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RESEARCH ARTICLE

The relationship between carbon dioxide emission and crop and livestock production indexes: a dynamic common correlated effects approach

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Abstract

Rapid increase in carbon dioxide emission triggers climate change, while climate change poses a threat to food security. On the other hand, emission increase as a result of agricultural production continues. Considering this cycle, it is thought that examining the relationship between agricultural production and carbon dioxide emissions can help countries take emission-reducing measures and develop policies to ensure food safety. With this thought, a common correlated effect estimator was used in this study to explain the relationship between crop and livestock production index and carbon dioxide emission of 184 countries with the use of data for the period of 1998–2014. Countries were classified under four categories: low-income countries, lower middle–income countries, upper middle–income countries and high-income countries. According to DCCE test results, it was reported that a 1% increase in crop production index had effect on CO_2 emission only in lower middle–income countries. A 1% increase in livestock production index, on the other hand, was reported to increase CO_2 emission rates by 0.28, 0.49, and 0.39 in lower middle–income, upper middle–income, and high-income countries, respectively. When evaluated in general, it could be stated that livestock breeding has a higher effect on CO_2 emission in agricultural production. The findings of the present study revealed that countries need to improve agricultural production methods in ways to minimize the positive association between vegetative and livestock production in accordance with their level of development, to adopt more environment-friendly agricultural technologies and to endorse international environmental policies.

Keywords Agricultural production · Carbon dioxide emission · Economic development · Cross-sectional dependence · DCCE model · World

Introduction

Increasing carbon dioxide levels exert increasing pressures on environment. The increase in carbon dioxide emissions is noted in situations such as irregular and rapid industrialization, urbanization, unbalanced economic growth, population growth, and energy consumption (Moutinho et al. 2018). Especially considering the population growth and industrialization, agricultural production increase is inevitable in order to ensure food security and to guarantee the regular flow of raw materials to the industry. While the increase in production increases carbon dioxide emissions, there is a much higher increase than expected as a result of the wrong practices (Schneider and Smith 2009; Celikkol Erbas and Guven Solakoglu 2017). Indeed, wrongful agricultural practices such as agricultural production in areas that are not suitable for agriculture in order to increase production, pesticides, and chemical fertilizers, irrigation, soil processing, mistakes in plant hormone use, burning of the stubble, and dumping unsuitable animal waste to soil increase CO_2 emissions due to crop production (Önder et al. 2011; Waheed et al. 2018). Similarly, incorrect grazing, inactive fertilization methods, pasture destruction, and inaccuracies in feeding technique in animal husbandry could lead to CO_2 emission increases. On the other hand, such pressures raise concerns about environmental destruction and sustainability of agriculture and food

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security. Although industry is the primary source of carbon dioxide emissions, spatial distribution and progress of agricultural carbon dioxide emissions play an important role in climate change. Agriculture has a 14% share in global carbon dioxide emissions, and even further percentages are expected in the future (FAO 2019). Agriculture-originated carbon dioxide emissions have an increasing trend in the 2010–2016 period. In 2010, total CO_2 emission coming from agriculture was 5088.7 Mt, and this value reached to 5285.5 Mt by the year 2016 (FAO 2019). Agricultural sector has a 24% direct and a 0.87% indirect contribution to atmospheric greenhouse gas emissions (Waheed et al. 2018; Earth System Research Laboratory 2019). Since greenhouse gases are the primary source of climate change, agriculture-induced greenhouse gases have considerable negative impacts on environment (Yohannes 2016; Bennetzen et al. 2016; Rebolledo-Leiva et al. 2017; Zhang et al. 2019; Tubiello 2019).

During the last 40 years, world population has grown about 1.77 times, and such a growth has made increase in agricultural production inevitable. Together with increasing population, diversity of population has led the emergence of different needs and demands, and thus resulted in an asymptotic increase in agricultural productions. In this sense, agriculture not only meets the food demand of increasing populations but also supplies raw materials to industry and service sectors to meet different needs of these increasing populations. Therefore, there is always an increasing interest in agriculture and an ever-increasing pressure on the environment (Havemann 2014; Edoja et al. 2016; Zafeiriou and Azam 2017).

The share of agricultural sector in growth is inversely proportional to the economic development level of the countries. Added-value to GDP by agricultural sector in low-income, lower middle–income, upper middle–income and high-income countries is 25.2%, 15.5%, 6.7%, and 1.3%, respectively (World Bank 2019). It is a fallacy to interpret the relationships between agricultural sector and carbon dioxide emissions based on these values. Effects of agricultural sector on CO_2 emissions based on the development level of the economy vary with the agricultural practices, production technologies, land use, and production potential of the countries (Al Mamun et al. 2014; Luo et al. 2017; Narasimham and Subbarao 2017; Qiao et al. 2019). For this reason, there is a need for detailed studies that demonstrate the contribution of the agricultural sector to carbon dioxide emissions with many different variables.

It is possible to find many studies that reveal the link between the agricultural sector and CO_2 emissions in the literature. These studies evaluate the environmental impacts of the agricultural sector in general considering the agricultural growth, agricultural practices, crops, and product groups (see "Literature" review). However, in the context of economic and ecological sustainability, more specific studies are needed especially taking into account sub-activities of agriculture. In line with this need, we discussed crop and livestock production aspects of agriculture in our study and investigated the correlation between crop production index and livestock production index and CO_2 emissions. Demonstrating the impact of agricultural indices on carbon dioxide emissions from an ecological and economic perspective would help to evaluate emission-reducing approaches more effectively. Indeed, considering the different intensities of the impacts from crop and livestock production, it is important to treat the applications that would reduce their impact on the environment in different dimensions. Although there are few studies for the purpose of our study in the literature, it is known that there is no study in global scale. Parallel with our work, Sarkodie and Owusu (2017) assessed the relationship between agricultural production and CO_2 emissions using agricultural production indices for Ghana in a single-country level, while Appiah et al. (2018) carried out their work in the context of emerging economies (based solely on four countries). Unlike these studies, we have explained the effects of agricultural production on carbon dioxide emissions for each income group, taking into consideration the income levels of the world countries (184 countries) and made a comparison between these groups. The study carries a global scale as it stands, and the study reveals the causality relationship between CO_2 emissions and agricultural production from a global perspective.

In light of the findings, the present study would enable countries to develop policies to achieve agricultural sustainability and to use strategies that could reduce the negative effects of agricultural activities on the environment based on their level of development. In addition, policy proposals on reducing the pressure of crop and livestock production on the environment and ensuring production growth were presented. In conclusion, it could be stated that the present study gave clues regarding how the countries could contribute to environmental improvement based on their level of development.

The rest of the article was organized as follows: the "Literature review" interprets the opinions reported in the literature, the "Material and methods" outlines the methodology, the "Results" presents and discusses the results, and finally, the "Conclusions" discusses policy implementations and creates awareness for future research.

Literature review

The amount of carbon dioxide emission is considered an important criterion in measuring environmental deterioration. In this context, there are many studies in the literature examining the association of carbon dioxide emissions with many factors such as energy, population, industrialization, economic growth, trade, and financial development (Dogan and

Turkekul 2016; Alvarado et al. 2018; Moutinho et al. 2018; Khan et al. 2019a; Dogan et al. 2019; Khan et al. 2019b; Anwar et al. 2020; Khan et al. 2020; Ahmed et al. 2020; Dogan and Inglesi-Lotz 2020). In addition, studies that reveal the effects of direct sectors are also frequently encountered (Al Mamun et al. 2014; Sakaue et al. 2015; Sohag et al. 2017).

From the perspective of the agricultural sector, in the literature, many empirical studies, which investigated the relation between agricultural sector and carbon dioxide emission, can be found. The results of these investigations on the relation between agricultural sector and CO_2 emission have not reached a complete conclusion. Different results from various studies are mainly a result of the differences in the dataset, the selected country or country groups, time periods, and methods used. Studies that investigated the relation between CO_2 emission and agricultural sector have reported three fundamentally different conclusions. The first one argues that there is a linear relation between agricultural sector and CO_2 emission. Dogan (2019) used the 1971–2010 series to examine the effect of agriculture on CO_2 emissions for China by using the autoregressive distributed lag (ARDL) method and reported that CO_2 emission would increase in the long term as the additional value of agriculture increased. Xiong et al. (2016) examined the relation between agricultural growth and agricultural CO_2 with the decoupling method, and although there were periodical differences, the agricultural CO_2 emission increased more compared with agricultural growth. Liu et al. (2017a) used fully modified ordinary least squares-dynamic ordinary least squares (FMOLS-DOLS) and vector error model (VECM) models to determine renewable energy, agriculture and environmental correlations in BRICS countries and reported a positive effect of agriculture on CO_2 emission and a unilateral causality relation from agriculture to CO_2 emission in the long term. Waheed et al. (2018) conducted a study and examined the renewable energy consumption, agricultural production, and forests on CO_2 emissions in Pakistan using the ARDL model in 1990–2014 to determine the long-term and short-term effects. As a result of the study, they reported that CO_2 emission decreased with renewable energy consumption and increased forest areas. However, it showed parallels with increasing agricultural production. Zhangwei and Xungang (2011) concluded that there was a strong relation between agricultural CO_2 emission and agricultural economic growth. In other words, as agricultural growth increased, so did the agricultural CO_2 emission and total CO_2 emission. Sarkodie and Owusu (2016) investigated the relation between carbon dioxide emission and agricultural sector in Ghana by comparing ARDL and VECM models. As a result of the application of both models, the existence of a causality relation between agriculture and carbon dioxide emission was proven. In that study which used the data on the annual change in agricultural areas and the presence of space allocated for livestock and the production of selected products, it was determined that all variables including crop production increased CO_2 emission. Again, in another study conducted by Sarkodie and Owusu (2017), the relations between carbon emission, crop, and livestock production indices were examined for 1960–2013 period in Ghana. The study findings suggested that a 1% increase in crop production index would increase carbon dioxide emission at a rate of 0.52%, and a 1% increase in the livestock production index would cause an increase in carbon dioxide emission at a rate of 0.81%. Also, it was suggested that there was a bilateral causality relation between crop production index and carbon dioxide emission and a unilateral causality relation from livestock production index to carbon dioxide emission. Appiah et al. (2018) conducted a study and examined the causality relation between agricultural sector and carbon dioxide emission in selected emerging economies and determined the long-term relation with the FMOLS-DOLS model and the causality relation with the PMG estimator. The crop production index, livestock production index, population, energy consumption, economic growth, and CO_2 variables were used in the study. It was determined that a 1% increase in crop production index and livestock production index would result in a 28% increase in CO_2 emission. In addition, it was also found that there was a bilateral relation between CO_2 emission and livestock production index in the short term. However, no causality was detected between crop production index and CO_2 emission. In the long term, a bilateral causality relation was detected between crop production index and CO_2 emission, and a unilateral causality relation was detected from livestock production index to CO_2 emission. Ali et al. (2017) conducted a study covering the years 1960–1990 and examined the relation between agricultural growth and carbon dioxide emission with Johansen cointegration method. According to the analysis of the study for Pakistan, it was determined that agricultural growth in the short and long term contributed to CO_2 emission. Gokmenoglu and Taspınar (2018) examined the long-term relation between CO_2 emission, income increase, energy consumption, and agriculture for Pakistan for the 1971–2014 period using the fully modified least ordinary squares (FMOLS) method. According to the analysis results, it was determined that agriculture was inelastic in the long term and affected CO_2 emission positively. As a result of Todo-Yamato Granger Causality Test, a bilateral causality relation was detected between agriculture and CO_2 emission.

The second is that increased agricultural production reduces CO_2 emission or is ineffective on emission. Liu et al. (2017b) conducted a study that covered the 1970–2013 period in Indonesia, Malaysia, the Philippines, and Thailand, members of Association of Southeast Asian Nations (ASEAN), and examined the effect of renewable energy and agriculture on CO_2 emission using panel ordinary least squares (OLS), FMOLS, and DOLS methods. Based on predictions, they reported that increased renewable energy use and agricultural production would cause a decrease in CO_2 emission, and the increase in non-renewable energy use would cause an increase in CO_2 emission. Moreover, as a result of short- and long-term causality analyses, no relation was found between CO_2 and the agricultural sector in the short term. However, a bilateral causality relation was detected in the long term. Ben Jebli and Ben Youssef (2017) examined the role of agriculture and renewable energy in decreasing CO_2 emission with FMOLS-DOLS method in the long term and examined the causality with VECM Granger causality method. In that study which covered North African countries in 1980–2011, it was concluded that the increase in agricultural income would reduce CO_2 emission in the long term, and a bilateral causality relation was detected between the two variables in the short and long term. Dogan (2016) examined the relation between agriculture and CO_2 emission in Turkey using the ARDL model and reported that the increase in both short- and long-term crop productions would cause a decrease in CO_2 emission. Özçelik et al. (2012) evaluated the relation between agriculture and the environment in Turkey with the help of cointegration analysis to test the validity of environmental Kuznets curve (EKC) hypothesis. In the study that covered the years 1970–2010, CO_2 emission per capita increased with an increase in GDP per capita and with the increase in tractor presence per 100 km^2 of cultivatable land, and the increase in the value of crop production per capita CO_2 emission per capita may cause a decrease. Samargandi (2017) examined the relation between the additional value of sectors, technology, and CO_2 emissions in Saudi Arabia with the ARDL method both for the long term and short term. As a result, he reported that the service sector and the industrial sector had the effect of increasing CO_2 emission in the long term, and the agricultural sector had a reducing effect. Moreover, he also reported that the fact that the agricultural sector reduced CO_2 emission would cause that the sector would have a very low value in the growth rates, and therefore, the environmental regulations regarding the agricultural sector would have little effect on CO_2 emission.

The third one is that it is very common to evaluate the relation between economic growth and CO_2 emission with the environmental Kuznets curve approach. Similarly, it is possible to find studies reporting the relation between agricultural growth and CO_2 emission with this approach. According to this approach, it is hypothesized that the increase in crop production will have a short-term increase in CO_2 emission and a mitigating effect in the long term. Zafeiriou and Azam (2017) used the annual dataset for Portugal, Spain, and France for the 1992–2014 period to examine the relation between agricultural growth and agricultural CO_2 with the ARDL model and showed the validity status of the environmental Kuznets curve (EKC) hypothesis. In other words, although the share of agriculture in CO_2 emission decreased as agricultural income increased for France and Portugal, there was not a reversed U-shape. CO_2 emission decreased as agricultural income increased in Spain, and then it went on and had an upward trend again. This shows that the EKC hypothesis is valid for Spain. Alamdarlo (2016) conducted a study and covered the provinces of Iran for 2001–2013, for a 14-year period, and used panel data. The EKC hypothesis was confirmed as a result of that study dealing with the relation between carbon dioxide emission per capita stemming from the agricultural sector and the added-value per capita in this sector. However, it was also determined that this was not valid for all provinces of Iran. The main reason for this was reported as the heterogeneity of the agricultural development in Iran because agricultural infrastructure was not in a uniformed structure in all areas, and it was low in energy efficiency in some areas and caused more environmental pollution.

Material and methods

Panel data analysis was used in this study. In practice, use of panel data is known to have many superior attributes. Panel data combines horizontal cross-section and time series observations and allow studying with more observations. Furthermore, panel data takes into account more degrees of freedom and more sample variations compared with the models using the time series (Hsiao 2003). On the other hand, it is possible to perform econometric analyses in cases where the time series is short and/or inadequate, and horizontal cross-section observation exists. In addition, the panel data allows the constructing and testing models only for horizontal cross-section data or behavioral models that are more complex than time series data (Baltagi 2005). Although the use of panel data has several disadvantages due to heterogeneity and horizontal cross-section dependence, various tests taking into account these problems have been developed in recent years, and the econometric analysis technique that can be implemented with the help of these techniques could be determined. Accordingly, in this study, it was examined whether the panel dataset used in this study had heterogeneity and horizontal cross-section dependency problems. Then, the relationship between agricultural production indices and carbon dioxide emissions was investigated using the appropriate panel model.

Data

In this study, which focuses on the correlation between carbon dioxide emissions and agricultural production, we categorized agricultural production in the form of crop and livestock production in order to determine the impact on carbon dioxide emissions. Accordingly, CO_2 (carbon dioxide emission, kt), CPI (crop production index; 2004–2006 = 100), and LPI variables (livestock production index; 2004–2006 = 100) were used in the analysis. Crop production index includes all crop outputs except feed, while the livestock production index is the output index of animal husbandry products such as meat, milk, cheese, eggs, wool, honey, etc. The study covered the data from 184 countries in the period 1998–2014. Data for the countries were obtained from World Development Indicators (WDI) of the World Bank. The latest data available at World Development Indicators was until 2014, and data were available for all countries starting from 1998. In this study which used the data from 184 countries (see Appendix Table 9), countries are examined in four income groups taking into account heterogeneity in per-capita income according to World bank's classification:[1] low income, lower middle–income, upper middle–income, and high-income countries[2].

Descriptive analyses

Understanding the characteristics of the variables studied is very important in deciding the econometry method. The average, standard deviation, skewness, kurtosis, and distribution normality of the variables were descriptive statistics (Table 1). It could be stated that as the countries develop economically, CO_2 emissions increase. In terms of skewness of CO_2, the low-income group has positive skewness, while others have negative ones. For kurtosis, however, the low-income group has a leptokurtic distribution whereas others displayed platykurtic distribution. According to Jargue-Bera test statistics, it was determined that the series did not show normal distribution in all groups for the CO_2 variable. Averages for the CPI (crop production index) variable were close to each other in each group. While low-income and lower middle–income countries group had negative skewness and others had positive one, kurtosis displayed increase along with increasing income level. On the other hand, according to the Jarque-Bera test statistic, it was determined that the series did not show normal distribution in each group. For the LPI (livestock production index) variable, averages were close to each other in all groups, and there were positive distortions in each group, and kurtosis had leptokurtic pattern in each group.

Empirical model

In this study, a theoretical framework based on expected endogenous growth model was used to express agricultural production–dependent carbon dioxide emissions. Agricultural production is composed of crop and livestock production indices.

$$CO_{2_{it}} = f(CPI, LPI) \tag{1}$$

Variables were natural log-transformed to better interpret the coefficients for long-term relationships among the variables. Logarithmic form of the model was provided in Eq. 2. Model functional form was provided in Eq. 3:

$$log_e CO_2 = \alpha + \sum \alpha log_e(CPI, LPI) \tag{2}$$

$$lnCO_{2_{it}} = \alpha + \beta_1 lnCPI_{it} + \beta_2 lnLPI_{it} + \mu_{it} \tag{3}$$

where $CO_{2_{it}}$, $lnCPI_{it}$, and $lnLPI_{it}$ express the logarithmic form of carbon dioxide emission (kt), crop production index, and livestock production index variables, respectively. $i = 1,\ldots\ldots\ldots N$ denotes cross-section units, $t = 1,\ldots\ldots\ldots\ldots T$ denotes the periods, and μ denotes the error term and lack of serial correlation. Considering that the descriptive variables

Table 1 Descriptive statistical analyses

Variable	Obs	Mean	Std. Dev.	Max	Min	Skewness	Kurtosis	Jarque-Bera	Prob.
Low-income countries									
CO_2	493	7.360	1.547	11.250	4.477	0.662	3.062	36.139	0.000
CPI	493	4.634	0.227	5.282	3.742	0.098	4.139	27.479	0.000
LPI	493	4.633	0.211	5.488	3.975	0.380	4.577	63.000	0.000
Lower middle–income countries									
CO_2	731	8.778	2.407	14.626	3.2454	−0.064	2.613	5.045	0.080
CPI	731	4.626	0.236	5.646	3.763	0.377	4.948	132.9	0.000
LPI	731	4.623	0.190	5.305	3.7120	0.005	5.0353	126.164	0.000
Upper middle–income countries									
CO_2	884	9.367	2.833	16.147	1.992	−0.289	2.672	16.290	0.000
CPI	884	4.600	0.195	5.573	3.747	−0.230	5.151	178.310	0.000
LPI	884	4.633	0.165	5.167	4.025	0.069	3.403	6.698	0.035
High-income countries									
CO_2	1020	10.158	2.366	15.571	4.631	−0.312	2.499	27.242	0.000
CPI	1020	4.588	0.209	5.320	3.184	−2.159	16.012	7989.290	0.000
LPI	1020	4.616	0.178	5.899	3.666	0.527	14.244	5421.211	0.000

had a value different from zero, we suggest that CO_2 emissions output may vary depending on the developmental levels of economies. Therefore, similar to Stern (2004), we assume that agricultural activities would increase emissions.

Methodology

Cross-section dependence

In general, horizontal cross-section dependency is a fundamental problem in panel data models, especially when horizontal cross-section size (N) is large. Ignoring the horizontal cross-section dependency could lead to inability to explain the dependence of residuals which lead to efficiency loss and invalid test statistics in estimations. On the other hand, determining whether there is a horizontal cross-section dependency gives an idea for deciding the econometric method to be applied so as to eliminate misleading and ineffective statistical results. Therefore, to test horizontal cross-section dependency between the variables, Pesaran CD test which consider $N > T$ was employed.

The null hypothesis is cross-sectional independence, which means H_0: $\rho_{it} = \rho_{jt} = \text{Corr}(e_{it}, e_{jt}) = 0 \forall\ \hat{t}\ \forall i \neq j$ against the alternative hypothesis of cross-sectional dependence, H_1: Corr $(e_{it}, e_{jt}) \neq 0$ for some $i \neq j$, where the e_{it} are the estimated residuals of the regression estimated in the previous sub-section. Pesaran (2004) proposed the test based on the average of the pairwise correlation of residuals:

$$\mathrm{CD} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \acute{p}_{ij}\right) \quad (4)$$

where $\acute{p}_{ij} = \sum_{t=1}^{T} e_{it}e_{jt} / \left(\sum_{t=1}^{T} e_{it}\right)^{1/2}\left(\sum_{t=1}^{T} e_{jt}\right)^{1/2}$ test results for cross-sectional dependency of four samples are provided in Table 2. The hypothesis of "there is no cross-sectional dependency for each income group" was rejected. These findings indicate the second-generation unit root test application in the unit root test process.

Panel unit root test

We analyzed the stationary structure of the variables in the stage after the cross-section dependency test for the four country groups we discussed. In order to make any estimation, a panel unit root test should be selected to determine the integration level of the series. Such a process is required for two purposes: the first is to avoid surprising results of non-stationarity, and the second is to investigate potential of cointegration relationship. In the present study, existence of cross-sectional dependency was proved. Thus, a second-generation unit root test (cross-sectionally augmented IPS-CIPS) developed by Pesaran taking cross-sectional dependency into account was preferred. CIPS is the modified form of Im et al. (2003) approach. In the IPS procedure, an ADF (augmented Dickey-Fuller) regression is estimated for each cross-section as follows:

$$\Delta y_{it} = \rho_i y_{it-1} + \sum_{j=1}^{p_i}\beta_{ij}\Delta y_{it-j} + X'_{it}\delta_i + \varepsilon_{it} \quad (5)$$

where $i = 1,\dots\dots N$ indicate the countries observed over $t = 1,\dots\dots\dots T$ years; p_i denotes the number of included lags, which is permitted to vary across countries; ρ_i represents the autoregressive coefficient; X_{it} denotes any exogenous variables, including any fixed effects and individual trends. Under the null hypothesis, every series in panel has a unit root, while under the alternative hypothesis, the least of the individual series is stationary. Expressed formally: $H_1: \begin{cases} \rho_i = 0 & i = 1,\dots\dots, N_1 \\ \rho_i < 0 & i = N_1,\dots. N. \end{cases}$

This is contrast to common root tests where it is assumed that the autoregressive coefficients are homogeneous for all cross-sections. The IPS test statistics, $\bar{t}$, is calculated as the average of individual ADF test statistics. Im et al. showed that the $\bar{t}$ statistic is normally distributed under null hypothesis. Critical values are available from Im et al. (2003).

Pesaran's (2007) approach addresses the issue of cross-sectional dependence. He proposes that ADF regressions should be further augmented with cross-section averages of lagged levels and first differences of individual series. This leads to CIPS test statistics.

Table 2 Pesaran (2004) test for cross-sectional dependence

Sample type	Test statistic	Probability value
Low-income countries	36.994	0.0000
Lower middle–income countries	3.785	0.0002
Upper middle–income countries	3.504	0.0014
High-income countries	13.926	0.0000

The dynamic common correlated effects

Panel data analysis, which does not take into account cross-sectional dependency and heterogeneity, is known to produce misleading results. Panel data estimates such as mean group developed by Pesaran and Smith (1995) and pooled mean group developed by Pesaran et al. (1999) take into account the heterogeneous coefficients between cross-sectional units. However, these estimators can give inconsistent results when the cross-sectional dependency is not taken into account. For this reason, in this study, we explained the relationship between agricultural production and carbon dioxide emission by using the *dynamic common correlated effects* (*DCCE*) approach developed by Chudik and Pesaran (2015), which takes into account the cross-sectional dependency. This technique incorporates heterogeneous slopes and cross-sectional dependence by taking cross-sectional means and lags into consideration. Moreover, this method works well for small sample size by using the jack-knife correction approach (Chudik and Pesaran 2015). Another major benefit of this technique is its estimation robustness in the presence of structural breaks in data (Kapetanios et al. 2011). This technique also performs satisfactorily for unbalanced panel data (Ditzen 2018). DCCE equation is provided below:

$$CO_{2_{it}} = c_{yi} + \alpha_i CO_{2_{it-1}} + \delta_i x_{it} + \sum_{P=0}^{P_T} \gamma_{xip} \overline{X}_{t-p} + \sum_{P=0}^{P_T} \gamma_{yip} \overline{Y}_{t-p} + \mu_{it} \quad (6)$$

For our work, in Eq. (6), CO_2 refers to carbon dioxide emission, $\alpha_i CO_{2it} - 1$ is the lag of CO_2 as an independent variable, $\delta_i x_{it}$ refers to the set of independent variables, and P_T is the limit of lags included in the cross-section averages.

Results

Panel unit root tests

Cross-sectional dependency was detected in panel data for each group in the study. Therefore, the second-generation panel unit root test developed by Pesaran taking into account horizontal cross-section dependence was applied. The results for the unit root test are shown in Table 3. When the first-degree difference (I(1)) was taken in each income group, the CO_2 variable was stable. CPI (crop production index) variable was found to get stagnant when the first-degree difference (I(1)) was received in low-income countries and high-income countries, but it was stable at the level (I(0)) in other groups. The LPI (livestock production index) variable is concluded to be stable at the level (I(0)) for each income group. Thus, integration of some variables was achieved at the level, while some other was achieved at the first difference.

DCCE estimation results

As mentioned earlier, the PMG and DCCE estimator was one of the most common methods used in variables with different levels of integration. The results of both estimators for country groups are given in tables. However, the results of the PMG estimator have not been interpreted as they give inconsistent and biased results in the case of cross-sectional dependency. Short-term and long-term parameters were estimated by the DCCE estimator, taking into account cross-sectional dependence (Table 4).

Results for low-income countries

Table 5 contains the findings for low-income countries. There was no causality relationship between variables in the long term. In short run, on the other hand, there was a bidirectional causality from carbon dioxide emission towards crop production index. ECT values indicating long-run relationships between carbon dioxide emission, crop production index, and livestock production index were negative and less than 1 as expected. Accordingly, ECT values indicating the periods for the recovery of deviations from the balance for carbon dioxide emission, crop production index, and livestock production index were 1.49, 1.03, and 1.64 years, respectively. Elasticity values for carbon dioxide emission indicated that the crop production index and livestock production index had no effect on carbon dioxide emissions.

In low-income countries, agricultural income has a share of about 26% of GDP. Compared with other income group countries, the economy of these countries is predominantly agricultural. However, considering the agricultural production dimension, they make up only 4% of agricultural production in the world. The fact that production is maintained by traditional methods is the natural result of this. However, carbon dioxide emissions in these countries are also very low compared with other income-level countries. Indeed, these countries account for only 0.05% of total carbon dioxide emissions. Anwar et al. (2019), who examined the

Table 3 Unit root test results based on Pesaran (2007)

Var.	Low income	Lower middle–income	Upper middle–income	High income
CO_2	0.498	− 0.104	1.855	− 0.997
Δ CO_2	− 8.704***	− 13.343***	− 3.490***	− 16.159***
CPI	0.797	− 1.450*	− 3.118***	2.433
ΔCPI	− 7.769***	− 17.599***	− 13.364***	20.792***
LPI	− 1.725**	− 2.590***	1.371*	− 4.032***
ΔLPI	− 2.181**	− 12.767***	− 7.177***	− 15.462***

Lag lengths were determined based on Schwarz information criterion (SIC)

***, **, *respectively indicates 1%, 5%, and 10% level of significance

Table 4 Summary of results

Sample type	Short-run causality			Long-run causality		
Low-income countries	CO_2	↔	CPI	CO_2	≠	CPI
	CO_2	≠	LPI	CO_2	≠	LPI
	CPI	≠	LPI	CPI	≠	LPI
Lower middle–income countries	CO_2	→	CPI	CO_2	→	CPI
	CO_2	≠	LPI	CO_2	←	LPI
	CPI	≠	LPI	CPI	→	LPI
Upper middle–income countries	CO_2	≠	CPI	CO_2	≠	CPI
	CO_2	←	LPI	CO_2	←	LPI
	CPI	≠	LPI	CPI	≠	LPI
High-income countries	CO_2	≠	CPI	CO_2	≠	CPI
	CO_2	≠	LPI	CO_2	←	LPI
	CPI	≠	LPI	CPI	≠	LPI

environmental impact of agricultural practices and found similar results to our study, reported that agricultural production in low-income countries does not have a negative impact on the environment.

Results for lower middle–income countries

Results for lower middle–income countries are provided in Table 6. With regard to relationships between crop production and environmental pollution, there was a unidirectional causality between crop production index and carbon dioxide emission in the long run. In the short run, there was a unidirectional causality between carbon dioxide emission and crop production index. Thus, it was observed that crop production influenced carbon dioxide emission. With regard to relationships between livestock production and environmental pollution, it was observed that there was a unidirectional causality in the long run from livestock production index towards carbon dioxide emission. The ECT values indicating the periods for the recovery of deviations from the balance for carbon dioxide emission, crop production index, and livestock production index were 1.69, 1.09, and 1.22 years, respectively. In fact, considering the elasticity values, it is possible to state that these variables had higher levels of correlations in the long run. Elasticity values for agriculture indicated that crop production would generate greater carbon dioxide emissions than livestock production. For instance, while a 1% increase in crop production index increases carbon dioxide emission by 0.30%, a 1% increase in livestock production index increases carbon dioxide emission by 0.28%.

In this group of countries including Ghana, Tunisia, India, Pakistan, Nigeria, and Indonesia, our findings that

Table 5 Results for low-income countries

Dependent variable	CO_2		CPI		LPI	
	PMG	DCCE	PMG	DCCE	PMG	DCCE
Long-run coefficient						
CO_2			0.48	−0.06	0.03	− 0.14
CPI	1.43	− 0.58			0.16**	− 0.15
LPI	0.77	0.40	0.49	0.27		
ECT	− 0.09	− 0.67***	− 0.47***	− 0.97*	− 0.32***	− 0.61***
Short-run coefficient						
ΔCO_2			0.05	0.28**	− 0.01	0.02
ΔCPI	0.17	0.33*			− 0.03	0.01
ΔLPI	0.10	0.41	− 0.12	−0.27		
Constant	− 2.40	− 1.43		0.15	0.65**	0.22
Cd2-statistic	0.79	− 2.19**	5.57***	− 1.15	− 0.63	− 1.20
f-statistic	2.02***	1.41***	2.09***	2.10***	3.75***	2.33***

***, **, *indicates 1%, 5%, and 10% level of significance, respectively

Table 6 Results for lower middle–income countries

Dependent variable	CO_2		CPI		LPI	
	PMG	DCCE	PMG	DCCE	PMG	DCCE
Long-run coefficient						
CO_2			0.20**	0.07	− 0.09	0.09
CPI	0.15	0.30**			− 0.07	0.23*
LPI	0.44**	0.28*	0.40***	− 0.32		
ECT	− 0.54***	− 0.59***	− 0.62***	− 0.92***	− 0.13***	− 0.82***
Short-run coefficient						
ΔCO_2			− 0.34**	− 0.24	− 0.09	0.06
ΔCPI	− 0.09	0.16*			0.05	− 0.02
ΔLPI	− 0.11	0.12	− 017	− 0.03		
Constant	2.12***	1.05	− 0.83	4.14	0.36***	0.31
Cd2-statistic	1.73*	− 0.80	1.89**	− 1.07	3.01	− 0.42
f-statistic	2.00	1.18*	2.38***	2.46***	3.35***	1.68***

***, **, *indicates 1%, 5%, and 10% level of significance, respectively

livestock production increases carbon dioxide emissions showed parallels to the previous studies (Ben Jebli and Ben Youssef 2017; Gokmenoglu and Taspınar 2018; Sarkodie and Owusu 2017; Waheed et al. 2018). Contribution of lower middle–income countries to total agricultural production is approximately 29.36%, and agriculture has a high share of with 15.73% in gross domestic production. Food security is a major problem for the years to come, given the reciprocal interaction between agriculture and the environment. Therefore, sustainable environmental policies should be adopted for sustainable production in these countries which contribute considerably to world agriculture and where agriculture provides more added. In all sectors and especially in the agricultural sector, the development of policies supporting renewable energy sources to reduce fossil fuel use would be an important step for the agricultural sustainability of the countries in this group.

Results for upper middle–income countries

The results for upper middle–income countries are provided in Table 7. In the long run, there were not any causality relationships between the two variables. In the short run, there was a unidirectional causality relationship from crop production index to carbon dioxide emission. On the other hand, there was a unidirectional causality from livestock production index towards carbon dioxide emission.

Table 7 Results for upper middle-income countries

Dependent variable	CO_2		CPI		LPI	
	PMG	DCCE	PMG	DCCE	PMG	DCCE
Long-run coefficient						
CO_2			0.03	0.32	0.10*	0.04
CPI	0.19	− 0.23			0.18***	0.36
LPI	0.63**	0.49**	0.12	0.11		
ECT	− 0.54***	− 0.81***	− 0.31**	− 0.75***	− 0.46***	− 0.70***
Short-run coefficient						
ΔCO_2			0.01	− 0.20*	− 0.06	0.03
ΔCPI	−0.09	0.07			− 0.06	− 0.03
ΔLPI	0.21	0.18	− 0.06	0.05		
Constant	1.69***	− 1.66	1.57	0.67	0.24	− 0.56
Cd2-statistic	2.98***	0.56	1.72*	− 0.82	2.03***	0.24
f-statistic	2.83***	2.01***	3.46***	2.71***	2.78***	1.79***

***, **, *indicates 1%, 5%, and 10% level of significance, respectively

In other words, an increase in livestock production index leads to an increase in carbon dioxide emission in the long run. The ECT values indicating the periods for the recovery of deviations from the balance for carbon dioxide emission, crop production index, and livestock production index were calculated as 1.23, 1.33, and 1.43 years, respectively.

Considering the effects of agricultural production on environmental pollution in upper middle–income countries, while the effects of crop production index on carbon dioxide emission were not significant, livestock production index had significant effects on carbon dioxide emission, and a 1% increase in livestock production index led to 0.49% increase in carbon dioxide emission.

Upper middle–income countries lead to 46.56% carbon dioxide emissions around the world as a result of rapid growth in their economies and leading world agriculture (with a 44.85% share) and agricultural exports. In upper middle–income countries, the view that development in the industrial and service sectors triggers an increase in carbon dioxide emissions is dominant (Al Mamun et al. 2014; Sohag et al. 2017; Samargandi 2017). Sohag et al. (2017) found that impact of agricultural GDP on carbon dioxide emissions was not statistically significant in upper middle–income countries. However, given the livestock production index and crop production index values, Appiah et al. (2018) concluded that the crop production index and livestock production index could increase carbon dioxide emissions, which covers the selected emerging economies (China, Brazil, India, South Africa) among upper middle–income countries.

In our study, even if the effect of crop production index on carbon dioxide emissions was positive, there was no statistically significant relationship. However, the pressure of animal production on carbon dioxide emissions also applied to this country group. According to Bennetzen et al. (2016), emissions from livestock production in developing countries are heavily due to their livestock systems. From this point of view, it is thought that emissions from livestock production could be mitigated by the adoption of more effective production systems, improvement of pastures, and changes in animal feeding methods. In addition, in order to reduce greenhouse gas emissions as much as possible and to obtain the maximum energy from fertilizer, livestock waste needs to be collected quickly (Yohannes 2016).

Results for high-income countries

Results for high-income countries are provided in Table 8. There was no causality relationship between variables in the short term. There was only a unidirectional causality relationship from livestock production index to carbon dioxide emission. Carbon dioxide emission elasticity was 0.39% for livestock production index. All ECTs were significant and had expected signs.

Table 8 Results for high-income countries

Dependent variable	CO_2		CPI		LPI	
	PMG	DCCE	PMG	DCCE	PMG	DCCE
Long-run coefficient						
CO_2			0.08	0.59	0.50	0.10
CPI	0.09	− 0.23			0.01	− 0.19
LPI	0.55*	0.39*	0.38	0.28		
ECT	− 0.19***	− 0.71***	− 0.70***	− 0.90***	− 0.46***	− 0.74***
Short-run coefficient						
ΔCO_2			− 0.09	0.01	− 0.02	0.06
ΔCPI	− 0.07	0.13			0.06	0.17
ΔLPI	0.48	0.67	− 0.20	0.28		
Constant	1.52***	− 1.73	0.57	13.05	1.54**	− 0.43
Cd2-statistic	10.49***	0.65	5.53***	− 1.50	4.00***	1.03
F-statistic	1.22**	1.32***	3.01***	2.53***	1.52***	1.61***

While agricultural activities have very small shares in the economies of high-income countries, their share in the world agricultural production is over 20% due to the use of technology in production. According to the results of the analysis, the impact of the livestock production index on carbon dioxide emissions is positive and considerable. In particular, the excess demand for animal products and the development of the associated processing industry explain carbon dioxide emissions from animal production in high-income countries (McMichael et al. 2007)

***, **, *indicates 1%, 5%, and 10% level of significance, respectively

Conclusions

As the threat posed by climate change caused by carbon dioxide emissions continues, the anxiety it poses is increasing day by day. In this context, it is very important to identify the elements that trigger emissions and develop mitigating policies, especially within the scope of sectors and sub-sectors. Agriculture, like other sectors, contributes to carbon dioxide emissions, although it is one of the sectors that may be affected by climate change. Indeed, as shown by the results of the present study, it was observed that agricultural production was effective in emission growth and that agricultural production was met with difficulties along with the increase in emissions. Therefore, our findings will contribute significantly to the process of producing and developing policies on reducing agricultural emissions and ensuring agricultural sustainability.

According to the results of the study, different findings were obtained for each group of countries. In low-income countries, there was no relationship in long term from CO_2 emissions to crop production index and livestock production index. In lower middle–income countries, the flexibility values for carbon dioxide emissions were 0.30 and 0.28 for the crop production index and livestock production index, respectively. The DCCE results for upper middle–income countries are as follows: In terms of the impact of agricultural production on environmental pollution, the effect of crop production index on carbon dioxide emissions was not statistically significant in this group, and it was concluded that a 1% increase in the livestock production index would increase carbon dioxide emissions by as high as 0.49%. Finally, for high-income countries, flexibility values implied that a 1% increase in the livestock production index could lead to a 0.39% increase in CO_2 emissions.

Our findings showed that while the impact of the agricultural sector in carbon dioxide emission continues, increasing carbon dioxide emissions has a negative effect on agricultural production. Therefore, these results support our concerns about global food security and climate change. Thus, countries need different policy practices depending on the level of development to ensure food security by supporting agricultural sustainability, which will reduce the contribution of the agricultural sector to CO_2 emissions. In lower-upper middle–income countries (developing countries), the efficiency of energy use must be prioritized in order to mitigate the impact of agriculture on CO_2 emissions. In this context, the transition from fossil energy use to the use of renewable energy should be achieved, and the movement towards the use of environmentally friendly technology should gain momentum. On the other hand, considering the higher contribution of developing countries to agricultural emission, these countries need to develop new policies or to improve their current policies to optimize their pesticide and chemical fertilizer use to prevent the use of unsuitable forest land for agriculture. The contribution of high-income countries to carbon dioxide emissions through crop production is quite small compared with the countries in other income groups. This can be considered as another proof of the functionality of environmentally friendly policies in production. On the other hand, climate change has become a global problem. Given that carbon dioxide emissions are an effective factor in climate change, it is clear that ensuring agricultural sustainability and food security will not only be possible through environmental measures or policies taken towards agricultural production. In this context, it is important that high-income countries expand the scope of emission-reducing policies, especially in the industrial sector. In addition, developed countries should play an active role in reducing global emissions and provide support to countries in other income groups with various funds in this sense.

One of the most important findings we have obtained in our research is that animal production has an emission-enhancing effect in all groups of countries. The negative impact of animal production on the environment depends directly on production density, specific production practices, grown species, and local ecological situation. Therefore, as a result of the wrong practices, the increase in animal production leads to an increase in deforestation, water use, and water pollution through waste but also has a multiplier effect on emission increases. Measures such as effective pasture management, development of proper grazing and feeding methods, and dissemination of agricultural forestry will both increase the productivity and help reduce the emission due to animal husbandry. However, the widespread use of incentive and support programs taking into account the animal welfare and aiming to reduce food safety risks will allow countries to make economic gains and alleviate the emission from livestock production. On the other hand, in addition to the creation of training programs to reduce, monitor, and manage farm emissions in environmental production, producing digital tools related to these could also be useful. On the other hand, achieving energy gains by providing biomass production from animal fertilizer waste in developed and developing countries is also an issue that should be included in environmental policies. In general, one of our findings is that carbon dioxide emissions have a negative effect on agricultural production. In this context, of all emissions reduction measures that can be implemented in all economies, attention should be paid to the carbon tax and activities related to its implementation should be spread throughout the world.

Appendix

Table 9 List of sample countries

Low-income countries (29)	Lower middle–income countries (43)	Upper middle–income countries (52)	High-income countries (60)
Afghanistan	Angola	Albania	Antigua and Barbuda
Benin	Bangladesh	Algeria	Argentina
Burkina Faso	Bhutan	Armenia	Australia
Burundi	Bolivia	Azerbaijan	Austria
Central African Republic	Cabo Verde	Belarus	Bahamas, The
Chad	Cambodia	Belize	Bahrain
Comoros	Cameroon	Bosnia and Herzegovina	Barbados
Congo	Congo, Rep.	Botswana	Bermuda
Gambia	Cote d'Ivoire	Brazil	British Virgin Islands
Guinea-Bissau	Djibouti	Bulgaria	Brunei Darussalam
Haiti	Egypt, Arab Rep.	China	Canada
Korea, Dem. People's Rep.	El Salvador	Colombia	Cayman Islands
Liberia	Georgia	Costa Rica	Chile
Madagascar	Ghana	Cuba	Croatia
Malawi	Honduras	Dominica	Cyprus
Mali	India	Dominican Republic	Czech Republic
Mozambique	Indonesia	Equatorial Guinea	Denmark
Nepal	Kenya	Ecuador	Estonia
Niger	Kiribati	Fiji	Faroe Islands
Rwanda	Kyrgyz Republic	Gabon	Finland
Sierra Leone	Lao PDR	Grenada	France
Somalia	Lesotho	Guatemala	French Polynesia
Syrian Arab Republic	Mauritania	Guyana	Germany
Tajikistan	Micronesia, Fed. Sts.	Iran, Islamic Rep.	Greece
Tanzania	Moldova	Iraq	Hong Kong SAR, China
Togo	Mongolia	Jamaica	Hungary
Uganda	Morocco	Jordan	Iceland
Yemen	Myanmar	Kazakhstan	Ireland
Zimbabwe	Nicaragua	Lebanon	Israel
	Nigeria	Libya	Italy
	Pakistan	Macedonia, FYR	Japan
	Papua New Guinea	Malaysia	Korea, Rep.
	Philippines	Maldives	Kuwait
	Sao Tome and Principe	Mauritius	Latvia
	Solomon Islands	Mexico	Lithuania
	Sri Lanka	Namibia	Macao SAR, China
	Tunisia	Nauru	Malta
	Ukraine	Paraguay	Netherlands
	Uzbekistan	Peru	New Caledonia
	Vanuatu	Romania	New Zealand
	Vietnam	Russian Federation	Norway
	West Bank and Gaza	Samoa	Oman
	Zambia	South Africa	Panama
		St. Lucia	Poland
		St. Vincent and the Grenadines	Portugal

Table 9 (continued)

Low-income countries (29)	Lower middle–income countries (43)	Upper middle–income countries (52)	High-income countries (60)
		Suriname	Qatar
		Thailand	Saudi Arabia
		Tonga	Seychelles
		Turkey	Singapore
		Turkmenistan	Slovak Republic
		Tuvalu	Slovenia
		Venezuela, RB	Spain
			St. Kitts and Nevis
			Sweden
			Switzerland
			Trinidad and Tobago
			United Arab Emirates
			UK
			USA
			Uruguay

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