Testing the Agricultural Induced EKC Hypothesis: Fresh Empirical Evidence from the Top Ten Agricultural Countries

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Abstract

Within the scope of sustainable development goals and climate change mitigation, this study focuses on investigating the effects of energy consumption, agriculture, and economic growth on CO_2 emissions in the top ten agricultural countries for the period 1997-2016. By investigating the validity of the agricultural induced environmental Kuznets curve (EKC), the study mainly aims to explore how agricultural activities affect environmental quality. In doing so, this study utilizes the augmented mean group (AMG) estimator that allows for heterogeneity and cross-sectional dependence. The results of the AMG estimator suggest that the agricultural induced EKC hypothesis is valid for six out of the ten countries. The empirical results also indicate that agriculture reduces CO_2 emissions, while energy consumption accelerates environmental degradation. All these results suggest that agricultural production and economic development can play an essential role in reducing environmental pollution.

Keywords

Agriculture, EKC, energy consumption, heterogeneity, panel data.

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Introduction

Nowadays, environmental sustainability is an important issue for policy-makers and researchers. Environmental degradation seriously affects both sustainable development and human well-being. Since 1950s, human activities emitting greenhouse gasses (GHGs) have been considered as the most important cause of climate change (IPCC, 2013; Paramati et al., 2017). Among GHGs, carbon dioxide (CO_2) emissions directly contribute to global warming and enhanced greenhouse effects. Fossil fuel-based energy consumption (EC) is the primary source of CO_2 emissions. However, EC is an essential requirement for economic and social development (Cherni and Jouini, 2017; Zhang et al., 2019). In fact, EC and economic growth increased rapidly during and after the industrial revolution, which in turn resulted in an increase in CO2 emissions. In other words, the expansion of economic activities has led to an unprecedented increase in global EC, which has caused severe environmental problems such as air pollution, deforestation, desertification, and ozone depletion. These environmental problems bring ecological and sustainable development to the forefront.

The concept of environmental sustainability was first introduced in 1972 in the United Nations Conference on the Human Environment. The conference emphasized that economic growth will cause environmental problems. Later, in 1987, the United Nations published the report “Our Common Futures”. This report stated that economic development and environmental sustainability should be considered together. In 1992, the "United Nations Conference on Environment and Development" was held in Rio de Janeiro to identify the basic principles for sustainable development. These attempts led to the recognition of the high environmental costs and the emergence of the concept of sustainable development.

In the context of the Sustainable Development Goals (SDGs), the United Nations' 2030 global agenda helps to develop political action both to protect the planet and to promote prosperity for all nations (Sarkodie and Owusu 2017). Accordingly, the priority of the SDGs is to eradicate absolute poverty by 2030 (Muller et al., 2011). Agricultural sustainability coincides with some of the 17 SDGs. The SDGs that relate to agricultural activities can be listed as Goal 2: Zero Hunger, Goal 6: Clean Water and Sanitation, Goal 7: Affordable and Clean Energy, Goal 12: Responsible Consumption and Production, Goal 13: Climate Action, Goal 14: Life Below Water, and Goal 15: Life on Land. These SDGs are primarily aimed at increasing agricultural productivity.

Agriculture is an important component in achieving the SDGs, improving the quality of life, and reducing poverty and hunger (Ali et al., 2017; Ullah et al., 2018), which contributes to the improvement of the productivity of nations. Agricultural knowledge can support economic development by increasing competition in a country. In developing countries, it can be said that the effect of agricultural growth on poverty reduction is higher compared to other sectors (Timmer, 2009; Gokmenoglu and Taspinar, 2018). Higher productivity and production in agriculture are extremely important for the overall economic development of a country. The agricultural sector supplies raw materials to industry and provides food and feed for all living things. This sector also contributes to international imports and exports.

According to the World Bank (2020), the agricultural sector represented 43.68% of global employment in 1991, but this share declined to 26.86% in 2019. Although the share of agriculture in total employment has decreased over the years, this sector provides 1/4 of total employment. The decrease in employment in the agricultural sector is mainly due to the declining demand for labor. Mechanization in agriculture not only had a negative impact on employment but also had a significant impact on the environment. On the one hand, the machinery, tools, and equipment used in agriculture operate on fossil fuels, which are the main sources of air pollution (Chel and Kaushik, 2011; Liu et al., 2017). The agricultural sector uses non-renewable energy sources such as oil, natural gas, and coal to run machinery and equipment, heat or cool buildings, light the farm, and indirectly produce fertilizer, which leads to an increase in environmental pollution. On the other hand, CO_2 emissions can be significantly reduced through the use of environmentally friendly technologies and renewable energy in agriculture. In this regard, GHG emissions can be reduced by 80% by 2030 by regulating supply and demand in the agricultural sector. Agricultural pollution can be minimized with practices such as afforestation on the supply side and reduction of losses in the food supply chain on the demand side (IPCC, 2014). The negative effects of climate change can also be reduced through measures such as the use of animal manure in agriculture, the conversion of agricultural residues into energy, thus reducing the need for fossil fuels and promoting renewable energy (Liu et al., 2017).

Based on the above information on sustainability, economic development, EC, and agriculture, this study analyzes the validity of the agriculture-based environmental Kuznets curve (EKC) hypothesis in the top ten agricultural countries (T10AGR, i.e., China, India, Indonesia, Brazil, the United States, Nigeria, Turkey, Japan, Argentina, and Thailand). The EKC hypothesis represents an inverted U-shaped relationship between income level and environmental degradation. According to Grossman and Krueger (1991), environmental pollution indicators increase as the economy expands, but after reaching a certain level of wealth, environmental degradation can be reduced with increasing environmental awareness and developing technologies. Recently, several researchers have tested the validity of the agriculture-induced EKC hypothesis by including agriculture as an independent variable in the analysis in addition to income level (see, e.g., Aziz et al., 2020; Prastiyo et al., 2020; Ridzuan et al., 2020). To date, the validity of the agriculture-induced EKC hypothesis has not been analyzed for most agricultural countries. To our knowledge, only Qiao et al. (2019) tested the validity of the agricultural EKC hypothesis for the G20 countries. However, G20 countries do not include major agricultural countries such as Thailand and Nigeria. In this context, the analysis of T10AGR countries might give us with different results. The leading macroeconomic indicators of the T10AGR countries are shown in Table 1.

As can be seen in Table 1, T10AGR countries account for more than 50% of EC, GDP, agricultural value-added, and CO_2 emissions worldwide. In this regard, it is crucial to determine the validity of the EKC hypothesis in the T10AGR countries, which are responsible for 52% of the global GDP. Moreover, agricultural production in these countries, which was US$ 933 billion in 1997, increased by 93% and rose to US$ 1.801 trillion in 2016. During the same period, global agricultural production growth was 66%. This indicates that T10AGR countries play an essential role in providing food supply in the world and contribute

Variables	1997			2016		
	T10AGR	World	Share	T10AGR	World	Share
GDP	21.976	45.187	48.63%	40.766	77.937	52.30%
AGRV	933	1.800	55.15%	1.801	3.000	59.96%
EC	5.107	10.435	48.94%	8.435	15.294	55.15%
CO_2	12.370	24.191	51.13%	20.477	35.220	58.14%

Note: GDP and AGRV are measured in constant 2010 US dollars. EC and CO_2 emissions are measured in terawatt-hours and gigatonnes, respectively

Source: author´s elaboration based on World Bank (2020), Global Carbon Project (2020), and Our World in Data (2019)

Table 1: Energy consumption, agriculture, GDP and CO_2 emissions in the T10AGR countries.

to meeting the needs of other countries by exporting agricultural products. Therefore, studying the environmental impact of the agricultural and energy sectors in T10AGR countries will provide important evidence for poverty alleviation and global warming.

Despite the extensive literature on the impact of agriculture on GHG emissions, few studies have analyzed the relationships between agriculture and CO2 emissions in the EKC framework. (Gokmenoglu et al., 2019). In order to make more accurate decisions about the effects of agriculture on environmental pollution, it is important to test the agricultural EKC hypothesis for a different country or groups of countries and thus adding more evidence to the existing literature. In this context, our study contributes to the current literature in two ways. i) To our knowledge, this is the first attempt to test the validity of the agriculture-based EKC hypothesis in T10AGR countries. Examining the relationship between environmental pollution and agriculture in countries with intensive agricultural activities may provide findings that are more reliable. The T10AGR countries are responsible for 66% of the world's agricultural production. This ratio, which is equivalent to two-thirds of the world’s agricultural activities, provides a general picture of the relationship between agriculture and environmental pollution. ii) The validity of the agricultural EKC hypothesis may change depending on the agricultural indicators. While some studies in the literature use the agricultural value-added (Liu et al., 2017; Gokmenoglu and Taspinar, 2018; Aziz et al. 2020), others have included agriculture's share of GDP in the analysis. (Balsalobre-Lorente et al., 2019; Dogan, 2019; Prastiyo et al., 2020). Using both agricultural indicators, we aimed to determine the impact of agriculture on CO2 emissions in a more detailed and robust framework.

This study consists of five sections. A literature review is presented in the next section. The data, model, and methodology used in the study are presented in the following section. Then, the empirical findings are reported and discussed. Finally, the conclusion and policy recommendations are given in the last section.

Literature review

Since the pioneering work of Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), numerous research papers have investigated the EKC hypothesis, implying an inverted U-shaped relationship between environmental pollution and economic growth. Early studies included per capita GDP and per capita EC as independent variables in the analysis (see, for example, Selden and Song, 1994; Shafik, 1994; Holtz-Eakin and Selden, 1995). Subsequently, researchers have examined various variables such as foreign direct investment (Agboola and Bekun, 2019), human capital (Mahmood et al., 2019), industrialization (Pata, 2018a; Prastiyo et al., 2020), urbanization (Ridzuan et al., 2020), trade openness (Ben Jebli and Ben Youssef, 2017; Balsalobre-Lorente et al., 2019), and economic complexity (Yilanci and Pata, 2020) in analyzing the EKC hypothesis. Although the agricultural sector is an important factor in economic development, it was not a priority for researchers when testing the EKC hypothesis (Prastiyo et al., 2020). Recently, a limited number of studies have addressed the impact of agriculture on environmental pollution within the EKC hypothesis framework. The findings of these studies are summarized in Table 2.

Reviewing the existing literature, we conclude that the EKC hypothesis is validated in most studies that investigate the impact of agriculture on environmental pollution. However, Ben Jebli and Ben Youssef (2017) and Liu et al. (2017) failed to prove the EKC hypothesis. Moreover, there is no consensus among researchers about the influence of agriculture on environmental degradation. In eight of the 13 studies, researchers

Work	Countries	Time period	Method(s)	Variables	Agriculture-pollution nexus	A-EKC
Ben Jebli and Ben Youssef (2017)	Tunisia	1980-2011	Johansen-Juselius cointegration,	CO_2 | GDP, REC, NREC, TO AGRV	Agriculture →CO_2 (+)	X
Liu et al. (2017)	ASEAN-4	1970-2013	Kao panel cointegration test, OLS, DOLS and FMOLS	CO_2 | GDP, REC, NREC, AGRV	Agriculture →CO_2 (-)	X
Gokmenoglu and Taspinar (2018)	Pakistan	1971–2014	Maki cointegration, FMOLS	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (+)	✓
Agboola and Bekun (2019)	Nigeria	1981-2014	Bayer-Hanck cointegration test,	CO_2 | GDP, TO, FDI, EC, AGRR	Agriculture →CO_2 (+)	✓
Balsalobre-Lorente et al. (2019)	BRICS	1990-2014	Kao and Fisher panel cointegration tests, DOLS, FMOLS	CO_2 | GDP, ELC, MOB, TO, AGRR	Agriculture →CO_2 (+)	✓
Dogan (2019)	China	1971-2010	ARDL, FMOLS, DOLS, CCR	CO_2 | GDP, EC, AGRR	Agriculture →CO2 (+)	✓
Gokmenoglu et al. (2019)	China	1971-2014	ARDL	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (+)	✓
Qiao et al. (2019)	G20	1990-2014	Johansen-Fisher panel cointegration, FMOLS, DOLS	CO_2 | GDP, REC, AGRV	Agriculture →CO_2 (+)	✓
Zhang et al. (2019)	China	1996-2015	ARDL	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (-)	✓
Aydoğan and Vardar (2020)	E7	1990-2014	Pedroni cointegration, OLS, FMOLS and DOLS	CO_2 | GDP, REC, NREC AGRV	Agriculture →CO_2 (+)	✓
Aziz at al. (2020)	Pakistan	1990-2018	Quantile ARDL	EF | GDP, FA, REC, AGRV	Agriculture →EF (-)	✓
Prastiyo et al. (2020)	Indonesia	1970-2015	ARDL	CO_2 | GDP, IND, URB, AGRR	Agriculture →CO_2 (-)	✓
Ridzuan et al. (2020)	Malaysia	1978-2016	ARDL	CO_2 | GDP, HG, URB, CP, FP, LP	CP and FP →CO_2 (-)	✓

Note: ARDL: Autoregressive distributed lag model. MOB: mobile use. ELC: electricity consumption. TO: Trade openness. REC: Renewable energy consumption. NREC: non-renewable EC. EF: Ecological footprint. FA: Forest area. HG: hydroelectricity generation. CP: Crop production. FP: Fisheries production. LP: Livestock gross production. AGRV: Agricultural value-added. AGRR: Agricultural production (% of GDP). OLS: Ordinary least squares. CCR: Canonical cointegrating regression. DOLS: Dynamic OLS. IND: Industrialization. URB: Urbanization. FMOLS: Fully modified OLS
Source: own processing

Table 2: Literature review on the agriculture induced EKC hypothesis.

have found that agriculture accelerates CO_2 emissions. In contrast, Liu et al. (2017), Zhang et al. (2019), Aziz at al. (2020), Prastiyo et al. (2020), and Ridzuan et al. (2020) claimed that agriculture reduces environmental pollution and that increasing agricultural production helps to improve environmental quality. In terms of methodology, four out of the 13 studies used time series methods. When using panel data methods, Liu et al. (2017), Balsalobre-Lorente et al. (2019), Qiao et al. (2019), Aydoğan and Vardar (2020) neglected the effects of cross-sectional dependence (CSD) and homogeneity. Ignoring CSD and slope homogeneity in panel data analysis may lead to biased results (Breitung, 2005). In summary, there are two research gaps in the existing literature on the agricultural induced EKC hypothesis. i) Previous studies in the literature neglect CSD and homogeneity. ii) It is unclear whether the impact of agriculture on the environment is positive or negative. To address these research gaps, we investigated the impact of agriculture on CO_2 emissions in terms of both its GDP share and value-added. In this way, we aimed to obtain more robust findings and contribute to the current literature.

Materials and methods

Research data and model

To analyze the existence of the agricultural-induced EKC hypothesis in T10AGR countries, this study employs panel data from 1997 to 2014. Since the United States agricultural value-added data is available from 1997, and the data from EC for Nigeria is up to 2016, the period of analysis is limited to 20 observations for each country. Following Gokmenoglu and Taspinar (2018), Dogan (2019), and Qiao et al. (2019), we use Eqs. (1) and (2) to estimate the impact of agricultural value-added, EC, and economic growth on CO_2 emissions.

$$lnCO_{2i,t} = \delta_0+\delta_1\, lnGDP_{i,t} + \delta_2\, lnGDPSQ_{i,t} + \delta_3\, lnAGRV_{i,t} +\delta_3\, lnEC_{i,t} + e_t \quad (1)$$

$$lnCO_{2\,i,t} = \delta_0 + \delta_1\, lnGDP_{i,t} + \delta_2\, lnGDPSQ_{i,t} + \delta_3\, lnAGRR_{i,t} + \delta_3\, lnEC_{i,t} + v_t \quad (2)$$

where i denotes cross-sections, δ_0 is the constant term, δ_1, δ_2, δ_3, and δ_4 show the long-term coefficients, and e_t and v_t illustrate the error terms. In addition, $lnCO_{2i,t}$, $lnGDP_{i,t}$, $lnGDPSQ_{i,t}$, $lnAGRR_{i,t}$, $lnEC_{i,t}$ are logarithmic forms of per capita carbon dioxide emissions (gigatonnes), per capita gross domestic product (constant 2010 US Dollars), squared gross domestic product, per capita agricultural value-added (constant 2010 US Dollars), agricultural value added (% of GDP), and per capita energy consumption (kilowatt-hours), respectively. The variables were sourced from three different sources. On the one hand, the data for CO_2 emissions was originated from Global Carbon Project (2020), and the data for EC was derived from Our World in Data (2020). On the other hand, the data for GDP, AGRV and AGRR were obtained from World Development Indicators (World Bank, 2020). In the Equations, the agricultural-induced EKC hypothesis holds if $\delta_1 > 0$, $\delta_2 < 0$, and both coefficients are statistically significant. In all other cases, there is no inverted U-shaped relationship between economic growth and environmental pollution.

Estimation method

This study first investigates the existence of CSD among cross sections by using the Lagrange multiplier (LM) test of Breusch and Pagan (1980) and CD test Pesaran (2015). Along with examining the CSD, the study also performs delta $(\tilde{\Delta})$ and adjusted delta $(\tilde{\Delta}_{adj})$ tests developed by Pesaran and Yamagata (2008) to check for slope heterogeneity. In the LM and CD tests, the null hypothesis of no CSD is tested the alternative hypothesis of CSD. While the null hypothesis of the LM test shows that there is no CSD, the null hypothesis of the CD test implies that there is a weak CSD and this dependency can be eliminated when T and N increase. The alternative hypothesis of both tests demonstrates that there is a strong correlation between the cross-sections. In the delta and adjusted delta tests, the null hypothesis of slope homogeneity H_0: $\delta_i = \delta$ is tested against the alternative hypothesis of slope heterogeneity $H_{alternative}$: $\delta_i \neq \delta_j$. Delta tests have good power properties when $T > N$.

Eberhardt and Bond (2009) and Eberhardt and Teal (2010) developed the augmented mean group (AMG) estimator that takes into account CSD. A second advantage is that no pre-tests such as unit root and cointegration are required to apply the AMG estimator (Destek, 2017; Destek and Sarkodie, 2019). The AMG estimator uses a two-step method to estimate unobservable common effects and includes the common dynamic impact parameter. In the first step of this method, Equation (3) is estimated with time dummies.

$$\Delta CO_{2it} = \sigma_0\Delta GDP_{it} + \sigma_1\Delta GDP^2_{it} + \sigma_2\Delta AGRV|AGRR_{it} + \sigma_3\Delta EC_{it} + \sum_{t=2}^{T} h_t\, \Delta D_t + z_{it} \quad (3)$$

where Δ is the difference operator, D is the dummy variables, $h_t = \hat{\mu}_t \Delta CO_{2it}$ denotes the period of the dummies, z_{it} indicates the error term. In the second step, Equation 4 is calculated by converting the estimated h_t to $\hat{u}_t$.

$$\Delta CO_{2it} = \sigma_0\Delta GDP_{it} + \sigma_1\Delta GDP^2_{it} + \sigma_2\Delta AGRV|AGRR_{it} + \sigma_3\Delta EC_{it} + d_i\hat{\mu}_t + z_{it},\quad AMG = N^{-1}\sum_{i=1}^{N}\tilde{\sigma}_i \quad (4)$$

At this stage, $\hat{\mu}_t$ is included in each of the regressions, and finally, the coefficient of the relevant variable can be calculated for each cross-section.

Results and discussion

In the first stage of the analysis, we explore the data properties. Table 3 presents basic descriptive statistics of the series used

Variables	$lnCO_2$	lnGDP	lnAGRV	lnAGRR	lnEC
Mean	1.162	8.799	6.132	1.937	9.537
Median	1.232	8.836	6.196	2.198	9.666
Maximum	3.058	10.871	7.076	3.609	11.449
Minimum	-1.125	6.588	5.134	-0.066	7.146
Std. Dev.	0.980	1.212	0.395	1.017	1.046
Skewness	0.095	0.268	-0.490	-0.728	-0.119
Kurtosis	2.504	2.081	3.209	2.379	2.539
Jarque-Bera	2.347	9.424	8.371	20.911	2.238
Probability	0.309	0.008	0.015	0.000	0.326
Sum	232.428	1759.945	1226.468	387.557	1907.445
Sum Sq. Dev.	191.339	292.393	31.101	205.886	218.095
Observations	200	200	200	200	200

Source: own processing

Table 3: Descriptive statistics.

in the analysis. Among the series, $lnCO_2$, lnEC, and lnAGRR have the highest standard deviation. All series exhibits positive averages, while $lnCO_2$ and lnAGRR data contain negative values. Moreover, $lnCO_2$ and lnGDP display a long right tail, whereas lnAGRV, lnAGRR and lnEC are negatively skewed.

In the second stage of the analysis, we perform CSD and homogeneity tests. The results in Table 4 demonstrate that the null hypotheses for cross-sectional independence and homogeneity are rejected. This shows that agricultural countries interact with each other, and any external shock can have an impact on another country. In addition, the null hypothesis of slope homogeneity is rejected at the 1% significance level. Since panel data are heterogeneous and cross-sectionally dependent, the first-generation panel data estimators may produce biased results. Therefore, to obtain reliable findings, second-generation panel methods that account for CSD and heterogeneity should be used.

CSD	*Test statistics*	*p-value*
LM	331.341***	0.000
CD	52.526***	0.000
Slope homogeneity	*Test statistics*	*p-value*
$\hat{\Delta}$	6.387***	0.000
$\hat{\Delta}_{adj}$	4.447***	0.000

Note: *** indicates the rejection of the null hypothesis at 1% significance level

Source: own processing

Table 4: CSD and homogeneity tests results.

In the third stage of the analysis, we employ the AMG estimator because it does not require leading tests such as cointegration and unit root, and also takes into account CSD and heterogeneity.

Table 5 presents the findings of the AMG estimation for the AGRV model. The results show that EC has a positive impact on CO_2 emissions and the agricultural induced EKC hypothesis is not valid for the whole panel. However, with respect to the country-specific results, we conclude that the agriculture-induced EKC hypothesis is valid in five out of ten countries. In addition, the results show that an increase in agricultural value added reduced environmental pollution in Indonesia, Turkey, and Argentina.

With respect to the AGRR model, the long-term results are given in Table 6. As expected, EC has a statistically significant and positive impact on CO_2 emissions. As in the AGRV model, the agricultural induced EKC hypothesis does not hold for the entire panel, but looking at the country-specific results, we conclude that the hypothesis holds for the United States, Turkey, Argentina, and Thailand. Moreover, agriculture plays an important role in reducing emissions in Nigeria, the United States, and Turkey. Therefore, it can be concluded that agricultural production in the three countries is carried out with environmentally friendly technologies. Regarding EC, a positive relationship with environmental degradation is found in China, India, Brazil, the United States, Japan, Turkey, Argentina, and Thailand.

Countries	lnGDP	lnGDP2	lnAGR	lnEC	A-EKC
China	-2.436*** [1.491]	0.125*** [0.952]	0.464 [0.308]	1.271*** [0.154]	U-shaped
India	-3.367 [2.287]	0.24 [0.162]	0.264 [0.340]	1.028*** [0.293]	X
Indonesia	18.826** [9.179]	-1.147** [0.646]	-0.237** [0.193]	0.277 [0.314]	✓
Brazil	-16.549 [19.988]	0.827 [1.095]	0.043 [0.102]	2.522*** [0.397]	X
United States	30.590** [14.178]	-1.422** [0.660]	0.005 [0.249]	1.396*** [0.070]	✓
Nigeria	61.352*** [22.99]	-4.016*** [1.517]	-0.409 [0.436]	0.432 [0.288]	✓
Turkey	7.224** [3.443]	-0.392** [0.183]	-0.742** [0.044]	0.882*** [0.189]	✓
Japan	-44.738 [53.053]	2.126 [12.346]	0.096 [0.152]	0.082 [0.170]	X
Argentina	28.336*** [8.160]	-1.529*** [0.450]	-0.057** [0.067]	0.275** [0.356]	✓
Thailand	2.399 [4.531]	-0.135 [0.273]	0.409 [0.061]	0.557** [0.282]	X
Panel	1.424 [8.048]	-0.104 [0.411]	0.096 [0.067]	0.757*** [0.169]	X

Note: *** and ** indicate statistical significance at 1% and 5% levels, respectively. The values in brackets represent standard errors

Source: own processing

Table 5: AMG results for per capita agricultural value added (constant 2010 US $).

Countries	lnGDP	lnGDP2	lnAGR	lnEC	A-EKC
China	-1.158 [1.894]	-0.765 [0.104]	0.484 [0.307]	1.225*** [0.159]	X
India	-1.224 [1.748]	0.103 [0.115]	0.202 [0.132]	0.941*** [0.202]	X
Indonesia	15.721 [11.129]	-0.918 [0.702]	0.13 [0.359]	0.13 [0.359]	X
Brazil	-38.879** [21.052]	2.078** [1.160]	0.084 [0.094]	1.598*** [0.571]	U-shaped
United States	23.215* [28.626]	-0.995* [1.235]	-0.251* [0.124]	1.011** [0.826]	✓
Nigeria	-41.621** [20.744]	1.942** [0.997]	-0.133* [0.051]	1.165 [0.130]	U-shaped
Turkey	9.943*** [11.712]	-3.016*** [2.517]	-0.231*** [0.153]	0.721* [0.346]	✓
Japan	-126.759 [143.971]	-5.965 [6.723]	0.058 [0.110]	0.463* [0.157]	X
Argentina	28.136* [8.990]	-1.517* [0.495]	0.03 [0.039]	0.491** [0.278]	✓
Thailand	2.346** [4.231]	-0.433** [0.216]	0.027 [0.073]	0.346** [0.326]	✓
Panel	1.521 [8.037]	-0.102 [0.399]	0.043 [0.067]	0.853*** [0.235]	X

See notes for Table 5

Source: own processing

Table 6: AMG estimation results for agricultural value added (% of GDP)

In the next stage, the long-term findings of the two models are comparatively summarized in Table 7. As can be seen in the table, the validity of the EKC hypothesis varies for Indonesia, Nigeria, and Thailand, depending on the agricultural indicator. At the same time, the difference of variables affects the significance of coefficients of agriculture in the United States, Nigeria, Indonesia, and Argentina, and EC in Japan. Therefore, it can be said that researchers should carefully examine the impact of AGRR and AGRV on the environmental indicators.

Considering the two models, the EKC hypothesis can be verified in Indonesia, Nigeria, the United States, Turkey, Argentina, and Thailand. The validity of the EKC hypothesis is in line with the results of Gokmenoglu and Taspinar (2018), Agboola and Bekun (2019), Balsalobre-Lorente et al. (2019), Dogan (2019), Gokmenoglu et al. (2019), Qiao et al. (2019), Zhang et al. (2019), Aydoğan and Vardar (2020), Aziz at al. (2020), Prastiyo et al. (2020), and Ridzuan et al. (2020) However, it is contrary to the findings of Ben Jebli and Ben Youssef (2017) and Liu et al. (2017). According to Pata (2018b), pollution can be reduced above a certain income level by increasing environmental awareness and energy use efficiency. Although economic development initially leads to environmental degradation in the six out of the ten countries, this situation reverses over time and the quality of the environment improves due to rising income. However, China, India and Japan, where the EKC hypothesis is not valid, are among the highest CO_2 emitters in the world. The failure of the EKC hypothesis may be due to the ineffective implementation of environmental laws and measures in these three countries and Brazil.

The coefficient of EC is positive and statistically significant in eight of the ten countries, except Indonesia and Japan. This result is similar to that of Gokmenoglu and Taspinar (2018), Agboola and Bekun (2019), Dogan (2019), Gokmenoglu et al. (2019), Zhang et al. (2019), and Pata (2021). EC is closely related to GHGs, which is a serious problem for developing countries (Abdallah, 2013). According to World Bank (2020), in 2014, fossil fuels accounted for 93% of total EC in Japan, 87% in China and Argentina, 73% in India, 79% in Thailand, 59% in Brazil, 83% in the United States, and 89% in Turkey. The use of fossil fuels, such as oil and coal, is the largest contributor to the increase in CO_2 emissions (Lotfalipour et al., 2010; Saboori and Sulaiman, 2013). Therefore, for a better environment, the share of fossil fuels in total energy should be reduced in the eight countries included in the T10AGR.

Finally, agricultural production is a solution to the environmental problems in Indonesia, Turkey, Nigeria, Argentina, and the United States. In these countries, production in the industrial sector increases environmental pollution more than in the agricultural sector. As Rafiq et al. (2016) noted, although the industrial sector increases environmental pollution, agriculture and the service sector could mitigate environmental degradation. Therefore, reducing the share of the industrial sector in GDP in the United States, Nigeria and Turkey and increasing the agricultural sector can have a positive impact on improving environmental quality. Contrary to the common findings that

Countries	AGRR model			AGRV model		
	Energy	Agriculture	A-EKC	Energy	Agriculture	A-EKC
China	Positive	–	–	Positive	–	U-shaped
India	Positive	–	–	Positive	–	–
Indonesia	–	–	–	–	Negative	Valid
Brazil	Positive	–	U-shaped	Positive	–	–
United States	Positive	Negative	Valid	Positive	–	Valid
Nigeria	–	Negative	U-shaped	–	–	Valid
Turkey	Positive	Negative	Valid	Positive	Negative	Valid
Japan	Positive	–	–	–	–	–
Argentina	Positive	–	Valid	Positive	Negative	Valid
Thailand	Positive	–	Valid	Positive	–	–

Source: own processing

Table 7: Summary of the long-run estimation.

agriculture increases environmental pollution, our results are in line with the findings of Liu et al. (2017), Zhang et al. (2019), Aziz et al. (2020), Prastiyo et al. (2020) and Ridzuan et al. (2020) who claimed that agriculture reduces environmental degradation. Agriculture plays a crucial role in the food supply and consumption chain. With the COVID-19 pandemic, the importance of agricultural production has become more evident than ever. In this context, the reduction of CO_2 emissions and sustainable food supply can be achieved through modern agricultural practices.

Conclusion

This study aimed to investigate the impact of agriculture, EC, and GDP on CO_2 emissions using a panel of T10AGR countries under the agricultural EKC hypothesis. In performing this task, we used the AMG panel estimation method and found an inverted U-shaped EKC relationship between per capita GDP and per capita CO_2 emissions in six out of the ten countries. This finding shows that the increase in the income level of Argentina, Indonesia, Nigeria, Thailand, Turkey, and the United States will lead to a decrease in environmental pollution above a certain threshold. However, the EKC hypothesis is not valid in Brazil, China, India, and Japan. The rising income level in these four countries is not a solution to environmental pollution. Another finding of the study is that more EC stimulates CO_2 emissions, while agricultural activities help to improve the environment. Based on these findings, we provide substantive policy recommendations related to emission reduction.

As the agricultural sector is responsible for 1/5 of global GHGs, it has an important responsibility in reducing climate change. FAO (2016) in its report stated that agricultural CO2 emissions are caused by conversion of forests to pasture or cropland and land degradation associated with overgrazing. At the same time, the production of chemicals used in agriculture and the use of fossil energy on farms and in fields contribute significantly to the increase in GHGs. All of these problems can be reduced through better farming management practices.

In order to reduce environmental degradation and ensure sustainable agriculture, the widespread use of synthetic fertilizers should be avoided, and organic farming should be promoted. To mitigate CO2 emissions, measures can be implemented to improve irrigation systems in rice cultivation and to increase efficiency in energy use. In addition, the governments of T10AGR countries can allocate additional funds for agricultural research and development expenditures to reduce environmental pollution. Besides, as fossil fuels used in agricultural activities increase environmental pressure, decision-makers in these countries need to support the use of renewable energy in the transportation and retail stages of agricultural products. It is possible to significantly reduce agricultural CO_2 emissions by replacing fossil fuels with renewable energy types such as wind, solar, and hydropower. Furthermore, governments and companies can organize awareness-raising and supportive training programs for farmers on organic farming, conscious production, and renewable energy use. Companies that consume large amounts of agricultural raw materials should be provided with subsidies and tax exemptions for the use of green energy sources in agricultural activities. All these policies will help reduce environmental pollution and achieve the goals of SDG.

Finally, more climate finance and agricultural investment is needed to facilitate the transition to sustainable agricultural practices. However, available funding for agricultural investments falls far short of the need (FAO, 2016). Therefore, the funds that will provide climate finance should be established as soon as possible by institutions, organizations, and governments.

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