(0.99)	-1.947**(0.02)	2.367(0.99)	-1.942**(0.02)	2.339(0.967)	16.940**(0.031)
FOR	0.697(0.75)	-4.115***(0.00)	2.257(0.99)	-2.581***(0.00)	1.321(0.995)	22.303***(0.004)
REN	0.011(0.50)	-6.518***(0.00)	0.721(0.76)	-3.906***(0.00)	4.871(0.771)	27.991***(0.001)

Panel cointegration test results

As a precondition of the panel co-integration test all the variables should be non-stationary at levels, and stationary in I(1). Based on the results of the unit root tests all the variables were non-stationary at level and stationary at the first difference (Table 4). Thus, with a fulfill of the precondition of the panel co-integration test the Pedroni and Kao panel co-integration test can be run. The Pedroni and Kao panel co-integration test results are shown in Table 5.

Table 5
Pedroni and Kao panel co-integration test.
Source: Authors` own invention

Pedroni residual co integration test				
	Statistic	Prob.	Weighted Statistic	Prob.
Alternative hypothesis: common AR coefs. (within-dimension)				
Panel v-Statistic	-0.101	0.541	0.097	0.461
Panel rho-Statistic	0.370	0.644	-0.494	0.311
Panel PP-Statistic	-2.078**	0.019	-2.759***	0.003
Panel ADF-Statistic	-2.298***	0.011	-2.758***	0.003
Alternative hypothesis: individual AR coefs. (between-dimension)				
Group rho-Statistic	0.406	0.658		
Group PP-Statistic	-2.571***	0.005		
Group ADF - Statistic	- 2.811***	0.003		
Kao residual co integration test				
			t-Statistic	Prob.
ADF			-3.004***	0.001

***, ** shows significance at the 1 and 5 percent level, respectively. Barlett kernel method was utilized in Pedroni and Kao co-integration test and Bandwith width was determined by Newey-West method.

The fact that 4 out of 7 Pedroni co-integration tests indicate a statistically significant and negative relationship between analyzed series. The null hypothesis that there is no co-integration between analyzed series should be rejected and alternative hypothesis that there is a co-integration between analyzed series should be accepted. Which in turn denotes that there is a long-term co-integration between the analyzed series. Thus, this determines the existence of a long-term relationship between the independent variables in the model, such as agriculture value-added forest areas and renewable energy, and the dependent variable carbon dioxide (CO_2) emissions. According to another test, the Kao co-integration test, the null hypothesis was rejected at the 1% significance level. Therefore, the alternative hypothesis (there is co-integration between the series) was accepted. In other words, the results of the Kao co-integration test also revealed the existence of a long-term relationship between the series, which supports the results of the Pedroni co-integration test. Long-term coefficient estimation results obtained with OLS, FMOLS, and DOLS estimators are presented below in Table 6.

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Variables	lnAGRI	lnFOR	lnREN	R^2	Adjusted R^2
OLS	-0.364*** (0.000)	-1.153*** (0.012)	-0.309*** (0.000)	0.935	0.930
FMOLS	-0.339*** (0.000)	-1.103*** (0.000)	-0.344*** (0.000)	0.947	0.942
DOLS	-0.596*** (0.000)	-1.476*** (0.002)	-0.350*** (0.000)	0.989	0.971

Notes: *** and ** denote significance at the 1% and 5% levels, respectively.
P-values are shown in parentheses.

Table 6
OLS, FMOLS, and DOLS long-run test results.
Source: Authors` own invention

When we examine the results of Table 6, we see that there is a negative relationship between agricultural value added, forestry and renewable energy and carbon dioxide emissions according to the results of all three tests. According to the results of the FMOLS test, a 1% increase in agricultural added value in GUAM countries reduces carbon dioxide emissions by 0.339%. This result is in line with the results of Ben Jebli and Ben Youssef (2017), Liu et al (2017), and Peng et al (2019). A 1% increase in forestry reduces carbon dioxide emissions by 1.103%. This result is similar to the research results of Khan et al. (2018), Waheed et al. (2018), Parajuli et al. (2019), Peng et al. (2019), Yasmeen et al (2022). A 1% increase in renewable energy consumption causes a 0.344% decrease in CO2 emissions. This result is line with the research results of Liu et al. (2017a), Liu et al. (2017b), Khan et al. (2018), Waheed et al. (2018), Qiao et al. (2019), Peng et al. (2019), Aydogan and Vardar (2020), and Eyuboglu and Uzar (2020).

Conclusions

The rapid growth of the world's population has increased the need for food, and in response to this, the production of agricultural products has increased greatly. However, this huge increase in agricultural production has also caused environmental pollution, which is more common in developing countries that have transitioned from a closed economy to an open economy than in developed countries. After the collapse of the Soviet Union, the economic relations formed in the former Soviet countries have stagnated, and all mechanisms designed for agri-culture and agricultural industry have declined. Thus, the formation of the national economy, based on traditional and extensive development factors, far from innovative technologies, and dominated by dirty production that disrupts the ecological balance, has begun. This study examines the relationship between per capita CO2 emissions, agriculture value added, forest area and renewable energy consumption for the GUAM countries between 1996 and 2019. Pedroni and Kao panel cointegration analysis was employed in the study to investigate the existence of a relationship between these variables, and OLS, FMOLS and DOLS methods were utilized to check the existence of a long-term relationship between the analyzed variables. As a result of the Pedroni and Kao panel cointegration test used in the study, it was confirmed that there is a long-term relationship between the independent variables (Agriculture value added, renewable energy, forest areas) and the dependent variable (carbon dioxide emissions). As the next step, OLS, FMOLS, and DOLS tests were used to determine the type of relationship between the independent and dependent variables. Based on the results of these tests, it was confirmed that there is a negative relationship between the independent variables (Agriculture value added, renewable energy, forest areas) and the dependent variable (Carbon dioxide emissions). As it is known from the results of previous studies conducted by researchers, the increase of renewable energy, forest areas and agricultural production lead to reduction of carbon emissions. The reasons behind the negative impact of all three variables on CO_2 emissions can be explained as follows:

High carbon sequestration capacity of forest areas is an important factor in reducing carbon emissions. Forest areas play an important role in creating a sustainable environment. Because forest areas reduce the harmful effects of climate change, and also ensure the vitality of the ecosystem. Forests are the most important carbon trap, capturing and sto-

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ring 76-78% of the organic carbon in the terrestrial ecosystem. Therefore, forest ecosystems play an important role in reducing the negative effects of global warming (Haripriya, 2002).

Fossil fuels, which are non-renewable energy sources such as coal, oil, gas, etc., used in traditional agriculture, have a huge negative impact on the environment, especially to the atmosphere. After the collapse of the Soviet Union, GUAM countries, in accordance with the world trend, increased the production of renewable energy and reduced the consumption of traditional non-renewable energy sources, reducing the amount of carbon emissions in the atmosphere accordingly. In recent times, the transition to a green economy related to the fight against global warming, promoting the use of ecologically clean energy sources is one of the main factors influencing the formation of this result.

As the main reason for the negative relationship between agricultural production and carbon emissions, we can point out such factors as the transition from traditional agriculture to no-till agriculture, the reduction of fertilizer and pesticide consumption, and the replacement of non-renewable energy consumption with renewable energy. All these listed factors increase the carbon capacity of agriculture and reduce CO_2 emissions.

The study contains important conclusions for policymakers regarding the importance of considering the impact of agriculture, forest areas and renewable energy consumption on environmental pollution in the sustainable development of GUAM countries. It is for this reason that importance should be given to the coordinated development of all three factors.

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