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The influence of agricultural policy on carbon emissions in selected OECD countries

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ABSTRACT

Global agriculture is actively impacted by policies which affect the composition and location of produce and the production methods. This paper examines how agricultural policy affects carbon emissons in 27 OECD countries over the period 2000 to 2020. This research deploys the Generalised Methods of Moments (GMM) and Pooled Mean Group (PMG) to analyse panel data. The study findings demonstrate that the indicators of agricultural policy (agricultural financial support and producer protection ratio) predominantly display a significantly positive relationship with emissions in the short term. Still, that link is mostly significantly negative in the long run. As such, agricultural policy is a driver of emissions in the short run, which is in line with the extended STIRPAT model, although in the long run, the variable seizes to be a driver. Economic growth, transport services and human capital support that their association is positively significant in the short run, chiefly negative and significant in the long run. There is overwhelming evidence that renewable energy is negatively and significantly associated with emissions in both periods. This research analysis is imperative to create vital cornerstones towards a complete understanding of the effects of agricultural policy on developing green economies.

1. Introduction

Given the exponential growth in the global population, interest in food security by agriculture has become an essential debate for various schools of thought in the short and long term. On that note, it is imperative that policies and accounting systems should be integrated to guarantee healthy food while simultaneously mitigating dangers relating to climate change [1]. Environmental interest groups have pinpointed agriculture as one of the main factors that trigger carbon emissions growth. For example [2], reports that agriculture adds 19–29% of total greenhouse gas (GHG) emissions. In addition, the [3] lamented that global total agriculture emissions actualised 9.3 billion tonnes of carbon dioxide equivalent (Gt CO2eq). Thus [4], highlights the importance of sound governance through effective regulation and policies to curtail environmental damage [5]. suggests promoting green financing and low carbon economy concepts in managing country's essential sectors so that pro-environmental conduct is supported.

Previous studies have demonstrated that agricultural policies and carbon emissions research have generated mixed results [6,7]. For instance Ref. [8], found conflicting results on the effect of agricultural technologies on short-term and long-term emissions in Pakistan. Other studies produced positive findings, while others acquired negative outcomes [9–12]. While [13] evaluate the environmental effects of agricultural policies [14], examine the connection involving agricultural policies, productivity and sustainability and [15] investigates environmental sustainability in agriculture with emphasis on noting bottlenecks in the OECD economies this

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study expounds this discussion by taking into account other monetary variables in the sector. In this case, the paper considers such financially related variables to inform how financial decisions in the sector can affect emissions. Furthermore, we can also affirm that questions still remain regarding the effect of agricultural policies on emissions since the complexities of parameters embedded in economic, social, political, technological, legal and environmental structures among countries lay out ambiguities to establish consensus. Therefore, this study is imperative in green economy policy formulation.

More specifically, this paper evaluated two proxies of agricultural policy (Agricultural Financial Support and Producer Protection Ratio) to ascertain the effect of this policy on carbon emissions. The aim of this study is, thus, to evaluate the impact of agricultural policy on carbon emissions. In this vein, the objectives of this paper are: Do agricultural financial support influence carbon emissions in selected OECD countries? And Do producer protection ratios affect carbon emissions in selected OECD economies? The combined impact of these indicators of agricultural policy on carbon emissions in the OECD countries will also be analysed.

This research deploys the OECD countries as the case study [16]. spotlights that while emissions remained unchanged from 1993 to 2005, they heightened by 0.2% annually in the OECD economies between 2003 and 2015. Thus, the report identified the use of synthetic fertilisers as the primary contributor to agricultural emissions in the OECD. Moreover, in the OECD, agriculture is estimated to become the second sector which adds many economic destructions from climate change, only after damages linked to health factors [17]. OECD [18] posits that some OECD economies' agricultural sector adds more than 20% of their country's total greenhouse gas emissions. The OECD also highlights that the influence of climate change on agriculture is also an issue of interest to stakeholders [19]. expresses that concerns in OECD agricultural practices related to pollution are heightening point pollution from agriculture (associated mainly with livestock farming), widened public consciousness of the destruction of aquatic ecosystems owing to specific agricultural initiatives, leaching of agricultural chemicals affecting groundwater and coastal environments, and more significant uncertainty about poor agricultural policies and management systems [20]. also noted that agriculture changes land use, including high desertification and deforestation of fragile natural environments. Such changes inevitably affect the earth's capacity to absorb and/or reflect heat along with light. Therefore, it is apparent that the OECD economies are the perfect case for this research.

Considering the above discussion, the contribution of this paper is further emphasized in the existing literature. Initially, up to now, few studies have emphasized the importance of agricultural policy (in the context of Agricultural Financial Support and Producer Protection Ratio) for the OECD countries, even though this subject has evolved to be a topical issue among diverse stakeholders globally. As such, this paper endeavours to bridge this gap and provide more evidence regarding this topic. In the same vein, the paper will show evidence of whether agricultural policy is a driver of emissions in the BRICS contexts using the extended STIRPAT model. In this vein, this survey is vital for policy-making authorities to comprehend the major motivators of carbon emissions so that efficient and effective agricultural policies are integrated to mitigate emissions emerging from agricultural practices. Furthermore, the combined deployment of the indicators of agricultural policy will provide complete and critical insights to decision-makers for strategic policy planning. In this regard, the adoption of the Agricultural Financial Support and Producer Protection Ratio will further empower harmonious interchange and close collaboration of these measures in efforts lower emissions.

Second, the Generalised Method of Moments (GMM) method and The Pooled Mean Group (PMG) technique were used to establish the impact of these proxies on the short-run and long-run scenarios as there is a paucity of research that deploy econometric techniques to evaluate the impact of agricultural policy on carbon emissions. In this vein, using these two different econometric techniques improves the robustness of the findings, which is another contribution of the research. Moreover, this study utilises a particular group of countries (the OECD economies) in respect of a specific sector (agriculture), which will equip decision-makers to develop specific and strong agricultural policies to minimise emissions and attain sustainable green development. The outcomes of this research widen knowledge on the impacts of the drivers of emissions from the OECD agricultural sector and the conclusions which can be drawn from attaining green economy objectives and other developmental goals.

In the second section of the paper, the literature review is presented. The research methodology section is discussed in the third section of the study. The results of the study are given in section four. The discussion is presented in section five. Lastly, the conclusion of the paper is provided in section six.

2. Literature review

To offer convincing proof of evidence on the relationship between agricultural policy and carbon emissions, many schools of thought have produced numerous studies with various frameworks, countries and samples. Nonetheless, these research still do not offer common consent. On the whole, there have been three major points of view in existing studies: agricultural policy lowers carbon emissions, heightens carbon emissions and other viewpoints.

[13] confirm that in the country contexts surveyed, market price support and payments based on unconstrained variable input use provide the most adverse effects on the environment among the analysed agricultural support policies (decoupled support payments based on non-current crop area are the least harmful) [14]. demonstrate that countries attain heightened sustainable productivity when livestock density is low and agricultural support payments are either not coupled to production or if those payments possess environmental restrictions [15]. posit that reduced production intensity, minimised livestock density and cropland share are essential settings for heightened environmental sustainability (they are also influenced by previous and existing production-coupled agricultural support policies).

[21] analysed how agricultural policy influences carbon emissions in Latvia and highlights that there are various limitations to reducing emissions. The paper created a framework that enhances decision support impact assessment of different indicators along with decisions on agricultural sector emissions. Likewise, Henderson and Lankoski (2021) evaluated the natural environmental effects of agricultural policies in different country contexts. The outcomes posit that market price support and payments founded on

unrestricted factor input consumption enhance environmental damage, while decoupled support model payments established on noncurrent crop areas generate less damage. In a related study [22], explored the effect of agricultural production efficiency on emissions in China spanning 2010 to 2019, and the findings illustrate an inverted U-shaped association involving these parameters. Moreover [23], surveyed the relationship between agricultural production and emissions in different continents. The findings prove that emissions mitigation potential is enhanced by improved management of land resources, better manure management, broadening the role of agro-forestry in agriculture, distinct feed quality and greater adoption of Nitrogen fertilisers.

In addition [24], studied the link involving emissions, energy and emissions in Zambia. The results indicate that the parameters are cointegrated, and a short-run causality from agriculture and energy use to carbon emissions is valid. Then [25], conducted a farm-level investigation of Common Agricultural Policy (CAP) payments and emissions in Italy. The paper shows that CAP expenditure plays a part in the growth of emissions, and the impact varies across studied farms. Still in Europe [26], express that from 2000 to 2008, the yardsticks of the Nitrates Directive resulted in lowered emissions by using the MITERRA-Europe model for the European Union. For another block of countries [11], assessed whether agricultural initiatives enhance emissions in Brazil, Russia, India, China and South Africa from 1990 to 2014. The research proves that agriculture negatively influences carbon emissions in these countries. Similarly [27], highlights that the value added of agriculture to the Gross Domestic Product (GDP) negatively affects carbon emissions in the explored South Asian countries.

Further [28], explain that the service sector and agricultural sector contributions to economic growth play a major role in lowering emissions for the evaluated high, medium and low-income countries during the period 1980 to 2010. Additionally [29], spotlights that agriculture, green energy and globalisation develops a positive connection to emissions for Turkey from 1970 to 2017 using the bootstrap autoregressive distributed lag (ARDL) approach. Also, Wang et al. (2022a) analysed if agricultural specialisation affects emissions in China between 2000 and 2019 b y creating a mediating framework. The outcomes demonstrate that the country's unique agricultural specialisation encourages the growth of emissions. However [9], study on Non-European Union countries shows that agricultural development mitigates emissions. Lastly, Karimi Alavijeh et al. (2022) add that agricultural development generally produces a positive and significant link with carbon emissions for the evaluated 15 developing economies from 2004 to 2020.

The studies discussed above draw out knowledge that the impact of agricultural policy on carbon emissions is still an issue under discussion in empirical and theoretical studies. This indicates that the debate is rather complex and difficult to explain and detect. Theoretical studies support perspectives that agricultural policy has both negative and positive impacts on carbon emissions, and the size of the negative and positive influences ascertains the total effect. Empirical studies confirm that agricultural policy's effect on carbon emissions differs across countries and regions studied. While the impacts of agricultural policy on emissions have continued to be debated, various lessons have been drawn to aid green policy. Nonetheless, there are limitations found in current studies. Firstly, most studies examine the individual country and also specific agricultural sectors, but only some have focused on countries from the global viewpoint, more specifically, the OECD countries and their partners. In addition, deploying various approaches, data, and samples has produced contexts of difficulty for comparison by diverse interested stakeholders.

Moreover, this paper notes that the other main reason diverse research has produced different outcomes is that they employed different indicators of agricultural policy. As such, since diverse parameters influence these various proxies, their impact on emissions eventually becomes varied. On that account, this paper gathers data from 27 OECD countries to examine the influence of agricultural policy on carbon emissions so that enhanced empirical evidence on this topic is generated.

2.1. Theoretical foundation: extended STIRPAT model

The IPAT model was proposed to investigate the major driving variables of human environmental effects [30]. The underlying idea of this model is that environmental effects are multiplicative result of parameters which are namely population size (*P*), affluence (*A*) - affirmed as per person consumption or production, along with technology (*T*)- confirmed as influence per unit of usage or production. In order to analyse other variables which impacts the environment and not limiting influence to the factors mentioned earlier T in the IPAT model was disintegrated into C and T thereby generating the ImPACT model [31]. Debates also rose that human behaviours, social development along with social abilities require to be added to the model. Hence [32], introduced the STIRPAT model which is highly innovative, provide better testing settings and mitigates problems linked with the IPAT model.

The general STIRPAT model is rearranged as follows:

$$\mathrm{I} = m\, P^{n} A^{o} T^{q}\, e \qquad [1]$$

In this case, *I* show the human environmental effect, *P* denotes the population, *A* depicts the affluence, and *T* is the level of technology (is a function of other drivers). As regards to the coefficients, m is a constant term, and *n,o, q* are exponential factors of *P, A* and *T*. *e* is the error term.

Taking into account that equation [1] only contains limited number of parameters this paper extends the basic STIRPAT by taking into account agricultural policy, and other factors into consideration. Population is supported by human capital [33], affluence with economic growth, technology with renewable energy consumption. The extended STIRPAT model is shown as follows:

$$LogCO_{2it} = m + n\, LogHMC_{it} + oLogGDP_{it} + qLogREN_{it} + rLogAGS_{it} + sLogPRT_{it} + vLogTRS_{it} + \varepsilon_{it} \qquad [2]$$

where $LogCO_{2it}$ stands for carbon emissions, $LogHMC_{it}$ displays human capital, $LogGDP_{it}$ is economic growth, $LogREN_{it}$ shows renewable energy consumption, $LogAGS_{it}$ depicts agricultural financial support, $LogPRT_{it}$ outlines the producer protection ratio and $LogTRS_{it}$ illustrates the transport services. In this case, the driving force coefficients *n, o, q, r, s* and *v* are the percentage changes in carbon emissions in response to a one percent change in the other variable (driving force) holding other parameters constant.

3. Research methodology

This section describes the data and econometric instruments deployed by this research.

3.1. Data

To evaluate the association of the variables defined in Table 1 below, data was gathered from 27 OECD countries on the OECD database (see Table 1). The period considered to explain the relationship is between the periods 2000 to 2020.

3.2. Generalised Method of moments (GMM) method

This research evaluates the dynamic relationships between agricultural policy and carbon emissions by following [34] and, [35]; which are normally adopted in empirical research studies. This study estimates the equation as follows:

$$Y_{it} = \alpha_i Y_{it-1} + \beta_i L_{it} + \gamma_i A_{it} + x_i + c_i + \varepsilon_{it} \quad [3]$$

In this case, i represents the country ($i = 1, 2, 3 \ldots N$), and t shows the time events ($t = 1, 2, 3 \ldots T$). Y_{it} indicates the carbon emission levels of country i at the end of period t. L_{it} is the list of control factors which also affect carbon emissions. A_{it} is the proxy for agricultural policy. α, β and γ are parameters. x_i shows country-specific effects. c_i depicts period-specific effects. ε_{it} is the error term.

The primary control parameters are economic growth, renewable energy consumption, transport services and human capital and equation [3] lays the foundation of this paper's analysis. The proxies for agricultural policy employed in this paper are agricultural financial support and producer protection.

[36] put forward the adoption of the first differences of the factors to get rid of the fixed effects, that is, the Standard or Difference GMM. On that account, the first difference state of equation [3] is shown as follows:

$$\Delta Y_{it} = \alpha_i \Delta Y_{it-1} + \beta_i \Delta L_{it} + \gamma_i \Delta A_{it} + \Delta x_i + \Delta c_i + \Delta \varepsilon_{it} \quad [4]$$

Thus, equation [4] represents the first difference state of equation [3]. Nonetheless, the challenge of correlation involving the lagged dependent factor as well as the error variable continues; hence the integration of instrumental variables is essential. To mitigate this challenge [36], used suitable lags of the dependent and explanatory factors as instruments. The lagged states of explanatory variables may be less strong instruments for the differenced factors that cannot be solved in the difference framework. Particularly, Blundell and Bond (1998) assert that the first difference GMM model acts poorly and generates great sample biases if the explanatory parameters remain over time. Furthermore [37], argue that the scarcity of information regarding the focus parameters in the level contexts can lead to the depletion of a considerable portion of the total variance in the data.

To mitigate the challenges linked with the Difference GMM, [37]; along with [38]; suggested the System GMM approach. The approach joins in a framework with the equation in first differences and with the equation in the levels form. To get results from the System GMM, factors in differences state are instrumented with the lags of the differences of these same variables [39], which serve to improve the efficiency in the computation. As regards the System GMM, although the levels of independent parameters are basically correlated with the country-specific fixed effect, the differences are ascertained to be not correlated. Moreover, time-specific effects can be handled by adding time dummies, while country dummies (to remove cross-sectional dependence) can be employed to handle country-specific effects. The other advantage of the System GMM is that it is suitable for unbalanced panel data; hence the drawback of magnifying gaps is eliminated [40]. The paper also conducts a post-estimation approach, the Hansen J-test test, for over-identifying restrictions.

Nevertheless, the GMM approach has drawbacks. Firstly, the technique makes coefficients different in each panel unit and does not report dynamic attributes along with long-run cointegration. To improve the robustness of the GMM approach, this paper also deploys

Table 1
Showing detailed description of variables.

Variable	Definition	Unit	Source
LogCO_2	Carbon emissions	Metric tons per capita	Global Carbon Atlas
LogAGS	Agricultural Financial Support	Percentage of gross farm receipts	OECD database
LogPRT	Producer Protection Ratio	Ratio between the average price received by producers (measured at the farm gate), including net payments per unit of current output, and the border price (measured at the farm gate).	OECD database
LogGDP	Economic Growth	GDP per capita (constant 2015 US$)	WDI database
LogREN	Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	WDI database
LogTRS	Transport services	[(% of service exports, BoP) + (% of service imports, BoP)]/2	WDI database
LogHMC	Human capital	Human Capital Index	Penn World Tables

the Pooled Mean Group (PMG) estimating procedure. According to Ref. [41]; the PMG can provide the variables with a regular and stable mean value. Moreover [42], also adds that the PMG technique produces efficient outputs in the long run with great sample sizes [43]. put forward the PMG tool, which permits short-run variables to be different among groups at the same time exerting pressure on long-run variables to be unified. To such a great extent, the PMG permits dynamic features in the short run to be different, meanwhile restricting the corresponding long-run coefficients, which is advantageous. In itself, the PMG method will compute long-run elasticities, ascertain the speed of correction to long-run equilibrium, and investigate the robustness of findings generated by the GMM technique.

3.3. The Pooled Mean Group (PMG) technique

This paper also employed an econometric approach which has gained wide reception in research involving carbon emissions – the PMG approach spotlighted by Ref. [43]. The Mean Group (MG) method permits handling individual heterogeneity in panelised data by computing individual regressions for each cross-section and averaging the variable results. On that note, it has been identified to be very effective in consistently computing average heterogeneous variables [41]. On the other hand, the cross-sections can be pooled by adopting dynamic fixed effects or related approaches. This technique allows for various intercepts, although it demands that slope factors be homogenous in the cross-sections, which is generally a strictly limiting assumption.

The PMG approach gains an advantage from the good standards of the above-mentioned approaches since it harmonises these two techniques. Short-run coefficients are allowed to be different across the rest of the countries (similar to the MG approach), and long-run coefficients demand to be the same for the rest of the countries (common with the fixed effects method). The PMG technique possesses some advantages when compared to other estimators. In this vein, the method can be deployed in cases where the parameters are I (0) or I (1). As well, the short-run and long-run causality conclusion can also be derived in the context where cointegration is not validated. In addition, in circumstances where long-run coefficients are in logarithm form, they can be explained or comprehended as elasticities. Suppose we have the highlighted ARDL [1, 1, 1, 1, 1] regression:

$$Y_{it} = \alpha_i Y_{it-1} + \sum_{j=0}^{1} \delta'_{ij} K_{it-j} + x_i + \varepsilon_{it} \qquad [5]$$

Where K_{it-j} now represents the vector of all the explanatory parameters of the study. δ'_{ij} depicts the coefficient vector. In this regard, equation [5] can be reorganised into an error correction framework presented as equation [6] below:

$$\Delta Y_{it} = \rho_{1,i}\left[Y_{it-1} - \theta'_{1,i} K_{i,t-1}\right] + \delta^{*'}_{1,i} \Delta K_{it} + x_i + \varepsilon_{it} \qquad [6]$$

Where $\rho_{1,i} = -(1 - \lambda_i)$, and $\theta_{1ji} = \frac{\sum_{j=0}^{1} \delta_{ij}}{1-\lambda_i}$. δ^* illustrates the short-run coefficients of the equation, while θs demonstrates the long-run coefficients of the equation. The validity of these coefficients is confirmed when the error correction term of the regression is both significant and negative. ρs are the error correction terms of the equation. The speed of adjustment output is the inverse estimate of the absolute value of the coefficients. The traditional Hausman test is used to test whether the MG or PMG estimator is the most appropriate for the model.

4. Results

This section presents the results of panel root tests, the GMM technique and the Mean Group method for this study.

Table 2 outlines various panel unit root tests, including the Phillips–Perron test (PP), the Levin, Lin and Chu test (LLC) and the ADF tests (utilised to verify stationary of the panel data series). With the exception of renewable energy consumption and human capital, all variables indicate that at least two of the tests; when the tests are used at first differences, the null hypothesis is rejected in favour of the alternative hypothesis, showing that the panel is first difference stationary (that is, the variables are I (1)).

To further add to the issue of heterogeneity of the panel data, this study used the CD test [44] to evaluate the parameters and

Table 2
Panel Unit test results.

Variable	At Level			At 1st Difference		
	ADF statistic	LLC Statistic	PP Statistic	ADF statistic	LLC Statistic	PP Statistic
$LogCO_2$	−1.5038	−2.7910***	−1.5038	27.1986***	−2.7400***	27.1986***
LogAGS	7.5218***	−2.4151***	7.5218***	59.5870***	−11.1482***	59.5870***
LogPRT	10.3417***	−5.0608***	10.3417***	67.5194***	−11.9521***	67.5194***
LogGDP	6.8218***	−6.9910***	6.8218***	4.9244***	3.0204	4.9244***
LogTRS	−2.6686	0.6788	−2.6686	36.1803***	−6.2518***	36.1803***
LogREN	−3.1922	15.9801	−3.1922	−1.9463	64.9822	−1.9463
LogHMC	6.1590***	–	6.1590***	−3.4067	–	−3.4067

Notes: ***: ** and × indicate that the coefficients are significant at the 1%, 5% and 10% level of significance, respectively.

analyse whether the panel data is cross-sectionally independent or vice-versa. The findings are shown in Table 3. Except for producer protection ratio and transport services parameters, the linked p-values of the remaining factors demonstrate that the null hypothesis (independent cross-sections) is rejected in favour of the alternative hypothesis (dependent cross-sections) for the studied panel data series.

This paper adopts a specific second-generation the CIPS unit root tests [45] to evaluate in a robust manner the concerns about cross-sectional dependence and heterogeneity so that findings which are more accurate and efficient are produced. In this regard, there is evidence that the considered variables are cross-sectionally independent and not homogenous. In light of this, the outcomes from the CIPS tests are reported in Table 4. The results indicate that at the first difference (using constant and trend specification), the variables (except for economic growth and human capital) became stationary (while at the level, some were still non-stationary). Hence, most of the investigated parameters are integrated of order one, that is, I (1), and the study can ascertain if the long-run relationship amongst the variables is supported.

Table 5 reviews the results of the Kao cointegration and Pedroni cointegration tests for the agricultural policy and carbon emissions models. As regards the Kao test, the paper shows that the ADF test statistic rejects the null hypothesis (No cointegration) at the 10% significance level. Thus, a cointegrating association between the factors is evident. The Pedroni cointegration test results prove that six out of ten tests reject the null hypothesis of no cointegration. The findings of the Kao and Pedroni tests, therefore, confirm that a long-term link involving the analysed parameters exists.

Table 6 outlines the short-run GMM findings for equation [1] with the Agricultural Financial Support (LogAGS) as the main explanatory variable and equation [2] with the Producer Protection Ratio (LogPRT) as the principal independent term. Equation [3] with both Agricultural Financial Support (LogAGS) and Producer Protection Ratio (LogPRT) as the major independent variables. The associated long-run GMM findings of this paper are outlined in Table 7 (equation 4- has Agricultural Financial Support (LogAGS) as the primary explanatory term, equation 5- depicts the Producer Protection Ratio (LogPRT) as the main independent variable and equation (6)-support both Agricultural Financial Support (LogAGS) and Producer Protection Ratio (LogPRT) as the main independent variables.)

To ensure comparativeness of the GMM results and the Pooled Mean Group (PMG) and Mean Group (MG) estimator outcomes this paper will also explain the findings presented in Table 8. Therefore, Table 8 outlines the results of the Pooled Mean Group (PMG) and Mean Group (MG) estimator. In this regard, equation [7] comprise the Agricultural Financial Support (LogAGS) as the main explanatory variable and equation [8] shows the Producer Protection Ratio (LogPRT) as the principal independent term. Equation [9] illustrates both the Agricultural Financial Support (LogAGS) and Producer Protection Ratio (LogPRT) included as main independent factors.

This research has generated interesting results. Firstly, Table 6 demonstrates that the lag parameters of the dependent variable-carbon emissions are significantly positively associated with carbon emissions for all regressions [1–3] in the short run. This context illustrates that a percentage rise in previous carbon emissions results in high carbon emissions in the short term. Thus, past carbon emissions circumstances in the short run do not affect the current carbon emissions contexts within the studied OECD economies, hence are not drivers of environmental quality in this period [46]. express that if countries fail to meet the temperature goals of the Paris Agreement, emissions will continue to rise.

Secondly, agricultural financial support, to the greatest extent, demonstrates that the parameter is positive and significantly connected with carbon emissions, as shown in Tables 6 and 8 [Equations (1) and (9)] in the short term. However [47], research on China's 30 provinces from 2000 to 2019 depict that agricultural financial support lessens emissions in agricultural production. Another proxy of agricultural policy, the producer protection ratio, is also significantly positively rated with carbon emissions [Equations (2) and (3)] in this paper for the short run. In the long run, both indicators of agricultural policy, agricultural financial support [Equations (1), (3) and (9)] and producer protection ratio [Equations (2) and (3)] illustrates that (to the greatest extent) they are negative and significantly associated with carbon emissions. Conclusively, this paper confirm that agricultural policy (agricultural financial support, producer protection ratio) is a principal driver of emissions in the short run within the BRICS setting, although in the long run, it is a non-driver.

Third, economic growth in the sampled economies also encourages the growth of carbon emissions in the short term [Equations ((1), (3), (7) and (9)] [48]. also contributes that economic development increases carbon emissions in a study done on Pakistan between 1975 and 2016. Howbeit, in the long run, for the studied OECD economies, this study spotlights that economic growth (most of

Table 3
Showing CD tests results.

Variable	CD test	p-value
LogCO_2	7.77	0.000***
LogAGS	8.81	0.000***
LogPRT	–	–
LogGDP	75.96	0.000***
LogTRS	–	–
LogREN	30.48	0.000***
LogHMC	74.21	0.000***

Notes: [1] Null hypothesis: cross-sectional dependence (CD ~ (0, 1). Prob. [2] ***: ** and × indicate that the coefficients are significant at the 1%, 5% and 10% level of significance, respectively.

Table 4
CIPS test findings of unit roots.

Variables	Level [constant and trend]	First Difference [constant and trend]
$LogCO_2$	−2.547	−3.944
LogAGS	−2.327	−4.712
LogPRT	−3.017	−4.847
LogGDP	−1.705	−2.799
LogTRS	−2.423	−4.276
LogREN	−2.373	−4.070
LogHMC	−0.697	−1.021

Notes: The critical values at 1%, 5%, and 10% are −2.81, −2.66 and −2.58, respectively.

Table 5
Showing findings on panel cointegration tests.

Kao panel cointegration tests					
Variable	Statistic	*p*-value			
ADF	−1.413846				
Residual Variance	0.000340	0.0787*			
HAC Variance	0.000352				
Pedroni panel cointegration tests					
Within-dimension (panel statistics)			**Between-dimension (panel statistics)**		
Test	**Statistic**	**Probability**	**Test**	**Statistic**	**Probability**
Pedroni (1999)					
Panel v-statistic	−1.820418	0.9657	Panel rho-statistic	3.999807	1.000
Panel rho-statistic	2.226413	0.9870	Panel *PP*-statistic	−3.423081	0.0003***
Panel *PP*-statistic	−3.529291	0.0002***	Panel ADF-statistic	−3.500672	0.0002***
Panel ADF-statistic	−3.948295	0.0000***			
Pedroni (2004) Weighted Statistic					
Panel v-statistic	−1.930378	0.9732			
Panel rho-statistic	2.143985	0.9840			
Panel *PP*-statistic	−3.110268	0.0009***			
Panel ADF-statistic	−3.252700	0.0006***			

Notes: ***: ** and × indicate that the coefficients are significant at the 1%, 5% and 10% levels of significance, respectively.

Table 6
Two-step system-GMM short-run findings with (a) LogAGS, (b)LogPRT, (c) Combined.

	Regression 1 (LogAGS)	Standard Error	Regression 2 (LogPRT)	Standard Error	Regression 3 (Combined)	Standard Error
	Coefficient		Coefficient		Coefficient	
$LogCO_{2it-1}$	0.8553***	0.0382				
$LogCO_{2it-1}$			0.8745***	0.0562		
$LogCO_{2it-1}$					0.7843***	0.0667
LogAGS	0.0172*	0.0098	–	–	−0.0083	0.0176
LogPRT	–	–	0.0567*	0.0328	0.1152**	0.0577
LogGDP	0.0314*	0.0178	0.0224	0.0226	0.0558**	0.0259
LogTRS	0.0118	0.0192	0.0292*	0.0171	0.0289	0.023
LogREN	−0.0357***	−0.0357	−0.0291*	0.0166	−0.0526***	0.0182
LogHMC	0.171***	0.0264	0.1529***	0.0355	0.2107***	0.0441
Constant	−0.0919	0.0624	−0.0845	0.0754	−0.1533***	0.0694
Wald (χ^2)	448066.53***				639586.19***	
Arellano-Bond test for AR (1) in first differences	z = −3.91 Pr > z = (0.00) ***		z = −3.82 Pr > z = (0.00)***		z = −3.36 Pr > z = (0.00) ***	
Arellano-Bond test for AR (2) in first differences	z = −1.20 Pr > z = (0.228)		z = −1.17 Pr > z = (0.243)		z = −1.11 Pr > z = 0.265	
Hansen's test of over-identifying. Restrictions	Chi-square = 23.65 Prob > chi2 = (1.000)		Chi-square = 23.15 Prob > chi2 = (1.00)		Chi-square = 21.29 Prob > chi2 = 1.000	
Observations	533		533		533	

Notes: [a] ***; ** and × indicate that the coefficients are significant at the 1%, 5% and 10% level of significance, respectively. [b] The null hypothesis of diagnostic statistical results generated in the table above is (1) The Arellano-Bond test for autocorrelation: H_0 = no autocorrelation; (2) The Hansen: H_0 = the set of instruments is valid.

Table 7
Two-step system-GMM long-run findings with (a) LogAGS, (b)LogPRT, (c) Combined.

	Regression 4 (LogAGS) Coefficient	Standard Error	Regression 5 (LogPRT) Coefficient	Standard Error	Regression 6 (Combined) Coefficient	Standard Error
LogAGS	−0.8381***	0.0395	–	–	−0.7927***	0.0631
LogPRT	–	–	−0.8178***	0.0653	−0.6691***	0.1005
LogGDP	−0.8239***	0.0547	−0.8520***	0.0784	−0.7286***	0.0919
LogTRS	−0.8434***	0.0508	−0.8453***	0.0709	−0.7554***	0.0749
LogREN	−0.891***	0.0285	−0.9036***	0.031	−0.837***	0.0495
LogHMC	−0.6843***	0.0626	−0.7216***	0.091	−0.5736***	0.1093

Notes: ***; **; * mean significant at 1%, 5% and 10% significance levels, respectively. Numbers in brackets are *p*-values.

Table 8
Results of the pooled mean group (PMG) and mean group (MG) estimator equation.

	Regression 7 (LogAGS) Coefficient	Standard Error	Regression 8 (LogPRT) Coefficient	Standard Error	Regression 9 (Combined) Coefficient	Standard Error
Long run equation						
LogAGS	0.0310**	0.0128	–	–	−0.048***	0.0111
LogPRT	–	–	0.252	0.3006	0.9123***	0.1322
LogGDP	0.1602***	0.1602	0.7477***	0.194	0.0584	0.0473
LogTRS	0.0091	0.0088	0.062	0.0598	−0.2393***	0.0376
LogREN	−0.4704***	0.0399	−0.2011**	0.0955	−0.2981***	0.0159
LogHMC	0.6284***	0.1452	−1.841**	0.8109	2.1276***	0.2232
Short run equation						
ECT (-1)	−0.1713***	0.0516	−0.8898***	0.0608	−0.161***	0.0537
LogAGS	−0.0027	0.006			0.0507***	0.0164
LogPRT	–	–	−0.2131	0.1620	−0.8506	0.7548
LogGDP	0.6114***	0.1025	−0.0761	−0.0761	0.6525***	0.1317
LogTRS	0.0665**	0.0286	0.0561	0.0587	0.061***	0.022
LogREN	−0.1292*	0.0739	−0.0171	0.0621	−0.1467**	0.0592
LogHMC	−1.4651	1.5518	1.7071*	0.8729	2.1602	1.7682
Constant	0.0483***	0.0183	−0.8078	0.6246	−0.0092	0.0123
Hausman Tests against Mean Group (MG) Estimator	Statistic = 3.20 *p*-value = 0.6694		Statistic = 23.21 *p*-value = 0.003***		Statistic = 8.12 *p*-value = 0.2295	
No. Of obs	533		533		533	

Notes: ***; ** and × indicate that the coefficients are significant at the 1%, 5% and 10% levels of significance, respectively.

all) develops a significantly negative link with emissions [Equations (1)–(3)]. In this case, economic development drives emissions in the short run but fail to propel emissions in the long run for the sampled economies. This is also evident in the case of transport services. Thus, more paper results show that transport services in this survey are adding more carbon emission levels [Equations (2), (7) and (9)] in the short run, but reducing emissions in the long term [Equations (1)–(3) and (9)]. Conflicting with this paper's long-run findings [49], exploration of the seven-transport carbon-emitting economies from 2000 to 2015 spotlights that the transport sector heightens carbon emissions in the analysed countries.

More outcomes in the short run outline that renewable energy mitigates carbon emissions in the short run [Equations (1)–(3) and (7) and (9)] and also long run [Equations (1)–(3) and (7)–(9)] within the studied OECD economies. Therefore, it is apparent that in this paper that green energy use is a not a driver of emissions in the short and long run for the BRICS economies. Nevertheless [50], analysis of 24 economies of the Middle East and North Africa (MENA) region from 1980 to 2015 highlights that renewable energy is weak in promoting better carbon emissions contexts. Evidence from this research also confirms that human capital motivates the growth of carbon emissions in the short term [Equations (1)–(3) and (8)], but the reverse holds in the long run [Equations (1)–(3) and (8)]. Howbeit [51], study of the G7 economies from 1971 to 2014 demonstrates that human capital reduces ecological footprint. Thus, human capital is a driver of environmental quality in the short run, but the reverse is true in the long run for the BRICS.

The findings of the GMM estimations presented in Table 6 show the following. Firstly, the equations have a significant AR (1) and an AR (2), which is not significant, as depicted by the p-value. This implies that the serial correlation in the error terms is not second order. The Hansen J test confirms the validity of the instruments in this paper, as illustrated by the p-values. In this regard, all equations in Table 6 are suitably specified, as demonstrated by the test statistics described above.

Moreover, for diagnostic purposes, the results of the Pooled Mean Group (PMG) and Mean Group (MG) Estimator in Table 8 are supported by essential findings. Firstly, regressions seven and nine support the PMG regression, as evidenced by the Hausman test results, while regression 8 supported the MG regression. The confidence ellipse in Figures (a)–(f) in the Appendix section demonstrates the coefficient diagnostic test results. The diagrams for all the independent parameters outline that their stability points are predominantly inside the ellipse, confirming a significant confidence level.

5. Discussion

The above study findings demonstrate important outcomes regarding the effect of agricultural policy on carbon emissions. Using the two proxies of agricultural policy (namely, agricultural financial support and producer protection ratio), the econometric (that is, GMM and Panel Mean Group techniques) results show that in the short-run is the period where these policies to a greater extent, fail to mitigate carbon emissions when compared to the long-run scenario. In this regard, there is overwhelming evidence that agricultural policy in the OECD lower carbon emissions in the long term. On that note, there is a need to strengthen the agricultural financial support and producer protection ratio policies in the short term so that high-quality agricultural practice supporting agriculture's greening is enhanced. This can be achieved through establishing, implementing and regular monitoring of these policies using carbon accounting yardsticks, as well as carbon pricing measures. Such benchmarks can also be extended to other subsectors of the industry so that continued prospects to lower emissions along with ascertaining carbon sinks can be determined.

Moreover, regarding agricultural financial support, it is imperative to innovate this facility and extend it to reach the country's remote areas. In this case, agricultural financial products and services must cater to rural and remote green economy interests. Moreover, banks and other financial entities should be encouraged to set up environmentally compatible instruments (along with increasing their diversity) that enhance agriculture's greening. For instance, farmers will need financial assistance that empowers them to lower their emissions, preserve the local natural resources and environment, and control pollution. In some cases, improved financial support should be made available to encourage realising carbon emission goals and benchmarks in the sector. Also, green credit facilities (offered at low or zero interest rates) are crucial to permit farmers to buy organic fertilisers, green machinery and equipment which save energy and reclaim agricultural land. In the same vein, green products and services from financial entities should be more flexible in undertaking and implementing so that benefits from agriculture and the natural environment are optimised. Such activities grow the farmer's income while addressing the challenges associated with emissions growth. As such, greening of the OECD economies should take into account strategies that foster concurrent contexts of climate change mitigation and adaptation.

It is important to also consider that green research and development projects related to agriculture should also be given more attention. Thus, green innovation along with research capacity building result in better agricultural practices and assessment approaches that enhance linking with suitable institutions and incentives. In this respect, special green funding tools should be established to foster agricultural scientific studies and technological innovations. Moreover, policymakers should encourage private investors to invest in initiatives that discontinue the use of fossil fuels and switch to green energy technologies. In the same vein, decision-makers should lower organic fertiliser prices through subsidisation and encourage farming communities to practice afforestation so that natural resources are protected, and food production heightens to meet consumer demands. Ideally, financial subsidies can also be made available to agricultural activities that conduct green production. Organic fertilisers are recyclable, environmentally friendly, increase soil fertility, and mitigate soil degradation. As such, green education in the agricultural sector is critical, and governments should prioritise more financial resources to educate farming communities, even on issues that relate to consciousness about green financing.

Furthermore, there is a need for farmers to develop standards to ensure resilience and sustainability in production. For instance, frameworks that gather agricultural data, revenue and cost aspects, quality management, waste management and so forth will enhance farmers to foster the achievement of climate-smart agriculture scenarios. These frameworks assist farmers in managing price distortions (in the form of producer protection contexts, input prices, volatility in government subsidies, and so forth), thereby keeping their practices optimised on a green and sustainable path. Still, on price volatility in this sector, green tools that stabilise internal and external agriculture market systems should receive the highest preference. In this setting, agricultural policy is not treated in isolation (for instance, it should be aligned to the 2030 Agenda for Sustainable Development, the Paris Climate Change agreement and so forth) but permitted spaces and courses in which it can coordinate with other important sectors of the economy so that climate change challenges are mitigated in an effective manner. Thus, aligning agricultural policy with the global green development agenda also enhances the detection of those synergetic and contradicting impacts of policy structures and tools.

6. Conclusion

This research investigated the influence of agricultural policy on carbon emissions. This study utilises data from 2000 to 2020 for 27 selected OECD countries. This paper utilised the GMM and the PMG techniques to acquire consistent and efficient results. The empirical findings of the paper show that agricultural financial support and producer protection ratios, as proxies of agricultural policy, predominantly depict a significantly positive association with carbon emissions in the short run, but that relationship is mostly significantly negative in the long term. Other explanatory variables reveal the following. Economic growth, transport services and human capital also confirm that their link with carbon emissions in the short term is positive and significant, although that relationship is also chiefly negative and significant in the long run. Renewable energy consumption's relationship with carbon emissions is significantly negative in both the short and the long run for the sampled economies.

Further studies should put more emphasis on determining other agricultural instruments and benchmarks that can be employed to motivate agricultural emission abatement. Also, the impacts of agricultural policy may be diverse in different countries. Hence, more research is vital to ascertain these variances and also extend surveys on various forms of greenhouse gases from this sector (for example, nitrous oxide and methane) to fully comprehend how low and/or zero-carbon environments can be achieved. Future research can also be directed towards evaluating dimensions of agricultural financial support and producer protection ratio as measures of agricultural policy effects on the different types of greenhouse gases at country and regional levels.

Author contribution statement

Ganda Fortune: Conceived and designed the experiments; Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

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Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

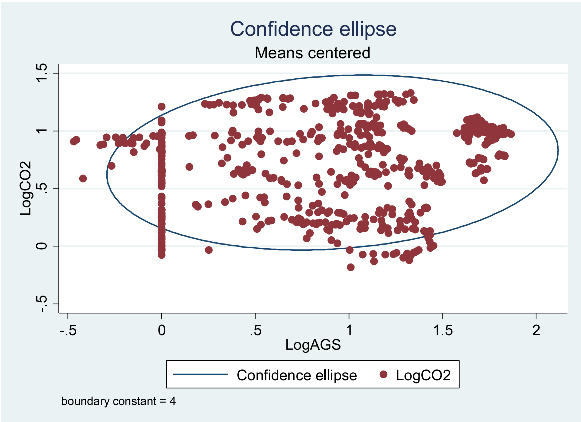

Fig. A. Confidence ellipse involving carbon emissions and agricultural financial support.

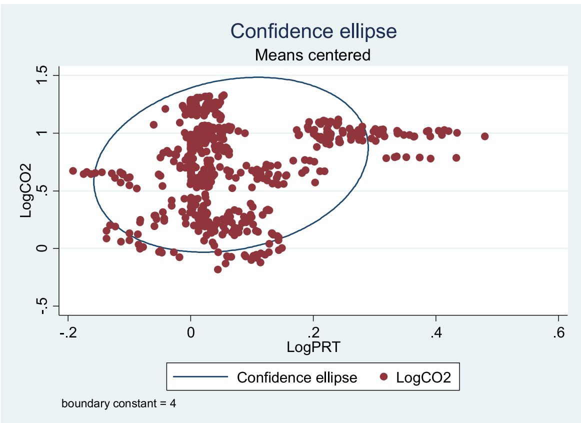

Fig. B. Confidence ellipse involving carbon emissions and producer protection ratio.

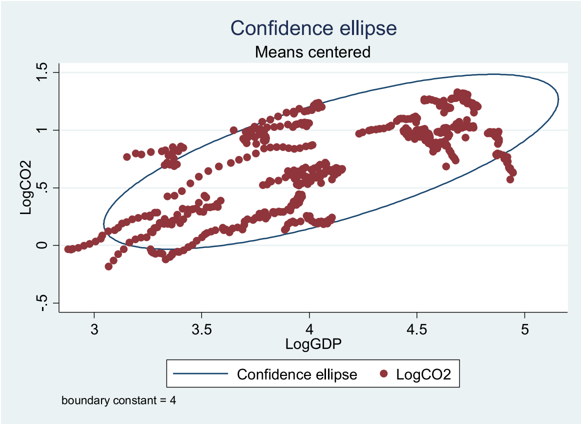

Fig. C. Confidence ellipse involving carbon emissions and economic growth.

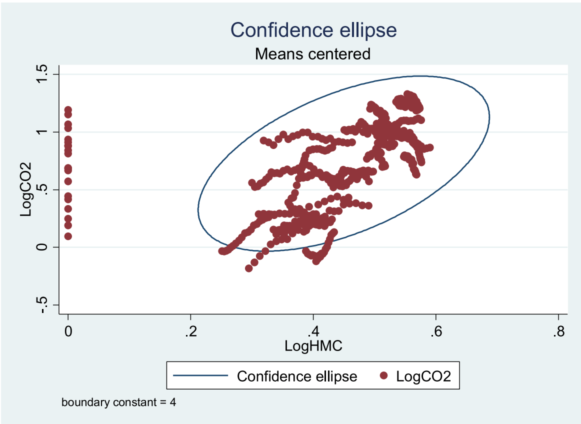

Fig. D. Confidence ellipse involving carbon emissions and human capital.

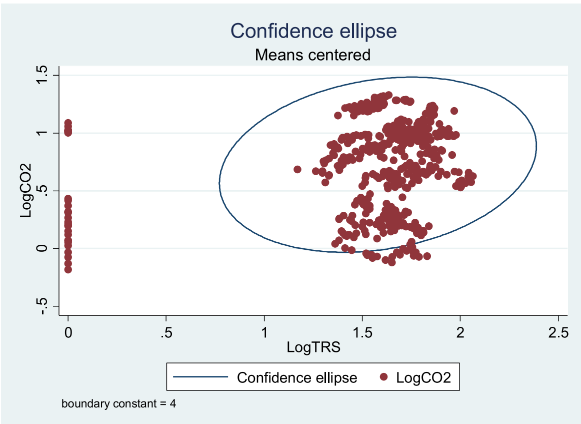

Fig. E. Confidence ellipse involving carbon emissions and transport services.

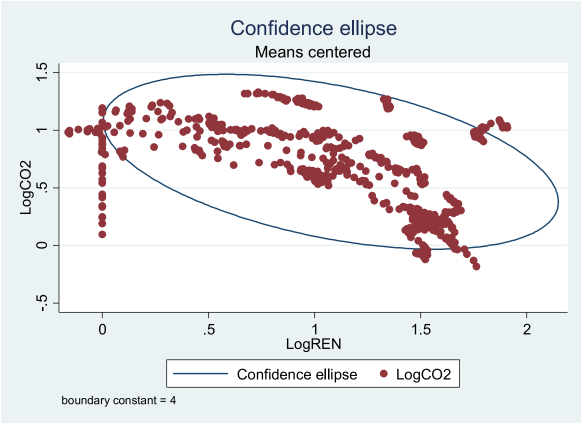

Fig. F. Confidence ellipse involving carbon emissions and renewable energy.

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