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RESEARCH ARTICLE

Does agricultural value-added induce environmental degradation? Evidence from Azerbaijan

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Abstract

This study empirically analyzes the long-term relationship between agricultural production and carbon dioxide (CO_2) emissions in Azerbaijan using annual data covering the period of 1992–2014. Additionally, real income and energy consumption variables were included in the model in testing the existence of the environmental Kuznets curve (EKC) hypothesis. Autoregressive distributed lag (ARDL) method is undertaken to reveal the existence of the long-term relationship between the CO_2 and its determinants. The ARDL mechanism shows that gross domestic product (GDP) and energy consumption have a positive and statistically significant effect on carbon dioxide emissions. However, agricultural production and the square of GDP have a negative impact on air pollution. Furthermore, when the coefficients of real GDP and squared GDP included in the model were examined to analyze the inverted-U-shaped relationship between economic growth and environmental pollution, the EKC hypothesis was confirmed to be valid. According to Toda-Yamamoto causality test results, there is a bidirectional relationship between GDP, the square of GDP, and carbon emissions. From energy consumption and agricultural value-added to CO_2 emissions, a unidirectional Granger causality relationship was found. Ultimately, the findings suggest that policies and reforms that increase or support agricultural production will help lower the country's CO_2 emissions level.

Keywords Climate change · Air pollution · Agriculture · Environmental Kuznets curve · ARDL · Causality · Azerbaijan

Introduction

Reducing the adverse effects of climate change is among the main issues in the development policies of countries. The destructive effects of economic growth on the environment have been one of the most talked about and discussed topics in almost every platform over the last decade.

The industrialization has led to heavy consumption of fossil fuels such as oil, natural gas, and coal. The accelerated use of natural resources and the uncontrolled growth of the economies have brought about an environmental problem (Gokmenoglu and Taspinar 2018). The rapid consumption of fossil fuels has led to an increase in greenhouse gas (GHG) emissions density in the atmosphere. The significant increase in the amount of other GHGs, especially carbon dioxide (CO_2) in the atmosphere, becomes a significant threat to the environment and human health (Javid and Sharif 2016; Yurtkuran and Terzi 2018).

The environmental Kuznets curve (EKC) hypothesis explains the relationship between environmental pollution and economic growth. The EKC hypothesis is based on the thesis that there is an inverse-U-shaped relationship between the level of economic development and environmental pollution (Wagner et al. 2020). The EKC derives its name from Kuznets' (1955) claim that there is a nonlinear relationship between income inequality and economic progress. Kuznets (1955) in his work, where he scrutinizes the way economic growth affects income inequality, expressed the relationship between income distribution inequality and per capita income with an inverted-U-shaped curve. Investigating the relationship between environmental indicators and per capita income, Grossman and Krueger (1991) showed that the relationship between per capita income and environmental degradation is similar to the relationship between income inequality and economic increase in the original Kuznets curve. Therefore, this relationship between economic growth and environmental

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quality is known as EKC (Dogan 2016; Gokmenoglu et al. 2019).

The pioneering studies on EKC were undertaken by Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Panayotou (1993). According to the EKC, environmental degradation increases in the early stages of economic growth, but when income reaches a certain level, this environmental degradation begins to decrease. This relationship can be defined as consumers' demand for a clean environment increases as their income increases. The research results on EKC vary depending on the selection of dependent and independent variables, the selected country and time interval, the econometric model and empirical methods used (Gokmenoglu and Taspinar 2018).

CO_2 emission is used as an indicator of environmental degradation or environmental pollution in studies related to EKC (Dogan 2016). One of the main reasons for this is that CO_2 emission is considered a pollutant with global effects. CO_2 is directly related to the problems affecting living life on earth, such as the GHG effect, global warming, and climate change (Gokmenoglu and Taspinar 2018). For the above reasons, CO_2 emissions were used as the dependent variable in the model in our study.

Agriculture and the environment are intertwined. Activities in the agricultural sector cause GHG emissions. Causes of GHG emissions from agriculture include livestock farming, rice farming, enteric fermentation, and mismanagement of fertilizer use (Ramachandra et al. 2015). GHG emissions from agricultural activities account for about 21% of total human-induced GHG emissions (Liu et al. 2017a).

The primary purpose of this study is to test the hypothesis that the agricultural sector may be the cause of environmental pollution for Azerbaijan. Besides, the impact of gross domestic product (GDP) and energy consumption on carbon emissions is being investigated. Accordingly, firstly, standard unit root tests such as augmented Dickey and Fuller (ADF) (1981) and Phillips and Perron (PP) (1988) were performed. Also, the Zivot and Andrews (1992) unit root tests, which take into account the structural breaks in the series, determined the degree of stability of the series. Then, the short- and long-term relationships between the series were determined with the autoregressive distributed lag (ARDL) bound test developed by Pesaran et al. (2001). Finally, with the help of Toda-Yamamoto (1995) causality analysis, the existence of causality relationships amid the variables was determined.

Literature review

Increasing environmental problems have resulted in a wide range of literature, and a significant portion of this research has been conducted by using the EKC hypothesis. These studies using EKC used diverse methods and diverse data sets (Gokmenoglu et al. 2019). The first studies on the EKC hypothesis only tested the relationship between economic growth and environmental pollution. In later studies, variables that are likely to affect environmental degradation such as *foreign direct investment* (Lau et al. 2014; Ibrahiem 2015; Abdouli and Hammami 2017; Mahmood and Alkhateeb 2018; Mahmood et al. 2019), *trade* (Zhang et al. 2017; Lu 2018; Amri 2018; Habib-Ur-Rahman et al. 2020), *water use* (Duarte et al. 2013; Katz 2015; Choi et al. 2015; Gu et al. 2017; Sun and Fang 2018), *energy consumption* (Alkhathlan and Javid 2013; Salahuddin and Gow 2014; Alam et al. 2016; Keho 2017; Usman et al. 2019), and *renewable energy consumption* (Al-mulali et al. 2016; Sinha and Shahbaz 2018; Zhang 2019; Bulut 2019; Yao et al. 2019) were added to the model as independent variables.

In the literature, there are studies in which some economic sectors are included in the model to investigate the adverse effects of economic growth on environmental quality. Among these, studies related to *transportation* (Cox et al. 2012; Liddle 2015; Nassani et al. 2017), *tourism* (Katircioglu 2014; De Vita et al. 2015; Zhang and Gao 2016), *oil* (Balaguer and Cantavella 2016; Boufateh 2019; Fethi and Rahuma 2019), and *finance* (Adjei Kwakwa et al. 2018; Shujah-ur-Rahman et al. 2019; Destek and Sarkodie 2019) sectors are more common.

Studies on the impact of agricultural activities on CO_2 emissions have received little attention from academics and economists. Few studies available have been undertaken in recent years. More work needs to be done, considering the economic importance of the agricultural sector and the role of agricultural production in terms of GHG emissions. Dogan (2016) analyzed the relationship between energy use, agriculture, GDP, the square of GDP and CO_2 emissions for Turkey between 1968 and 2016 using the ARDL approach. The results indicate that GDP has a significant positive effect on CO_2 emissions in both the long and short period, while agriculture impacts CO_2 emissions adversely in both periods. Liu et al. (2017a) examined the relationship between renewable energy consumption, agricultural value-added, and CO_2 emissions per capita for four selected The Association of Southeast Asian Nations (ASEAN) countries (Indonesia, Malaysia, Philippines, and Thailand) in the period 1970–2013. The results of the study do not support the inverted-U-shaped EKC hypothesis: increased renewable energy and agriculture reduce carbon emissions. In another research, Liu et al. (2017b) examined the relationship amid renewable and non-renewable energy, agriculture, and CO_2 emissions per capita using 1992–2013 period data for BRICS (Brazil, Russia, India, China, and South Africa) countries. The test results show that non-renewable energy and agriculture have positive effects on carbon emissions. Gokmenoglu and Taspınar (2018) examined the effect of energy use, agricultural value-added, GDP per capita, and the square of GDP per capita on CO_2 emissions between 1971 and 2014 for Pakistan. Toda-Yamamoto causality test and FMOLS (fully modified ordinary least squares) method were used in the study. They concluded that GDP has a positive elastic effect on carbon emissions, and energy use and agricultural value-added have an inelastic positive effect. In another study, Dogan (2019) analyzed the long-term relationship between agricultural production and China's CO_2 emissions using annual data covering the years 1971–2010. She used the ARDL approach to determine the existence of a long-term relationship between CO_2 emissions and agriculture. FMOLS, DOLS (dynamic ordinary least squares), and CCR (canonical cointegrating regression) methods were used as cointegration methods. The results of the study suggest that agriculture increases China's long-term carbon emissions. Qiao et al. (2019) tested the relationship between renewable energy, economic growth, agriculture, and carbon emissions for the G20 (Group of Twenty—19 countries and the EU) countries in the period from 1990 to 2014. Panel unit root test and FMOLS cointegration test were used in the study. According to test results, agriculture significantly increases carbon emissions in G20 countries. Burakov (2019) examined the effects of energy use, GDP, the square of GDP, and the share of agriculture in GDP over carbon emissions in the period of 1990–2016, through the EKC hypothesis model. ARDL mechanism was used in the study to evaluate the short- and long-term relationships amid variables. It is concluded that the agricultural sector is a statistically significant determinant of CO_2 emissions in Russia.

In addition to the research cited above, further research in the literature confirms the impact of agricultural activities on CO_2. Table 1 summarizes the recent literature on the relationship between agriculture and CO_2 emissions.

The literature review has revealed a small number of studies that test the validity of the EKC hypothesis regarding the Azerbaijani economy in general or its sub-sectors (Mikayilov et al. 2018; Hasanov et al. 2018; Mikayilov et al. 2019). The importance of the agricultural sector in the economy, the changing relationship between agriculture and environment, and the patterns of energy use in agriculture have made agriculture a vital issue to be investigated within the EKC framework. However, the study investigating the impact of the agricultural sector on environmental pollution within the EKC framework has not been carried out to the best of our knowledge. This study aims to fulfil this gap.

Data source and econometric methodology

Data sources

This study aims to empirically analyze the long-term relationship between agricultural production and CO_2 emissions in Azerbaijan. We obtained data from the World Development Indicators (WDI) directory covering the years 1992–2014. All data used are included in the model by taking the natural logarithm. Since data on CO_2 emissions for Azerbaijan in the World Bank database covers the years 1992–2014, this period was used in the study. The study consists of one dependent and four independent variables, and there are 23 observations for each variable. CO_2 emission (metric tons per capita) was used as the dependent variable; GDP per capita (constant 2010 US$ per capita), energy consumption (kg of oil equivalent per capita), and agricultural value-added (constant 2010 US$) were used as independent variables. Figure 1 includes the graphs related to the series of variables used in the model.

Examination of Fig. 1 reveals that there was a decrease in CO_2 emission per capita and energy consumption per capita between 1992 and 2014. However, there had been various fluctuations during the periods. GDP per capita and agricultural value-added have increased steadily starting from the end of 1990s.

Econometric model

This analysis based on the work of Dogan (2016), Gokmenoglu and Taspinar (2018), and Gokmenoglu et al. (2019) to see whether agricultural activities impact environmental pollution. Therefore, the model has been determined as in Eq. (1).

$$CO_2 = f\left(GDP, GDP^2, ENG, AGRI\right) \tag{1}$$

Model in Eq. (1) was reconfigured and converted into a linear-logarithmic model.

$$\begin{aligned} lnCO_{2t} = \beta_0 + \beta_1 lnGDP_t + \beta_2 (lnGDP)_t^2 + \beta_3 lnENG_t \\ + \beta_4 lnAGRI_t + \varepsilon_t \end{aligned} \tag{2}$$

In the model, ln refers to the natural logarithm, while β refers to the rate of effect of independent variables on the dependent variable. $lnCO_2$ is the natural log CO_2 emissions (metric tons per capita), lnGDP is the natural log real income (constant 2010 US$), $lnGDP^2$ is the square of natural log real income, lnENG is the natural log of energy consumption (kg of oil equivalent per capita), lnAGRI is the natural log agricultural value-added (constant 2010 US$), and ε_t to the error term.

Stationarity tests and structural break test

The first concept met in studies on time series is stationarity. Therefore, first, whether the series is stationary is checked. If the series is not stationary, there is a false regression problem

Table 1 Review of the recent literature on agriculture–CO_2 emissions nexus

Authors	Countries	Period	Variables	Method	Results
Ben Jebli and Ben Youssef (2017)	Algeria, Egypt, Morocco, Sudan, Tunisia	1980–2011	CO_2, GDP, AGRI, REN	LLC, IPS, Fisher-ADF, Fisher-PP, Pedroni cointegration test, VECM Granger causality test	The increase in REN and GDP increase CO_2 emissions in the long run. AGRI decreases CO_2 in the long run
Ben Jebli and Ben Youssef (2019)	Brazil	1980–2013	CO_2, GDP, AGRI, CRW consumption	ARDL, Granger causality test	CRW consumption and AGRI contribute to increase economic growth and to decrease CO_2 emissions. There is a unidirectional causality running from AGRI to CO_2 emissions and GDP.
Chandio et al. (2020)	China	1990–2016	CO_2, CRP, LSP, FA, PC	ARDL, FMOLS, CCR	Crop production, as well as livestock production, has a significant positive effect on CO_2 emissions. However, power consumption in agriculture and forest area has a negative effect on CO_2 emissions.
Eyuboglu and Uzar (2020)	Malaysia, Indonesia, India, Kenya, Mexico, Colombia, and Poland	1995–2014	CO_2, GDP, ENG, REN, AGRI, OPE	Kao, Fisher-type Johansen and Westerlund panel cointegration tests. FMOLS, DOLS	Agriculture increases CO_2 emissions; renewable energy reduces carbon emissions. Furthermore, economic growth and energy consumption enhance CO_2 emissions.
Gokmenoglu et al. (2019)	China	1971–2014	CO_2, GDP, GDP^2, ENG, AGRI	ADF, PP, ZA, ARDL, Granger causality	GDP and ENG have a positive, elastic impact; AGRI has a positive, inelastic impact on CO_2 emissions where GDP^2 has a negative and inelastic impact on air pollution.
Waheed et al. (2018)	Pakistan	1990–2014	CO_2, REN, AGRI, FA	ARDL, VECM Granger causality test	Renewable energy consumption and forest have negative and significant effects on CO_2 emission. Agricultural production positively and significantly affects CO_2 emission in the long run.

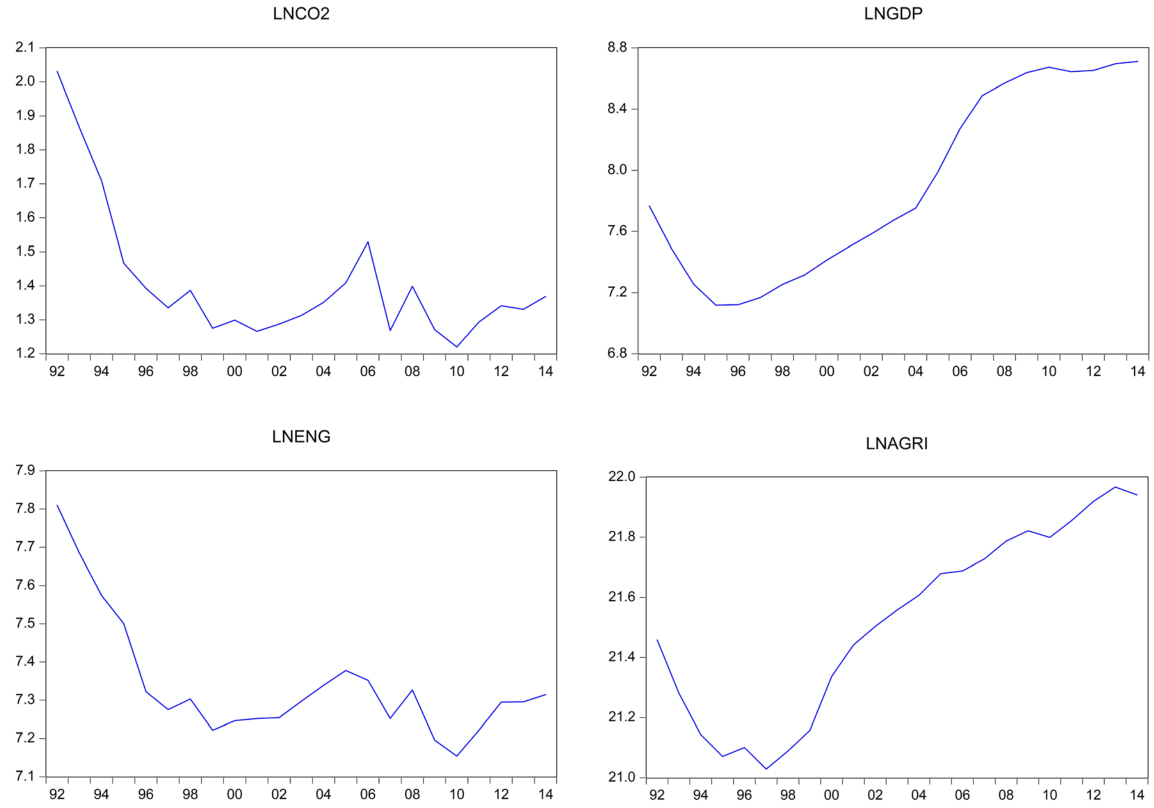
AGRI, agricultural value-added; *CRW*, combustible renewables and waste consumption; *CRP*, crop production; *ENG*, energy consumption; *FA*, forest area; *GDP^2* , square of gross domestic product; *IPS*, Im, Pesaran and Shin (2003) unit root test; Kao (1999) cointegration test; *KPSS*, Kwiatkowski et al. (1992) unit root test; *LLC*, Levin et al. (2002) unit root test; *LCP*, livestock production; *OPE*, trade openness; *PC*, power consumption in agriculture; *NRE*, non-renewable energy; *REN*, renewable energy consumption; *VECM*, vector error correction model; Westerlund (2007) cointegration test; *ZA*, Zivot and Andrews (1992) unit root test

in the analysis (Granger and Newbold 1974). The false regression problem causes the relationship between variables to be incorrect. In this study, augmented Dickey and Fuller (ADF) (1981) and Phillips and Perron (PP) (1988) unit root tests were used to test the stationarity of the series. ADF and PP unit root tests do not take structural breaks into account. Since the study covers 23 years, many structural changes in the economy may occur in this period. The results of the Zivot and Andrews (1992) test, which included structural breaks, were also taken into account. For unit root tests, the H_0 hypothesis states that the series contains a unit root and is not stationary.

In contrast, the H_1 hypothesis states that the series does not contain a unit root and is therefore stationary. Various methods can be used to determine the lag lengths in the models. The most common of these are Akaike information criterion (AIC), Schwarz information criterion (SIC), Bayesian information criterion (BIC), and Hannan-Quin criterion (HQC). In order to determine the appropriate lag length in the study, the AIC was preferred.

Cointegration analysis: ARDL bound testing approach

Various cointegration tests are used in time-series studies to research long-term relationships amid variables. Among the cointegration tests, the most commonly used in the literature are Engle and Granger (1987) test, Johansen (1988) test, and Johansen and Juselius (1990) tests. However, to apply these tests, all variables must be at first level stationary. In other words, all variables must be I(1). This provision causes some problems in the application. This problem has been solved with the ARDL approach developed by Pesaran and Smith (1998), Pesaran and Shin (1999), and Pesaran et al. (2001). This approach has been widely used in cointegration analysis recently. ARDL bound test approach has some advantages over other cointegration tests. This method can be applied regardless of whether the degree of integration of the series is I(0) or I(1) (Tang 2003). In other words, the level of integration of the relevant variables may not be the same as expected. Another advantage is that it can be applied to small samples. Even in these cases, it produces consistent and


LNCO2

LNGDP

LNENG

LNAGRI

Fig. 1 Graphical representation of the series in the model. InCO$_2$, the natural log carbon dioxide emissions; lnGDP, the natural log real income; lnENG, the natural log of energy consumption, lnAGRI, the natural log agricultural value-added

reliable results. When using this method, it is essential to note that the series is not integrated in the second or higher order (Narayan and Narayan 2004). Due to these advantages, we preferred the ARDL model and is formulated as in Eq. 3.

$$\begin{aligned}\Delta \mathrm{CO}_{2\mathrm{t}} = \alpha_0 &+ \sum_{i=1}^{m} \alpha_{1i}\Delta CO_{2t-i} + \sum_{i=0}^{m} \alpha_{2i}\Delta GDP_{t-i}\\ &+ \sum_{i=0}^{m} \alpha_{3i}\Delta GDP2_{t-i} + \sum_{i=0}^{m} \alpha_{4i}\Delta ENG_{t-i}\\ &+ \sum_{i=0}^{m} \alpha_{5i}\Delta AGRI_{t-i} + \alpha_6 CO_{2t-1} + \alpha_7 GDP_{t-1}\\ &+ \alpha_8 GDP2_{t-1} + \alpha_9 ENG_{t-1} + \alpha_{10} AGRI_{t-1}\\ &+ \mu_t \end{aligned} \tag{3}$$

In this model, Δ illustrates the first difference operator, the error term in the $\mu\ t$ period, and m stands for the optimal lag length. Furthermore, the coefficients $\alpha 1$, $\alpha 2$, $\alpha 3$, $\alpha 4$, and $\alpha 5$ indicate the short-term relationship between the variables, while the coefficients $\alpha 6$, $\alpha 7$, $\alpha 8$, $\alpha 9$, and $\alpha 10$ express the long-term dynamic relationship between the variables.

The ARDL bound test offers the possibility to test the long-term relationship between variables, cointegration, in other words, according to the following alternative hypotheses. The null hypothesis (H$_0$) in Eq. 4 indicates that there is no cointegration relationship between the variables, and the alternative hypothesis (H$_1$) indicates the cointegration relationship between the variables.

$$\begin{aligned} &H_0 : \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10}\\ &H_1 : \alpha_6 \neq \alpha_7 \neq \alpha_8 \neq \alpha_9 \neq \alpha_{10} \end{aligned} \tag{4}$$

In order for the limit test to be applied, the lag length shown as m in Eq. (3) must be determined first. Schwarz information criterion (SIC) was used to determine the lag length. For the bound test, the value at which the optimum lag length SIC is the smallest is selected. The bound test method is based on the F statistic or Wald statistic. The F value obtained from the model is compared with the lower and upper limit values calculated by Pesaran et al. (2001) and Narayan (2005). The critical values obtained by Pesaran et al. (2001) are produced for samples with a large number of observations (between 500 and 1000); it should be noted that it might yield misleading results in studies with small sample size. Therefore, Narayan (2005) created new critical values for sample sizes based on 30 to 80 observations. Since the sample size is 23, critical values calculated by Narayan (2005) were used in our study. If the calculated F statistic is less than the critical value of the lower bound, the null hypothesis is accepted and it is decided that there is no cointegration relationship between the series. If the F statistic is between the critical values of the upper and lower bounds, a definite interpretation cannot be made. In the case that the F statistic is higher than the critical value of the upper bound, the null hypothesis is rejected and it is concluded that there is a cointegration relationship between the dependent variable and the estimators. This result means that the variables used in the study act together in the long term. If there is a cointegration relationship between the series, ARDL models are established to determine the long- and short-term relationships. Long-term coefficients are obtained after understanding that the model has a cointegration relationship. In order to estimate the long-term coefficients, the ARDL model (5) is created.

$$\begin{aligned}\mathrm{CO}_{2\mathrm{t}} = \alpha_0 &+ \sum_{i=1}^{m} \alpha_{1i} CO_{2t-i} + \sum_{i=0}^{m} \alpha_{2i} GDP_{t-i} \\ &+ \sum_{i=0}^{m} \alpha_{3i} GDP2_{t-i} \sum_{i=0}^{m} \alpha_{4i} \Delta ENG_{t-i} \\ &+ \sum_{i=0}^{m} \alpha_{5i} AGRI_{t-i} + \mu_t \end{aligned} \tag{5}$$

After determining the coefficients of the long-term relationship, the model's diagnostic tests are checked and the suitability of the model is decided. An error correction model based on ARDL is used to determine short-term relationships between variables (shown in Eq. 6).

$$\begin{aligned}\Delta\mathrm{CO}_{2\mathrm{t}} = \alpha_0 &+ \sum_{i=1}^{m} \alpha_{1i} \Delta CO_{2t-i} + \sum_{i=0}^{m} \alpha_{2i} \Delta GDP_{t-i} \\ &+ \sum_{i=0}^{m} \alpha_{3i} \Delta GDP2_{t-i} + \sum_{i=0}^{m} \alpha_{4i} \Delta ENG_{t-i} \\ &+ \sum_{i=0}^{m} \alpha_{5i} \Delta AGRI_{t-i} + \alpha_6 ECT_{t-1} + \mu_t \end{aligned} \tag{6}$$

ECT_{t-1} refers to the error correction term in the model. The coefficient of *ECM* (error correction model) shows how much of the effect of a shock occurring in the short term will disappear in the long term (Pesaran et al. 2001). In order to investigate the stability of the ARDL model and to determine whether there are structural breaks related to variables, cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) test recommended by Brown et al. (1975) are widely used. If CUSUM and CUSUMSQ values are within the critical limits at 5% significance level, then H_0 is accepted, which indicates that the coefficients in the ARDL model are stable.

Causality test

After the cointegration relationship between the variables in the study was established, the causality test was performed to determine the causality relationship. The tests commonly used in the literature for determining the causality relationship are Granger and Toda-Yamamoto causality tests. For the causality test developed by Granger (1969) to be applied, the series should be stationary. If there is cointegration, there should be at least one-way causal relationship between them. For non-stationary series, Granger causality test is applied after the first difference is taken. This requirement is not sought in the causality test developed by Toda and Yamamoto (1995). The Toda-Yamamoto (1995) causality test is based on the VAR model and can be applied regardless of whether the series contain unit-roots. Toda-Yamamoto causality analysis uses the standard vector autoregressive (VAR) model that is created by using the level values of the series. Then, the optimal lag length (k) of the VAR model is determined. The next step is to have a maximum degree of integration (d_{max}) for the variables used. The maximum degree of integration (k+d_{max}) is then added to the lag length. Finally, the causal relationships between the series are decided by applying the Wald (MWald) test developed for the first k of the coefficients in the model for the (k+d_{max}) lag length (Toda and Yamamoto 1995). For the Toda-Yamamoto causality test, Eq. (7) was created in line with the variables in the model.

$$\begin{aligned}\begin{bmatrix} \mathrm{lnCO_2} \\ \mathrm{lnGDP} \\ \mathrm{lnGDP^2} \\ \mathrm{lnENG} \\ \mathrm{lnAGRI} \end{bmatrix} = \begin{bmatrix} \alpha \\ \beta \\ \delta \\ \varphi \\ \vartheta \end{bmatrix} &+ \sum_{i=1}^{k} \begin{bmatrix} b_{11i} & b_{12i} & b_{13i} & b_{14i} & b_{15i} \\ b_{21i} & b_{22i} & b_{23i} & b_{24i} & b_{25i} \\ b_{31i} & b_{32i} & b_{33i} & b_{34i} & b_{35i} \\ b_{41i} & b_{42i} & b_{43i} & b_{44i} & b_{45i} \\ b_{51i} & b_{52i} & b_{53i} & b_{54i} & b_{55i} \end{bmatrix} \times \begin{bmatrix} \mathrm{lnCO_{2t-i}} \\ \mathrm{lnGDP_{t-i}} \\ \mathrm{lnGDP^2{}_{t-i}} \\ \mathrm{lnENG_{t-i}} \\ \mathrm{lnAGRI_{t-i}} \end{bmatrix} \\ &+ \sum_{j=k+1}^{d_{max}} \begin{bmatrix} b_{11j} & b_{12j} & b_{13j} & b_{14j} & b_{15j} \\ b_{21j} & b_{22j} & b_{23j} & b_{24j} & b_{25j} \\ b_{31j} & b_{32j} & b_{33j} & b_{34j} & b_{35j} \\ b_{41j} & b_{42j} & b_{43j} & b_{44j} & b_{45j} \\ b_{51j} & b_{52j} & b_{53j} & b_{54j} & b_{55j} \end{bmatrix} \times \begin{bmatrix} \mathrm{lnCO_{2t-j}} \\ \mathrm{lnGDP_{t-j}} \\ \mathrm{lnGDP^2{}_{t-j}} \\ \mathrm{lnENG_{t-j}} \\ \mathrm{lnAGRI_{t-j}} \end{bmatrix} \\ &+ \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{bmatrix} \end{aligned} \tag{7}$$

Empirical results and discussion

This section presents and discusses the empirical results. Table 2 presents the basic descriptive statistics and correlation values of the variables used in the study.

According to the correlation matrix results, there is a strong relationship between energy consumption and CO_2 in a positive way and between agricultural value-added and GDP in a negative way. Descriptive statistics and correlation matrix provide some preliminary information about the relationships between variables. However, econometric analysis methods will be used to obtain more valid information about the relationships between variables.

Table 2 Descriptive statistics and correlation of the variables

Variables	$lnCO_2$	lnGDP	$lnGDP^2$	lnENG	lnAGRI
Mean	1.409359	7.902260	62.80129	7.342137	21.52029
Median	1.341526	7.752615	60.10304	7.297491	21.55859
Maximum	2.030597	8.711540	75.89093	7.809784	21.96730
Minimum	1.220306	7.118823	50.67765	7.154266	21.02910
Std. Dev.	0.200826	0.609708	9.703640	0.157941	0.314351
Skewness	1.948338	0.178838	0.219216	1.677552	− 0.199336
Kurtosis	5.971165	1.396570	1.391724	5.162486	1.646957
Jarque-Bera	23.01141	2.586466	2.662992	15.26919	1.906761
		Correlation			
$lnCO_2$	1				
lnGDP	− 0.258174	1			
$lnGDP^2$	− 0.263934	0.999744**	1		
lnENG	0.972031**	− 0.325652	− 0.331083	1	
lnAGRI	− 0.277174	− 0.959031**	− 0.954677**	− 0.318125	1

Source: Authors' calculation. **Statistical significance at 5%; *statistical significance at 1% level

Result of the unit root tests

The stationarity of the series should be investigated before proceeding to cointegration analysis. In studies with non-stationary time series, false regression problems arise. On the other hand, to be able to apply ARDL approach, the series must be maximum first-order stationary. For this reason, first of all, the stationarity test was carried out with the help of ADF and PP unit root tests. The results of the test are presented in Table 3.

The results of Table 3 show that all series have unit roots in their levels. Nevertheless, all series have become stationary when the first differences are taken. One of the reasons why time series are not stationary is that there are structural breaks in the series in question. Therefore, the Zivot and Andrews (1992) test was also used for unit root analysis, taking into account the presence of structural breaks. Zivot and Andrews (1992) test investigates the existence of structural breakage in series with three different models. Model A depicts only a break in the intercept; model B, a break only in trend; and model C, both break intercept and trend. The zero hypothesis for the Zivot and Andrews (1992) test is that the series contains a unit root, while the alternative hypothesis is that there is no unit root in the series, meaning that the series is stationary. Table 4 contains the results of the Zivot and Andrews test.

When we look at the results reported in Table 4, it is seen that the series are stationary when the first difference is taken. This result reveals that all variables are stationary in their first difference [I(1)] with structural breaks.

ARDL bound test

Once the integration level of the variables involved in the analysis is determined, the second prerequisite for the

Table 3 Augmented Dickey and Fuller (ADF) and Phillips and Perron (PP) unit root tests

Variables	ADF		PP	
	Level	1st difference	Level	1st difference
CO_2	− 1.381 (0.1505)	− 4.581*** (0.0001)	− 1.697 (0.0844)	− 4.580*** (0.0001)
GDP	1.896 (0.9809)	− 2.196** (0.0301)	0.952 (0.9033)	− 2.195** (0.0302)
GDP^2	1.679 (0.9728)	− 2.141** (0.0340)	0.998 (0.9101)	− 2.153** (0.0331)
ENG	− 1.504 (0.1211)	− 3.643*** (0.0009)	− 1.284 (0.1775)	− 3.618*** (0.0010)
AGRI	1.292 (0.9450)	− 2.755*** (0.0084)	0.932 (0.9003)	− 2.744*** (0.0086)

In the ADF test, the appropriate lag length was determined according to the Schwarz information criterion (SIC), and the maximum number of lag was selected as 4. In the PP test, the kernel method was determined according to the "Barlett kernel" and the "Newey West bandwidth" method. *p* values are presented in parentheses. Asterisks ***, **, and * denote statistical significance at 1%, 5%, and 10% levels respectively

Table 4 Results of Zivot and Andrews (ZA) structural break unit root test

Variables	ZA test at first difference					
	Intercept		Trend		Intercept and trend	
	t statistic	Break year	*t* statistic	Break year	*t* statistic	Break year
$\ln CO_2$	− 4.256***	1995	− 4.442***	1996	− 4.401***	1995
lnGDP	− 7.803***	2005	− 3.334***	2008	− 8.631**	2005
$\ln GDP^2$	− 7.892***	2005	− 3.027*	2008	− 7.851***	2005
lnENG	− 3.462***	1996	− 3.591*	1997	− 3.658**	1996
lnAGRI	− 3.658***	1996	− 3.803***	2011	− 4.441***	2006

*, **, and *** denote null hypothesis rejecting at 10%, 5%, and 1%, respectively

ARDL model is the determination of the appropriate lag length. The appropriate lag length for the ARDL model has been determined by using the VAR model. AIC, SIC, and HQC information criterion values are used to determine the lag length. The lag length for which the minimum critical value is provided is determined as the lag length for the model. However, there should be no autocorrelation problem in the model created with the associated lag length. In this study, the optimal lag length was determined as 2. There is no autocorrelation problem in the model, which has a lag length of 2. The results of the test for lag length are given in Table 5.

Following the determination of the appropriate lag level, the cointegration relationship between the series was investigated. Table 6 shows the cointegration test results. As can be seen from the table, the value of the *F* statistic that tests the long-term relationship was found to be 8.859. This value was found to be higher than the critical value of the upper bound at the 1% significance level indicated by both Narayan (2005) and Pesaran et al. (2001).

The result satisfies the criteria for continuing the analysis; hence, the existence of a cointegration relationship between the variables used in the model has been proved.

After determining the existence of a cointegration relationship between variables, we estimate the coefficients of the long-term relationship between variables. The Schwarz information criterion was used to determine the lag length for long-term relationships. Since the VAR analysis in Table 5 finds the most appropriate lag length that does not cause autocorrelation as lag 2, the analysis was first performed with a lag length of 2. However, the autocorrelation problem has arisen in this ARDL model with lag 2. Consequently, the ARDL (1,0,1,1,0) long-term model without autocorrelation problem was deemed to be appropriate. The long- and short-term equation results of the cointegration relationship are included in Table 7. The results support each other in the long and short term.

When the long-term relationship results between the variables are analyzed, it is seen that there is a statistically significant relationship between the independent variables GDP and energy consumption and the dependent variable CO_2 emission at a 1% significance level. When we evaluate these relationships according to the signs, it is concluded that there is a positive impact of GDP and energy consumption on CO_2. In this case, while other factors are constant, a 1% increase in GDP and energy consumption increases carbon emissions by 2.7% and 1.1%, respectively. This statistically significant ($p < 0.01$) and positive (1.10) relationship between energy consumption and CO_2 emission is an indication of energy consumption causing environmental degradation in Azerbaijan.

This result probably occurs since most of the energy consumption in Azerbaijan is derived from non-renewable energy. Compared to the literature, this study is consistent with the results of Jalil and Mahmud (2009), Apergis and Payne (2010), Ozturk and Al-Mulali (2015), and Amri (2017). Economic growth increases CO_2 emissions in the long term

Table 5 Lag length selection criteria for cointegration VAR lag order selection criteria

Lag	LogL	LR	FPE	AIC	SIC	HQC
0	72.61199	NA	1.10e-09	− 6.439237	− 6.190542	− 6.385264
1	191.0683	169.2233	1.63e-13	− 15.33984	− 13.84766	− 15.01600
2	252.1739	58.19580*	8.57e-15*	− 18.77846*	− 16.04281*	− 18.18476*

*Lag order selected by the criterion. *LR*, sequential modified LR test statistic (each test at 5% level); *FPE*, final prediction error; *AIC*, Akaike information criterion; *SIC*, Schwarz information criterion; *HQC*, Hannan-Quinn information criterion

Table 6 ARDL bound test

Cointegration	*F* value	Significance	Narayan critical values		Pesaran critical values	
			1(0)	1(1)	1(0)	1(1)
Yes	8.859***	10%	2.752	3.994	2.45	3.52
		5%	3.354	4.774	2.86	4.01
		1%	4.768	6.670	3.74	5.06

***Significant at 1%. Critical values are obtained from Pesaran et al. (2001) table Case 3 unrestricted intercept and no trend and Narayan (2005)

as a result of intensive consumption of increasing energy, especially fossil energy sources, for production purposes. This result is in line with the findings of Apergis et al. (2010) who obtained data from 19 developed and developing countries. Besides, the determination of GDP coefficient as positive (2.69), statistically significant ($p < 0.01$), and GDP square coefficient being negative (− 0.16), statistically significant ($p < 0.01$), indicates that there is an inverted-U-shaped relationship between environmental pollution and income ($\beta 1 > 0$, $\beta 2 < 0$). In other words, the EKC hypothesis in Azerbaijan is valid for the period 1992–2014. According to this result, the increase in income level initially increases environmental pollution, and as the income level rises, environmental improvement begins. This result shows that Azerbaijan focuses on economic growth rather than environmental quality. A significant negative relationship was found between agricultural value-added and carbon emissions at 1% significance level. According to this result, a 1% increase in agricultural value-added reduces CO_2 emissions by 0.4% in the long term. This result can be explained as the necessity to use energy more efficiently or to use more renewable energy in Azerbaijan's agricultural sector. The finding that agricultural production reduces CO_2 emissions is in line with the work of Dogan (2016), Liu et al. (2017a), Ben Jebli and Ben Youssef (2017), and Ben Jebli and Ben Youssef (2019).

The short-term results show that there is a positive impact on GDP and energy consumption on CO_2 emissions, as well as a negative impact on agricultural value-added, as in the long term. The fact that the error correction coefficient obtained by the error correction model − 1.540242 (0.0000) is statistically significant and negative indicates that the short-term equilibrium deviations in the model are balanced in the long term. Narayan and Smyth (2006) have stated that if the coefficient of the error correction variable is greater than 1, the system fluctuates and stabilizes. This fluctuation decreases each time, making it possible to return to equilibrium in the long term.

Diagnostic tests of the model

Diagnostic tests have been conducted to determine whether the model is functional or not. The diagnostic test results presented in Table 8 show that autocorrelation, normality, changing variance, and model building error test statistics are acceptable in the predicted model.

Table 7 Summary of ARDL cointegration and long-run coefficient estimation

Long-run analysis				Short-run analysis			
Variable	Coefficient	*t* statistic	Prob.	Variable	Coefficient	*t* statistic	Prob.
lnGDP	2.691563**	3.687404	0.0024	D(lnGDP)	4.145659**	3.151639	0.0071
$\ln GDP^2$	− 0.155981**	− 3.537466	0.0033	D($\ln GDP^2$)	− 0.254976**	− 3.015586	0.0093
lnENG	1.100209**	15.98405	0.0000	D(lnENG)	0.997851**	5.247413	0.0001
lnAGRI	− 0.387405**	− 4.293006	0.0007	D(lnAGRI)	− 0.596698**	− 3.532029	0.0033
C	− 9.800736**	− 4.886110	0.0002	CointEq(-1)	− 1.540242**	− 6.639562	0.0000
Sensitivity analysis							
R^2		0.957011					
Adjusted R^2		0.935516					
F statistic		44.52346					
Prob (*F* statistic)		0.000000					
Durbin-Watson stat		2.096815					

**Significance at the 1% level

Table 8 ARDL diagnostic tests results

Test	χ^2	Probability	Result
Breusch-Godfrey serial correlation LM test	1.297	0.523	No problem of serial correlations
Breusch-Pagan-Godfrey heteroscedasticity test	9.589	0.213	No problem of heteroscedasticity
Jarque-Bera test	0.169	0.919	Estimated residual is normal
Ramsey test	1.804	0.095	Model is specified correctly.

CUSUM and CUSUMSQ stability tests were also performed to test the structural stability in the predicted long-term model. Figure 2 shows these tests. When we look at the CUSUM and CUSUMSQ test results, it is seen that the predicted model is stable during the relevant period.

Granger causality test

The results of the cointegration test provide information about whether there is a long-term relationship between the variables. Nevertheless, this does not inform us about the direction of the relationship. Finally, the Toda-Yamamoto Granger causality test was applied to determine the direction of the relationship between the variables (Table 9).

The Toda-Yamamoto (1995) causality test results show that GDP and carbon emissions, square of GDP, and CO_2 emissions have bidirectional causal relationships. Several studies support bidirectional causation between economic growth and carbon emissions (Rehdanz and Maddison 2008; Halicioglu 2009). Furthermore, there is a unidirectional Granger causality running from energy consumption to CO_2 emission. Similarly, the causal relationship seen running from energy consumption to emission is supported by Shahbaz et al. (2013, 2015) and other studies. The unidirectional Granger causality from energy consumption towards economic growth confirmed the energy-dependent growth hypothesis for Azerbaijan during the period studied. This result shows that the Azerbaijani economy is dependent on energy and that energy makes an essential contribution to the economic increase. There are numerous studies in the literature pointing out that economic growth is dependent on energy (Lee and Chang 2005; Solarin and Shahbaz 2013; Iyke 2015)

Conclusion

This study tests the hypothesis that whether the agricultural sector causes environmental pollution for Azerbaijan. The hypothesis was examined through the ARDL boundary test method based on annual data covering the period 1992–2014. Analyses have shown that agriculture does not have a positive effect on CO_2 emissions for the period investigated. Conversely, a negative association was found between agricultural value-added and CO_2 emissions. In other words, the increase in agricultural value-added reduces carbon emissions. The negative relationship between the agricultural sector and CO_2 emissions suggests that the growth of the agricultural sector and the increase of agricultural production will have a positive effect on CO_2 emissions in Azerbaijan.

This research additionally revealed a significant positive relationship between energy use and CO_2 emissions and between GDP and CO_2 emissions. This finding suggests that the increase in energy consumption, which provides economic growth, causes an increase in CO_2 emissions. Meeting the increasing energy demand mostly through the consumption of fossil fuels (oil, natural gas, coal) eventually increases carbon emissions. According to calculations, approximately 60% of the total CO_2 emissions at the global level are due to fossil fuel use (Meng and Niu 2011).

Inclusion of the coefficients of per capita real GDP and squared GDP in the model to analyze the inverted-U-shaped relationship between economic growth and environmental pollution confirmed the validity of the EKC hypothesis. The experimental data of Toda-Yamamoto causality test indicate unidirectional causality running from energy consumption to carbon emissions, and agriculture value-added to CO_2 emissions. The bidirectional causal relationship is observed

Fig. 2 CUSUM and CUSUMSQ stability tests

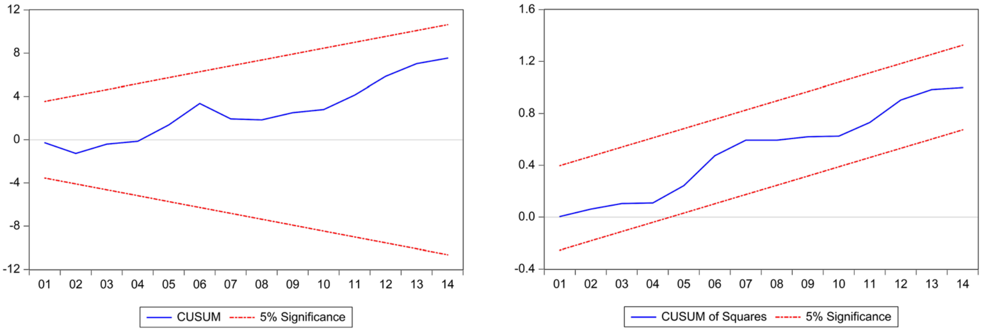


Table 9 Toda and Yamamoto Granger causality analysis

Variable	$\ln CO_2$	lnGDP	$\ln GDP^2$	lnENG	lnAGRI
$\ln CO_2$	-	5.297** (0.021)	4.554** (0.033)	0.061 (0.805)	0.932 (0.334)
lnGDP	34.613*** (0.000)	-	0.581 (0.446)	1.769 (0.184)	0.185 (0.667)
$\ln GDP^2$	34.737*** (0.000)	0.381 (0.537)	-	2.021 (0.155)	0.222 (0.638)
lnENG	20.496*** (0.000)	8.830*** (0.003)	8.601*** (0.003)	-	0.937 (0.333)
lnAGRI	6.555*** (0.011)	1.322 (0.250)	1.174 (0.279)	0.071 (0.792)	-
	$GDP \leftrightarrow CO_2$	$GDP^2 \leftrightarrow CO_2$	$ENG \rightarrow CO_2$	$AGRI \rightarrow CO_2$	$ENG \rightarrow GDP, GDP^2$

*, **, and *** denote null hypothesis rejecting at 10%, 5%, and 1%, respectively. The values in parentheses are the *p* values. The optimal lag length is selected using the Akaike information criterion (AIC)

between GDP and CO_2 emissions and between the square of GDP and CO_2 emissions. The presence of one-way causality from energy consumption to economic growth once again confirms to us that economic growth depends on energy.

This research shows how carbon emissions are related to the agricultural sector in Azerbaijan. The result showing that the increase in agricultural production does not increase CO_2 emissions, and does not cause environmental pollution, offers a unique opportunity for the development of Azerbaijani agriculture. The results of this study could serve as a guide for policymakers in developing countries trying to develop through industrialization rather than focusing on agricultural development, to formulate effective policies on environmental protection.

Policymakers should continuously monitor and measure the environmental impact of agriculture while increasing the share of agriculture in the Azerbaijani economy, and take into account that agriculture will adversely affect environmental degradation in the long term if agriculture continues with old traditional methods. Farmers should be informed about the latest agricultural developments and current environmental issues. They should be encouraged to be more interested in environmental issues, and take up practices such as precision agriculture, green farming, good farming practices, and green products in order to reduce the environmental degradation caused by agricultural activities. Agricultural production models must be quickly shifted in this direction, to be able to gain access to markets with high export potential, such as the European Union. The government should reassure farmers to adopt innovative and environmentally friendly technologies by providing rewards, incentives, and long-term and interest-free loans. Precisely, pioneer farmers should feel confident that they will get state support if they go ahead and invest in less polluting technologies. Furthermore, it is vital to invest in clean agriculture and simultaneously reinstate polluting energy consumption forms with renewable energy while promoting high-income growth. The state should encourage the use of alternative energy sources in other sectors as well as a substitute for fossil fuels, and long-term structural reforms should be implemented to increase the share of these resources in total energy consumption. Increasing the share of renewable energy in total energy consumption can be useful for reducing CO_2 density in the country. Besides, CO_2 capture and storage technologies should be used to prevent environmental pollution. CO_2 taxes should be introduced to reduce CO_2 emissions. Coal-fired power plants and emissions from these facilities can be reduced by introducing substitute energy sources. Universities in Azerbaijan should be encouraged to participate in active research, and both the state and private institutions should invest more in research and development (R&D) activities, and raise awareness about using fossil fuel mode of energy efficiently.

As with any research, there are a number of limitations in this research. We analyzed in this study how agricultural production has effected CO_2 emissions in Azerbaijan. Future studies should also be carried out to determine the impact of agricultural production not only on CO_2 emissions but also on methane (CH_4) and nitrous oxide (N_2O) gases. Further studies aimed at determining the impact of agricultural production on the ecological footprint will fulfil a necessary gap in Azerbaijan literature. They will serve as an example to similar agrarian countries.

In this respect, our research will guide the relevant authorities both in policymakers for the carbon-friendly growth of agriculture and future studies about the link between carbon emissions and agriculture.

Authors' contributions Ismail Bulent Gurbuz: conceptualization; writing–original draft; writing; review and editing; supervision

Elcin Nesirov: methodology; data curation; investigation; resources; software; validation; visualization; writing–original draft

Gulay Ozkan: writing–original draft; review and editing

Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate The study was approved by the ethics committee conducted according to the ethics guidelines set out in the Declaration of Helsinki. Verbal and written consent was obtained from the participants. All participants were informed about the purpose and design of the study and were ensured anonymity and confidentiality. Participation in the study was voluntary.

Consent for publication Not applicable

Competing interests The authors declare that they have no competing interests.

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