RESEARCH ARTICLE

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Agricultural Environmental Kuznets Curve: A Panel Data Approach

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Abstract
This study employs a panel regression model to empirically examine the association between environmental degradation and agricultural performance across a sample of 150 nations over the period of 2000-2020. Agricultural methane emissions serve as a metric for quantifying environmental damage. The measurement of agricultural performance is represented by two variables, namely, the net value added for agriculture and the livestock production index. While agricultural production is a significant source of methane emissions, it is noteworthy that the majority of existing literature mostly focuses on carbon dioxide (CO_2) emissions. The primary contribution of this study lies in the utilization of methane emissions as a surrogate measure for assessing the extent of environmental degradation. The findings substantiate the credibility of the agricultural Environmental Kuznets Curve (EKC), indicating a curvilinear association between agricultural net value added and methane emissions, characterised by an inverted U shape. In addition, it is worth noting that animal production exerts a substantial adverse influence on methane emissions. Hence, the development in net value-added in the agricultural sector might lead to a reduction in environmental degradation. Therefore, the results indicate that the use of agricultural production techniques and agricultural technology approaches is recommended in order to promote a more environmentally sustainable global context.
Keywords: Environmental Kuznets Curves, Panel Data, Agriculture, Net Value Added, Methane

INTRODUCTION

Climate change poses a significant risk to the agricultural sector and the overall stability of food production and availability. The productivity of farming systems in numerous locations is at risk due to the escalating temperatures and occurrences of extreme weather events. According to projections, the global population is anticipated to reach over 9-10 billion individuals by the year 2050. In light of this demographic trend, it is crucial to acknowledge the pivotal position that agriculture plays in providing sustenance for this expanding populace. The importance of agricultural economic growth has been increasingly evident in the current era of worldwide trade and self-sufficiency, particularly in light of the recent COVID-19 pandemic. Given the projected increase in global population, the agricultural industry is faced with the dual challenge of meeting the growing demand for food while also mitigating its environmental impact, particularly in terms of carbon emissions. Emissions of greenhouse gases (GHGs) are widely recognised as the primary catalyst for anthropogenic climate change. Agricultural operations are responsible for around 10-14% of global anthropogenic greenhouse gas (GHG) emissions. These emissions mostly consist of enteric fermentation (methane, CH_4), synthetic fertiliser application (nitrous oxide, N_2O), and tillage (carbon dioxide, CO_2) (IPCC, 2012).

The practices of livestock husbandry and field crop cultivation exert significant strain on the natural environment and contribute to the amplification of greenhouse gas emissions. In the realm of field crop production, the utilisation of fuel and the implementation of tillage operations contribute to the emission of carbon dioxide (CO_2), while the oxidation of soil organic carbon (SOC) also takes place. The utilisation of nitrogen fertilisers results in the release of nitrous oxide (N_2O). One particular source of greenhouse gas emissions within the cattle business is methane (CH_4) produced by ruminant animals. Specifically, in the year 2018, the emissions of methane (CH_4) resulting from the process of enteric fermentation occurring within the digestive systems of ruminant cattle remained the most significant contributor to greenhouse gas emissions at the farm level. This emission accounted for a total of 2.1 gigatonnes of carbon dioxide equivalent (Gt CO_2eq) (Faostat, 2020). The emissions resulting from agricultural activities, specifically those associated with crops and livestock, showed a notable increase between the years 2000 and 2018. In fact, at the end of this period, the emissions had expanded by around 14% in comparison to the levels observed in 2000.

Climate change is the result of prolonged alterations in temperature patterns. Since the 19th century, anthropogenic activities, specifically the combustion of fossil fuels such as coal, oil, and gas, have emerged as the primary catalyst for climate change. The combustion of fossil fuels leads to the release of greenhouse gases, which subsequently results in the retention of solar radiation and the subsequent elevation of temperatures. Alongside the phenomenon of global warming, the proliferation of agricultural activities emerges as a significant catalyst for worldwide environmental transformations. While agricultural activities play a significant role in fostering economic development, they also give rise to greenhouse gas emissions and contribute to environmental degradation through processes such as deforestation, land utilisation, and the use of fossil fuels, fertilisers, machinery, and the burning of crop residues. Agricultural operations have been found to be linked to detrimental environmental consequences. The possibility for soil damage can arise from alterations in land-use practices, as evidenced by activities such as the cultivation of previously uncultivated regions, the lack of implementation of soil conservation techniques, and the occurrence of excessive grazing. In addition, the agricultural sector contributes to the degradation of water quality through the contamination of surface and groundwater caused by the extensive use of chemical fertilizers. Furthermore, the increase in agricultural production requires a higher utilization of energy, primarily sourced from fossil fuels.

To meet the increasing global food demand driven by population increase, there has been a notable transformation of land that was formerly covered by forests, meadows, and other natural ecosystems for agricultural utilization (Tilman et al., 2001). One additional factor within the realm of agriculture that contributes to the phenomenon of global warming is the utilization of energy in croplands for activities such as pesticide application and tillage operations. These practices necessitate substantial quantities of fossil fuel consumption, as highlighted by Lal (2004) and Huggins and Reganold (2008). The expansion of cultivated areas through intensive agricultural practices has resulted in a significant increase in the emission of greenhouse gases.

The Environmental Kuznets Curve (EKC) is attributed to Simon Kuznets, who postulated a theoretical relationship between per capita income and environmental quality. The decline in environmental quality is observed during the initial stages of per capita GDP growth; however, beyond a specific threshold, a positive trend in environmental quality emerges. The utilization of energy is closely linked to the release of different pollutants, including carbon dioxide, sulfur, and nitrogen oxides.

EKC model illustrates the interplay among energy consumption, economic development, and environmental conditions. The relationship between per capita income and environmental damages or emissions follows an inverted U-shaped pattern. EKC, first proposed by Grossman and Krueger (1991), has emerged as the prevailing method employed by economists to analyze the relationship between ambient pollution concentrations and aggregate emissions.

EKC derives its nomenclature from Simon Kuznets, who postulated the correlation between ecological integrity and individual income. In the initial phases of per capita gross domestic product expansion, ecological integrity tends to diminish; however, beyond a certain threshold, it commences an upward trajectory. The release of diverse contaminants, namely carbon dioxide, sulfur, and nitrogen oxides, is intrinsically linked to energy consumption.

The EKC model portrays the correlation connecting energy utilization, economic expansion, and the surroundings. The ecological consequences or discharges per person are a function of per capita income that takes the form of an inverted U. Ever since the inception of the EKC by Grossman and Krueger (1991), it has emerged as the prevailing method employed by economists for representing the amalgamation of ambient pollution concentrations and overall emissions.

This research aims to examine the significance of contemporary climatic changes and the environmental implications of agricultural practices, specifically focusing on the escalating emissions of greenhouse gases resulting from animal husbandry and field crop production. The EKC in the context of agriculture can be used to analyze how agricultural practices impact the environment when economic development levels change. As agriculture develops, when a country's economy grows, there will be less reliance on traditional farming methods and more environmentally friendly farming methods will be applied. The country can thus invest in modernizing agriculture and sustainable practices, which can reduce the environmental footprint of farming activities. The EKC concept does not imply a fixed curve for all countries. With effective environmental policies and international cooperation, a shift toward sustainable agricultural practices and minimizing environmental degradation due to agriculture can be attained.

Using a panel data technique, the research empirically examines the relationship between environmental degradation and agricultural performance in 150 countries from 2000 to 2020. This paper's key contribution is to use methane emissions as a proxy for environmental degradation. The findings support the validity of agricultural EKC; an inverted U-shape relationship exists between agricultural net value added and methane emissions. The subsequent sections of this work are structured in the following manner. Section 2 elucidates the significance of the agriculture sector in the context of climate change. Section 3 of this paper comprises a comprehensive analysis and evaluation of pertinent scholarly works and literature. Section 4 of the paper provides an in-depth analysis of the data and the model employed in the study. Section 5 provides an empirical study and presents a comprehensive discussion of the findings. Section 6 serves as the final remarks.

The Role of the Agriculture Sector in Climate Change

Greenhouse gases (GHGs) have the capacity to absorb infrared radiation emitted by the sun and subsequently retain the heat within the Earth's atmosphere. This phenomenon, known as the greenhouse effect, is responsible for the occurrence of global warming and subsequent climate change. Major GHGs that are counted in international inventories are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), Nitrogen trifluoride (NF_3). According to World Development Indicators, CO_2 comprises the largest share among all GHGs, accounting for 73% in 2020. Methane is considered the second most abundant anthropogenic greenhouse gas, behind carbon dioxide (CO_2), and is responsible for around 18% of global emissions. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), it has been determined that the global warming potential of methane (CH_4) and nitrous oxide (N_2O) over a span of 100 years is projected to be 21 and 310 times greater than that of carbon dioxide (CO_2), respectively.

According to 2020 estimates, agriculture accounts for around 12% of total greenhouse gas emissions that contribute to climate change. When land-use change and forestry are factored in, this rate rises to 15%. As a result, agriculture is the second-highest emitter of greenhouse gases after energy production. Direct agricultural production, animal husbandry, and the loss of wooded areas in order to improve agricultural productivity all contribute to the emission of three greenhouse gases: methane (CH_4), nitrogen oxide (N_2O), and carbon dioxide (CO_2). The shares of agricultural production in these three greenhouse gas emissions are depicted in Figure 1. As a result, agriculture accounts for around 40% of overall CH_4 emissions, 73% of N_2O emissions, and only 3% of CO_2, the greatest contributor to total greenhouse gas emissions.

According to FAO (2021), the global emissions resulting from agricultural activities, encompassing activities within the farm gate as well as land use and land use change, amounted to 9.3 billion tonnes of carbon

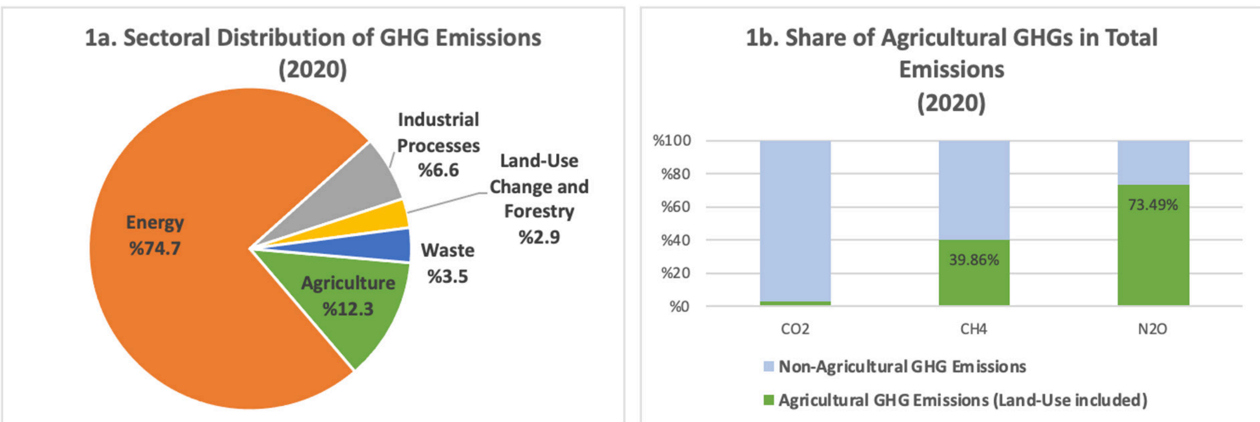

Figure 1. Sectoral Distribution of GHG Emissions and Share of Agricultural GHGs in Total Emissions
Source: (1a) Climatewatch (Link) (1b) FAOSTAT, http://www.fao.org/faostat

dioxide equivalent in 2018. The emission sources of methane and nitrous oxide deriving from crop cultivation and livestock operations accounted for 5.3 billion tonnes, reflecting a growth of 14% since the year 2000. Notably, the emissions arising from livestock production procedures such as enteric fermentation and the deposition of manure on pastures constituted the predominant portion of farm-gate emissions, yielding a total of 3 billion tonnes of carbon dioxide in 2018. Concurrently, emissions stemming from land use and land use change reached 4 billion tonnes of carbon dioxide in 2018, with deforestation being the primary cause (equating to 2.9 billion tonnes of carbon dioxide equivalent) and the incineration of organic soils through drainage burning contributing 1 billion tonnes of carbon dioxide equivalent. It is important to highlight that these land use emissions exhibited a global decrease of 20% since 2000. While emissions resulting from deforestation have shown a decline, those originating from drainage and the incineration of organic soils have witnessed an increase of nearly 35% since 2000.

The primary source of N_2O emissions can be attributed to the application of animal and synthetic fertilisers in agricultural practices, either through their incorporation into the soil or their release into the environment. According to Tilman et al. (2001), it is projected that by the year 2050, there will be a net increase of 3.5×108 hectares in worldwide agriculture. This expansion will be accompanied by a 2.4 to 2.7-fold increase in the usage of pesticides and fertilisers. Consequently, these intensified agricultural practices are expected to result in the contamination of ecosystems and the eutrophication of water sources. Specifically, the proportion of N_2O emissions originating from fertiliser residue on pastures accounts for 18% of the total greenhouse gas emissions in the agricultural sector. Additionally, within the realm of agricultural N_2O emissions, this particular source contributes to 48% of the overall emissions. The practice of tillage has the potential to contribute to the release of N_2O emissions from the soil, and this phenomenon is influenced by factors such as soil moisture, temperature, and nitrate (NO_3) concentration, as highlighted by Perdomo et al. (2009). The emission of N_2O is significantly influenced by the use of nitrogen-based fertilizers, as any surplus nitrogen that is not taken up by plants can be released into the atmosphere in the form of gaseous emissions (Smith et al., 2008).

Soil tillage is a significant factor in the generation of carbon dioxide (CO_2) emissions in agricultural areas, mostly due to the process of soil organic carbon (SOC) oxidation. The diminished soil organic carbon (SOC) reservoir has a detrimental impact on the physical and chemical characteristics of soil, as well as its fertility and productive potential (Stavi et al., 2011). Manuring is identified as a significant contributor to CO_2 emissions, primarily due to the stimulation of microbial activity (Matsumoto et al., 2008). The retention of manure decomposition rate on the soil surface has the potential to result in a decrease. Furthermore, the use of excessive fertilizers can lead to the runoff or leaching of water sources above or below the ground (De Angelo et al., 2006).

The major sources of CH_4 come from agriculture and oil and gas operations. Emissions of CH_4 derived from ruminant husbandry and rice cultivation. Enteric fermentation and paddy production are the two main sources of methane emissions from agricultural output. Enteric fermentation is the digestive process by which ruminant carbohydrates are broken down into simple molecules by microorganisms in their intestines, and methane is generated during this process. Methane is emitted by paddy grown underwater throughout the process. According to FAO data, methane gas emitted as a result of enteric fermentation accounted for 44% of all agricultural greenhouse gases in 2017, whereas it accounted for 70% of agricultural methane gas emissions.

The emission of CH_4 from ruminants is a specific consequence of the livestock industry. In order to rear livestock, it is necessary to provide the animal with an appropriate amount of food based on its body weight. The production of this feed not only involves the release of greenhouse gases through the operation of agricultural machinery and the use of fertilizers but also results in the generation of various wastes that contribute to greenhouse gas emissions (Fiala, 2009). Climate change has the potential to bring about changes in semi-natural ecosystems, and these alterations may have implications for the global livestock sector by reducing the availability of feed and pastures (Thornton & Gerber, 2010). The emergence, spread, and distribution of livestock diseases could also be influenced by climate change, as high temperatures can impact the rate of development of pathogens and parasites, potentially leading to shifts in disease patterns; consequently, there may be changes in the animal population (Randolph, 2008).

Literature Review

Commencing with the seminal contributions of Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992), numerous scholarly articles have delved into the examination of the Environmental Kuznets Curve (EKC) hypothesis, which elucidates an inverted U-shaped association between environmental pollution and economic growth. In earlier investigations, the analysis incorporated per capita GDP and per capita energy consumption as independent variables (Selden & Song, 1994; Shafik, 1994; Holtz-Eakin & Selden, 1995). Other variables that have been explored by researchers include foreign direct investment (Agvoola & Bekun, 2019), human capital (Mahmood et al., 2019), industrialization (Pata, 2018; Prastiyo et al., 2020), urbanization (Ridzuan et al., 2020), trade openness (Jebli & Youssef, 2017; Balsalobre-

Lorente et al., 2019), and economic complexity (Yılancı & Pata, 2020) in the analysis of the EKC hypothesis.

The agricultural sector was not a priority for researchers testing the EKC hypothesis, though its importance in economic development (Prastiyo et al., 2020). The findings of the limited number of studies in terms of agricultural impact on environmental pollution have been summed up in Table 1.

When a literature review is made of the existing studies, we conclude that the EKC hypothesis is validated for the impact of agriculture on environmental pollution by most of the researchers. There are some researchers who failed to validate the EKC hypothesis as Ben Youssef (2017) and Liu et al. (2017). Among 13 studies, eight of them state that agriculture accelerates carbon dioxide emissions. There are some studies stating that agriculture reduces environmental pollution, and to improve environmental quality, it is necessary to have agricultural production. (Liu et al. 2017; Zhang et al. 2019; Aziz at al. 2020; Prastiyo et al. 2020; and Ridzuan et al. 2020.)

S. Coderani and R. Esposti (2014) utilized a comprehensive panel dataset encompassing many years and focusing on a single country, specifically the Italian regions. Their objective was to examine the correlation between greenhouse gas (GHG) emissions in the agricultural sector and the rise of agricultural productivity. The panel focuses on the emissions of methane from 1951 to 2008 and N_2O from 1980 to 2008. The findings indicate that there may be a statistically significant association between greenhouse gas emissions in the agricultural sector and the rate of productivity increase. However, this link is observed to be consistently increasing or decreasing, without any fluctuations.

N. Dogan (2016) used annual data from 1968 to 2010 to experimentally examine the long-run link between agricultural performance and carbon dioxide emissions in Turkey. According to the findings, an increase in agricultural output would have the opposite effect on Turkey's carbon dioxide emissions in the long run.

E. Zafeiriou and M. Azam (2017) examine the veracity of the correlation between economic success per capita and CO_2 emissions in the agricultural sector across three Mediterranean nations, namely France, Portugal, and Spain. The validation of the Environmental Kuznets Curve (EKC) hypothesis has been observed in all nations included in the sample, as indicated by their findings.

M. B. Jebli and S. B. Youssef (2017) conducted an investigation into the dynamic causal connections between renewable energy consumption per capita, agricultural value added, carbon dioxide emissions, and real gross domestic product for a panel of five North African countries spanning the period 1980–2011. In the short term, Granger causality tests provided evidence of the existence of bidirectional causality between CO_2 emissions and agriculture. X. Liu et al. (2017) made an attempt to examine the impact of renewable energy consumption per capita and agricultural value added on carbon dioxide emissions in four selected countries of the ASEAN-4 (Indonesia, Malaysia, the Philippines, and Thailand) from 1970 to 2013. The results of their long-term estimates did not provide support for the inverted U-shaped Environmental Kuznets Curve (EKC).

K. Appiah et al. (2018) analysed the correlation between agriculture production and carbon dioxide emissions in emergent economies from 1971 to 2013. Empirical findings indicated that a 1% increase in economic growth, crop production index, and livestock production index would cause proportional increases in carbon dioxide emissions of 17%, 28%, and 28%, respectively, whereas a 1% increase in energy consumption and population would improve the environment of emerging economies.

Data and Model

The data utilized in this study was obtained from the World Development Indicators (2022) dataset, which was developed by the World Bank. The dataset encompasses information from 150 countries, covering the time period between 2000 and 2020. The selection of the study period and the national sample is contingent upon the availability of data. In the Human Development Index of 2022, it was seen that 54 of the sampled counties were categorized as having a very high level of human development, while 42 counties were classified as having a high level of human development. Additionally, 55 counties fell into the medium and poor human development categorization.

The primary focus of this study revolves around the examination of CH_4 emissions as an indicator of environmental deterioration within the agricultural sector. Chapter 4 is widely regarded as the most significant agricultural pollutant, accounting for approximately 18% of total greenhouse gas emissions. The percentage of methane emissions attributed to the agricultural sector on a global scale is 39.86%. The independent variables utilized in this study encompassed the value contributed by agriculture, forestry, and fisheries.

Given that the primary source of agricultural CH_4 emissions is enteric fermentation, it is pertinent to include the livestock production index as an additional explanatory variable in the model. This inclusion serves to provide supplementary support and enhance the explanatory power of the model. According to the World Development Indicators (WDI) for the year 2022,

Table 2 presents a summary of the descriptive statistics for the variables. There were a total of 3146 valid observations, with an average methane emission volume of 20543 thousand metric tons of CO_2 equivalent. The quantity of methane varies from 1,260 metric tons in Seychelles during the year 2012 to 502,192 metric tons in India during the year 2020. In terms of the economic

Table 1. Empirical Studies Relates Environmental Quality to Agriculture

Work	Countries	Time period	Method(s)	Variables	Agriculture-pollution nexus	A-EKC
Coderani & Esposti (2014)	Italian Regions	1951-2008 1980-2008	LSDV, LSDVC, GMM	N_2O &CH_4 | APG	Agriculture→N_2O (+) Agriculture→N_2O (+)	✓
Dogan (2016)	Türkiye	1968-2010	ARDL	CO_2 | GDP, EC, RIA	Agriculture →CO_2 (-)	✓
Zafeiriou & Azam (2017)	France, Portugal, Spain	1992-2014	ARDL	CO_2 | AGRV per capita, T	Agriculture →CO_2 (+) (France and Spain) Agriculture →CO_2 (-) (Portugal)	✓
Zafeiriou et al. (2017)	Bulgaria, Czech Republic, Hungary	1970-2014 1993-2014 (for Czech Republic)	ARDL	CO_2 | AGRV, D	Agriculture →CO_2 (+)	✓ (for Czech Rep. and Bulgaria in the LR)
Jebli &Youssef (2017)	North Africa Countries	1980-2011	Johansen-Juselius cointegration,	CO_2 | GDP, REC, NREC, TO AGRV	Agriculture →CO_2 (+)	X
Liu et al. (2017)	ASEAN-4	1970-2013	Kao panel cointegration test, OLS, DOLS and FMOLS	CO_2 | GDP, REC, NREC, AGRV	Agriculture →CO_2 (-)	X
Gokmenoglu & Taspinar (2018)	Pakistan	1971–2014	Maki cointegration, FMOLS	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (+)	✓
Appiah et al. (2018)	Selected emerging economies	1971-2013	FMOLS, DOLS	CO_2 | GDP, CP, LP, POP, EC	Agriculture →CO_2 (+)	Not tested
Agboola & Bekun (2019)	Nigeria	1981-2014	Bayer-Hanck cointegration test,	CO_2 | GDP, TO, FDI, EC, AGRR	Agriculture →CO_2 (+)	✓
Balsalobre-Lorente et al. (2019)	BRICS	1990-2014	Kao and Fisher panel cointegration tests, DOLS, FMOLS	CO_2 | GDP, ELC, MOB, TO, AGRR	Agriculture →CO_2 (+)	✓
Dogan (2019)	China	1971-2010	ARDL, FMOLS, DOLS, CCR	CO_2 | GDP, EC, AGRR	Agriculture →CO2 (+)	✓
Gokmenoglu et al. (2019)	China	1971-2014	ARDL	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (+)	✓
Qiao et al. (2019)	G20	1990-2014	Johansen-Fisher panel cointegration, FMOLS, DOLS	CO_2 | GDP, REC, AGRV	Agriculture →CO_2 (+)	✓
Zhang et al. (2019)	China	1996-2015	ARDL	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (-)	✓
Aydoğan & Vardar (2020)	E7	1990-2014	Pedroni cointegration, OLS, FMOLS and DOLS	CO_2 | GDP, REC, NREC AGRV	Agriculture →CO_2 (+)	✓
Aziz et al. (2020)	Pakistan	1990-2018	Quantile ARDL	EF | GDP, FA, REC, AGRV	Agriculture →EF (-)	✓
Prastiyo et al. (2020)	Indonesia	1970-2015	ARDL	CO_2 | GDP, IND, URB, AGRR	Agriculture →CO_2 (-)	✓

Ridzuan et al. (2020)	Malaysia	1978-2016	ARDL	CO_2 | GDP, HG, URB, CP, FP, LP	CP and FP →CO_2 (-)	✓
Selcuk et al. (2021)	N-11 Countries	1991-2019	CCEMG	CO_2 | GDP, EC, AGRV, FDI, TO	Agriculture →CO_2 (+)	Not tested
Ntim-Amo et al. (2021)	Ghana	1980-2014	ARDL, FMOLS, DOLS	CO_2 | GDP, EC, AGRV	Agriculture →CO_2 (+)	✓
Liu et al. (2021)	China, Three Gorges Reservoir Region	Not mentioned	OLS	Agricultural Chemicals | GDP, POP, Agricultural Investment	Agriculture →Agricultural Chemicals (+)	✓
Wang & Lv (2022)	China, Henan Province	2000-2019	OLS	Agricultural CO_2 | AGRV	Agriculture →Agricultural CO_2 (+)	✓
Cetin et al. (2022)	47 Developing Countries	1976-2017	DOLS, FMOLS	CO_2 | GDP, EC, AGRV	Agriculture → CO_2 (+)	✓
Atasel et al. (2022)	Top 10 Agricultural Countries	1997-2016	AMG	CO_2 | GDP, AGRV	Agriculture → CO_2 (-)	✓ (6 out of 10 countries)
Khan et al. (2023)	54 countries	1971-2017	PMG	ΔForestry | AGRV, ETR, UAG, FIND	Agriculture → ΔForestry (-)	X

Note: AGRR: Agricultural production (% of GDP), **AGRV:** Agricultural value-added, **AMG:** Augmented mean group estimator, **APG:** Agricultural production growth, **ARDL:** Autoregressive distributed lag model, **CCEMG:** Common correlated effects mean group estimator, **CCR:** Canonical cointegrating regression, **CP:** Crop production, **D:** Dummy, **DOLS:** Dynamic OLS, **EC:** Energy consumption, **EF:** Ecological footprint, **ELC:** Electricity consumption, **ETR**: Energy transition **FA:** Forest area, **FDI:** Foreign direct investment, **FIND:** Financial depth, **FMOLS:** Fully modified OLS, **FP:** Fisheries production, **HG:** Hydroelectricity generation, **IND:** Industrialization, **LP:** Livestock gross production, **MOB:** Mobile use, **NREC:** non-renewable EC, **OLS:** Ordinary least squares, **PMG:** Pooled mean group, **POP:** Population, **REC:** Renewable energy consumption, **RIA:** Real income from agriculture, **T:** Time trend, **TO:** Trade openness, **UAG:** Urban agglomeration, **URB:** Urbanization

Source: Based on Atasel et al. (2022: 34027), reviewed and updated by the author.

Table 2. Descriptive Statistics

Variable	Description	Min.	Max.	Mean	Std. Dev.
MET	Agricultural methane emissions *(thousand metric tons of CO2 equivalent)*	1,26	502192,29	20542,58	58039,45
NVA	Agriculture, forestry, and fishing, value added *(constant 2015 million US$)*	5,99	1095776,95	17504,84	71679,68
LIVESTOCK	Livestock production index *(2014-2016 = 100)*	18,47	278,17	93,13	21,58

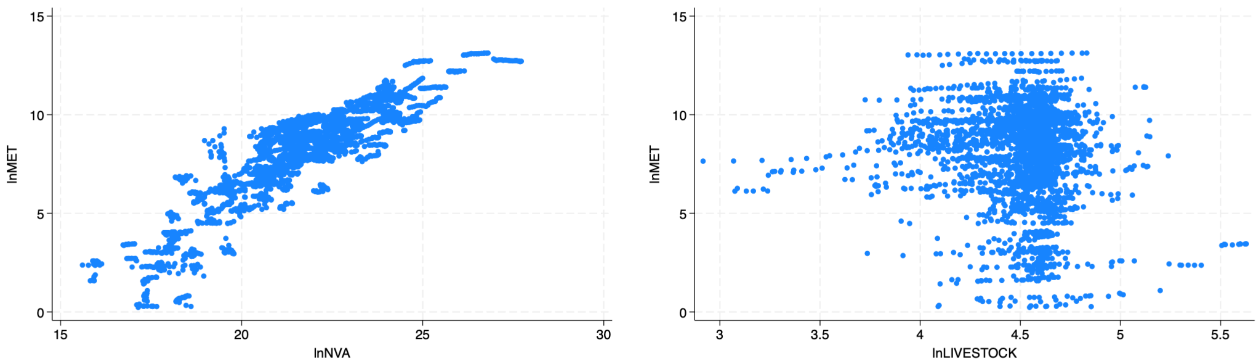

Figure 2. Scatterplots of variables

contribution of agriculture, forestry, and fisheries, China stands as the most affluent nation with a value-added of $1,095,777 million in 2020. Conversely, St. Kitts and Nevis ranks as the least prosperous country with a value-added of $5.99 million in 2000. In terms of the Livestock Production Index, Tajikistan exhibits the lowest rate of 18.47 in the year 2000, while Antigua and Barbuda showcases the greatest rate of 278.17 in 2006

Figure 2 illustrates the graphical representations of the value added for agriculture, forestry, and fishery (NVA) as well as the livestock production index in relation to agricultural methane (CH_4) emissions. As anticipated, a visual examination reveals an inverted-U-shaped correlation between NVA (non-volatile acidity) and methane emissions. However, despite the anticipation of a positive correlation between the animal production index and agricultural methane emissions, it appears challenging to ascertain this link based just on the scatterplot.

The utilization of a panel data model is recommended for this study due to the inherent advantages it offers in comparison to time series and cross-section data. One crucial aspect is that panel data analysis enables the elucidation of (i) the reasons for disparate behaviours among units (countries) and (ii) the factors contributing to variations in behaviour within a same unit (country) across different time periods. By taking into account our model, panel data is anticipated to possess a greater capacity in identifying and quantifying impacts that are not discernible in either pure cross-sectional or pure time-series data. According to Karlsson and Löthgren (2000) and Levin et al. (2002), the panel unit root test is considered to possess adequate robustness when used to panels of modest dimensions, specifically when the number of cross-sectional units (N) falls within the range of 10 to 250, and the time periods (T) range from 25 to 250. Nevertheless, when T is small, panel unit root tests exhibit limited statistical power, and there exists a possible danger of erroneously determining that the entire panel is nonstationary, even in cases where a significant fraction of the series inside the panel are stationary. In a similar vein, it is widely recognized that typical panel cointegration tests exhibit limited statistical power, particularly when applied to datasets with a small number of time periods (T) and a limited span of data (Baltagi, 2005). Hence, the researchers have opted for panel regression analysis as the appropriate method for this investigation, given the relatively limited time dimension (T=21).

The extensive body of material pertaining to the (EKC) hypothesis often operates under the assumption that the relationship between environmental degradation and income can be adequately explained by a quadratic function. The present study aims to investigate the relationship between agricultural revenue and methane emissions in the context of an agricultural Environmental Kuznets Curve (EKC). To achieve this objective, the following model will be utilized.

The vast literature on the EKC hypothesis generally assumes that environmental degradation is explained by the quadratic function of income. Since the study is interested in an agricultural EKC related to methane emissions in agricultural income, the following model will be considered:

$$lnMET_{it} = \beta_0 + \beta_1 lnNVA_{it} + \beta_2 lnNVA_{it}^2 + \beta_3 lnLIVESTOCK_{it} + \mu_i + u_{it} \qquad (1)$$

where i= 1, 2, ….N for each country in the panel and t= 1, 2, ……., T refers to the period. METit refers to the methane emissions, NVAit denotes the value added for agriculture, forestry, and fishing, and lastly, LIVESTOCKit indicates the livestock production index. All variables are transformed into natural logarithms to standardize the different scales of the variables. β_0 stands for the specific country-pair effects and allows controlling for all omitted variables that are cross-sectionally specific but remain constant over time. μ_i denotes the unobservable country-specific effect, and u_{it} means the remainder disturbance. β_1 and β_2 are the coefficients of NVA and squared NVA. Under the EKC hypothesis, the signs are expected to be positive and negative, respectively. The livestock production index is assumed as a supportive indicator of methane emissions. So, it is added to the model in linear form. The coefficient of the livestock production index, β_3, is expected to be positive. On the logarithmic scale, turning points (where methane emission is maximized) for income can be calculated as;

$$NVA^* = (-\frac{\beta_1}{2\beta_2}).$$

Exp(NVA*) represents the value of the turning points.

Empirical Analysis

The initial phase of the investigation entails prioritizing the selection of a sound model. The F-test and the Breusch and Pagan LM test were employed in this investigation to determine whether the characteristics of the data can be classified as pooled or panel. The results indicate that all data pertaining to the countries are in panel format. In order to ascertain the most suitable model for the panel analysis, the Hausman specification test was utilized to compare the Fixed Effect model (FEM) and Random Effect model (REM). The Hausman test indicates the rejection of the null hypothesis (H0), hence providing evidence in favour of the fixed effects model (FEM).

Subsequently, the model underwent testing to assess the presence of heteroscedasticity, cross-sectional dependence, and serial correlation. The Modified Wald test was employed to assess group wise heteroscedasticity, resulting in the rejection of the null hypothesis that assumes homoscedasticity. The cross-sectional independence test conducted by Pesaran

Table3. Panel-data Regression Results.

lnMET	Coefficient	Driscol/Kraay Standard Errors
lnNVA	0.756728*	0.1757755
lnNVA²	-0.161558*	0.0040274
lnLIVESTOCK	0.418183*	0.0220641
constant	**-2.668545**	1.978814
within R-squared	0.3247	
F (3, 149)	2385.55	
Prob > F	0.0000	
turning point for NVA	14827	

Coefficients with (*) are significant at 1%. The coefficient with bold is not significant.

revealed that the null hypothesis was rejected with a significance level of 1%. Both the Baltagi-Wu local best invariant (LBI) test and the Durbin-Watson test have indicated the presence of serial correlation. The test results are presented in the Appendix. In order to address the aforementioned concerns pertaining to heteroscedasticity, cross-sectional dependency, and serial correlation, the Driscoll-Kraay estimator was implemented. The coefficients displayed in Table 3 represent the robust estimates that have been corrected using the Driscoll-Kraay estimator.

The F-test indicates that the model is statistically significant. The coefficient of determination (R2) for the model is 0.3247, indicating that approximately 33% of the variation in agricultural methane emissions can be accounted for by the independent variables included in the model. With the exception of the constant term, all of the computed coefficients exhibit statistical significance.

The computed coefficients for the variable NVA and its squared term are determined to be statistically significant, with the expected positive and negative signs, respectively. According to Lind and Mehlum (2010), for statistical judgments regarding the presence of an inverted U-shape, it is necessary to consider not only the negative sign and significance of the second derivative but also whether the predicted extremum point falls within the range of the data. The estimated turning point of NVA for the inverted-U curve is $14827, expressed in constant 2015 million US dollars, 20 per cent of the valid observations in the sample, specifically 629 out of 3146 observations, above the threshold level. Thus, the Environmental Kuznets Curve (EKC) hypothesis is validated for the Northern Virginia area based on the data obtained from the sample. It can also be argued that a majority of the countries in the sample (2517 out of 3146 observations) exhibit a positive trend in the inverted-U-shaped graph. Therefore, the elevation of non-volatile acidity (NVA) has an adverse impact on environmental quality due to its association with increased methane emissions.

The statistical analysis reveals that the estimated coefficient of the livestock production index is both statistically significant and positive. This suggests that there is a detrimental effect of livestock production on environmental quality. Specifically, a 1% rise in the livestock production index is associated with a 0.4% increase in agricultural methane emission.

CONCLUSION

This study investigates the correlation between environmental degradation and agricultural performance across 150 nations for the period of 2000-2020, employing a panel regression model. Methane emissions are quantified as a surrogate indicator of environmental deterioration, while agricultural performance is approximated by the net value added for agriculture and the livestock production index. The findings of this study provide empirical evidence supporting the concept of the EKC in the agricultural sector. Specifically, the results demonstrate a curvilinear relationship, characterized by an inverted U shape, between agricultural net value added and methane emissions. The findings indicate that the adoption of agricultural production techniques and technology methods is imperative in order to foster a more environmentally sustainable global landscape. The peak point for the available data is determined to be $14,827. Furthermore, it is worth noting that the production of cattle has a substantial adverse effect on the release of methane emissions. Hence, the development in net value-added within the agricultural sector might have a consequential impact on the degradation of the environment. Climate change poses a substantial risk to the agricultural sector and global food security, particularly in light of the projected increase in the world's population to approximately 9-10 billion individuals by the year 2050. Agricultural activities make a significant contribution of approximately 10-14% to the overall anthropogenic greenhouse gas emissions on a global scale. This contribution principally stems from three key sources: enteric fermentation, synthetic fertilizer application, and tillage practices.

Climate change is an outcome arising from prolonged alterations in temperature patterns, predominantly influenced by anthropogenic activity, notably the combustion of fossil fuels. Consequently, the aforementioned phenomenon gives rise to the release of greenhouse gases, which subsequently ensnare solar radiation and contribute to the escalation of ambient temperatures. Agriculture, which plays a significant role in shaping global environmental dynamics, serves as a catalyst for economic development. However, it also gives rise to greenhouse gas emissions and environmental deterioration due to activities such as deforestation, land utilization, livestock management, fertilizer application, machinery usage, and the burning of crop residue. Agricultural activities are also associated with adverse impacts such as soil degradation, water pollution, and heightened energy consumption. The model known as the EKC, which is named after Simon Kuznets, posits that there exists an inverse relationship between environmental quality and per capita GDP growth, whereas a positive association is shown between environmental quality and heightened energy use. This paper examines the significance of contemporary climatic changes and the environmental implications of agriculture, with a specific emphasis on the amplified emission of greenhouse gases resulting from animal husbandry and field crop production. EKC can be employed as a tool for examining the environmental consequences of agricultural practices in the context of varying degrees of economic growth. Previous studies have dealt with carbon dioxide as a pollutant the uniqueness of this study is that methane gas is tested as an agricultural pollutant specifically. Methane has a larger warming potential than carbon dioxide over a shorter duration. Understanding its sources and effects in agriculture is important since its emission into the atmosphere causes climate change. Enteric fermentation in ruminants like cattle produces a lot of methane. Methane emissions can reveal animal management practices and environmental impacts. Flooded rice paddies produce methane through anaerobic breakdown. Understanding and reducing methane emissions from paddy fields is essential for sustainable agriculture because rice is a staple diet for many people. Manure Management: Organic manure decomposes to release methane. Management techniques affect methane emissions, and researching them can guide sustainable agriculture. In manure lagoons and wastewater treatment systems, anaerobic digestion occurs. These conditions produce methane, therefore researching these systems can help trap or reduce methane emissions. When discharged, methane can cause ground-level ozone, impacting air quality. Understanding how agriculture emits methane is essential for environmental management.

In other words, studying methane as an agricultural pollutant is about optimizing agricultural methods for sustainability and reducing climate and air pollution As agricultural advancements occur, nations have the opportunity to allocate resources toward the modernization of agricultural methods and the adoption of sustainable approaches, thereby mitigating their environmental impact. The issue of agricultural greenhouse gas (GHG) emissions poses a greater challenge in rising and developing nations since the agricultural sector is still undergoing transformation as a result of industrialization. Therefore, the results indicate that nations ought to embrace contemporary agricultural production methods in order to foster a more ecologically sustainable global ecosystem.

COMPLIANCE WITH ETHICAL STANDARDS

Peer-review

Externally peer-reviewed.

Conflict of interest

The author declares that there is no conflicts of interest.

Ethics committee approval

Ethics committee approval is not required.

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Consent to participate

Not applicable.

Consent for publication

Not applicable.

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