sustainability

MDPI

Article

Nexus between Agricultural Land Use, Economic Growth and N_2O Emissions in Canada: Is There an Environmental Kuznets Curve?

Azad Haider [1,*], Wimal Rankaduwa [2], Muhammad Iftikhar ul Husnain [3] and Farzana Shaheen [4]

1 Department of Economics, Dalhousie University, Halifax, NS B3H 4R2, Canada
2 Department of Economics, University of Prince Edward Island, Charlottetown, PE C1A 4P3, Canada; wrankaduwa@upei.ca
3 Department of Economics, COMSATS University, Islamabad 45550, Pakistan; iftikharhusnain@comsats.edu.pk
4 Department of Finance and Treasury Board, Government of Nova Scotia, Halifax, NS B3J 1V9, Canada; farzana.shaheen@novascotia.ca
* Correspondence: azad.haider@dal.ca

Abstract: The present study investigates the relationship between nitrous oxide emissions and economic growth using the ARDL bounds testing approach in Canada over the period of 1970–2020. The agricultural land use and exports are included in the estimated models as additional control variables. The empirical findings confirmed the environmental Kuznets curve hypothesis when total N_2O emissions are used as a dependent variable in the case of Canada, and similar results are found when we used agricultural induced N_2O emissions as a dependent variable. The results also indicate that Canada is already in the decreasing segment of the Kuznets curve, and the turning point of GDP per capita for the total N_2O emissions is $41,718, while for agricultural induced N_2O emissions, it is $38,825. Our empirical evidence confirms that agricultural land use had a positive and significant effect on total N_2O emissions, while a negative but insignificant effect in the case of agricultural induced N_2O emissions. However, Canadian exports are negatively associated with total N_2O emissions as well as agricultural induced N_2O emissions, but it requires more stringent laws to curb N_2O emissions-oriented exports to keep the ecosystem in balance in the short-run and intends to meet its long-term target of reducing emissions as it progresses towards Canada's 2050 net-zero ambition.

Keywords: N_2O emissions; agriculture; economic growth; environmental Kuznets curve

check for updates

Citation: Haider, A.; Rankaduwa, W.; ul Husnain, M.I.; Shaheen, F. Nexus between Agricultural Land Use, Economic Growth and N_2O Emissions in Canada: Is There an Environmental Kuznets Curve? *Sustainability* **2022**, *14*, 8806. https://doi.org/10.3390/su14148806

Academic Editor: Luigi Aldieri

Received: 16 May 2022
Accepted: 9 July 2022
Published: 19 July 2022

1. Introduction

In a short span of time, to grow rapidly has been a strong desire of all the countries, and this ambitious desire has helped the world economy to triple in the time span of only forty years [1], yet it has brought the sustainability of natural resources into question by emitting large amounts of greenhouse gases (GHGs) that have led to climatic variation. Climate change, the top-ranked problem stated by a scientist [2], is a consequence of human activities [3,4]. Currently, human survival is highly vulnerable to global warming [5], and this threat is strengthening with every passing day. On average, the anthropogenic emissions have seen annual growth of 1.3% and 2.2% from 1970 to 2000 and 2000 to 2010, respectively. The projected surface temperature would increase under all the assessed emissions scenarios for the 21st century [3]. This rising temperature may affect different aspects of the economy such as agriculture and forest productivity, marine life, recreational activities, and human health [6]. The close link between economic activities and pollution level deserves investigation to identify policies that could minimize GHGs emissions while sustaining economic growth. Furthermore, to mitigate global warming effects, political and environmental interests are growing as the challenge is to generate economic growth without sacrificing the quality of life of future generations.

GHGs are not equal in the context of their impact on the atmosphere, as each has a unique heat-trapping potential and average atmospheric lifetime (see Table 1). Though nitrous oxide (N_2O) emissions have a small share in GHGs (6%), its importance is immense since it is one of the most hazardous gases present in the ambient atmosphere [7], has an equivalent mass basis [8], can reside for a longer time in the ambient atmosphere, and has 300 times greater warming potential than CO_2 [9]. It has been responsible for stratospheric ozone destruction and global warming [10,11]. Fossil fuel combustion and agricultural activities are two primary sources of N_2O emissions [12,13]. Anthropogenic sources emit about 70% of N_2O emissions [14]. By using nitrogen-induced fertilizers and cultivating nitrogen-fixing crops, human actions have substantially hampered the cycling process of nitrogen [8]. The estimates show that by 2100, the total N_2O emissions from chemical fertilizers used in production will reach 4.2 Tg N y-1 [15,16].

Table 1. GHGs and global warming potentials (GWPs) greenhouse gas 100-year GWP.

Greenhouse Gas	Global Warming Impact	Estimated Atmospheric Life in Years
Carbon Dioxide (CO_2)	1	30–95
Methane (CH_4)	25	12
Nitrous oxide (N_2O)	310	114
Sulphur hexafluoride (SF_6)	22,800	3200
Hydrofluorocarbons (HFCs), 13 species	Ranges from 92 to 14,800	12
Perfluorocarbons (PFCs), 7 species	Ranges from 7390 to 12,200	

Source: The United States Environmental Protection Agency, IPCC Report, 2014, p. 7. Available online: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/quantification-guidance/global-warming-potentials.html (accessed on 20 August 2021).

Resultantly, 66% of global N_2O emissions originate from the soil process [17]. Furthermore, the concentration of various nitrogen oxides including N_2O beyond a certain level causes harmful diseases and damages lung tissues [18]. Projections reveal that due to N fertilizers, agriculture's share in build-up of global N_2O emissions will increase by 90% by 2026 [19]. The emissions from cultivated agricultural land could be doubled if an account is taken of dissolved N_2O in drainage and aquifer waters coming out of agricultural watersheds [20]. Therefore, it remains vital to understand what factors contribute to N_2O emissions and how their levels can possibly be reduced to a minimum level by framing policies in the context of sustainable human activities.

In the last few decades, voluminous research has been devoted to investigate the environmental Kuznets curve (EKC) hypothesis on groups of countries, individuals' countries using different pollution indicators and time periods as indicated by various studies such as Husnain et al. [21], Kijima et al. [22] and Carson [23]. Understandably, a substantial number of studies, especially empirical studies, analyzed the CO_2 emissions as they are significant contributors to global warming [24–34] and constitute 82% of the total GHGs emissions with a close association to economic, social, and industrial factors [35]. Khalil and Rasmussen [36] estimate that N_2O concentration in the atmosphere is increasing at the rate of $0.27 \pm 0.01\%$ yr-1. Furthermore, the international community is seriously concerned with minimizing CO_2 emissions. However, CO_2 emissions in a country only represent one GHG, and to have a comprehensive understanding of how a country affects the environment, other gases like methane and N_2O should be taken into account [37].

Though CO_2 is the "face" of the GHGs, N_2O has its own severe demerits. There are few studies on EKC that analyzed the relationship between N_2O emissions and economic growth [38], therefore, with respect to policy formulation, little had been done due to the lack of systematic and comprehensive studies on this issue. Apart from its immense importance in the greenhouse gas effect, economic growth is also a very crucial part of formulating the environmental and energy policy. The vast literature in this regard experienced a caveat that the studies conducted on EKC, especially N_2O emissions used as a pollution indicator, have not used additional control variables, particularly land use and exports in the model in Canada. This research is one of the first few attempts that investigate EKC in the case of N_2O emissions in Canada. Canada has relatively high levels of N_2O emissions and is ranked 16th out of 17 peer economies. Per capita nitrous oxide emissions in Canada were five times the emissions of Switzerland in 2009. More importantly, N_2O is the main GHG emitted from the cropping system and constitutes half of the GHG emission from agriculture. Consequently, analyzing the role of N_2O emissions in the context of Canada is critically important.

The present study contributes to the literature on EKC in respect of N_2O emissions in several ways: (a) this is the first-ever study conducted on Canada that explores the joint nexus between N_2O emissions, economic growth, land use, and exports. Studies on N_2O emissions from agriculture are fraught since uncertainty prevails about the actual contribution of agricultural practices to N_2O in the atmosphere. To meet environmental-related targets set in the Kyoto Protocol, countries need to pay attention to N_2O; (b) we use two closely related control variables, i.e., land use and exports, which make the analysis more insightful, particularly from a policy perspective; and (c) based on the findings of this research, we have suggested ways to optimize energy mixing in Canada.

Canadian Economy

Canada, by total area, is the second-largest country, and by land area, it is the fourth largest country in the world [39]. It is the seventh-largest economy in the world that has transformed from an agriculture-based economy to an urban economy with a major share of GDP coming from the services sector. According to the 2019 index, it is the 8th freest economy in the world, with a freedom score of 77.7. It is a modernized developed economy with a high level of well-being. A high-level of well-being has been achieved based on rapid GDP growth since 2009, except for a sharp decrease in 2020 due to the COVID-19 pandemic that hit hard all around the world (see Figure 1).

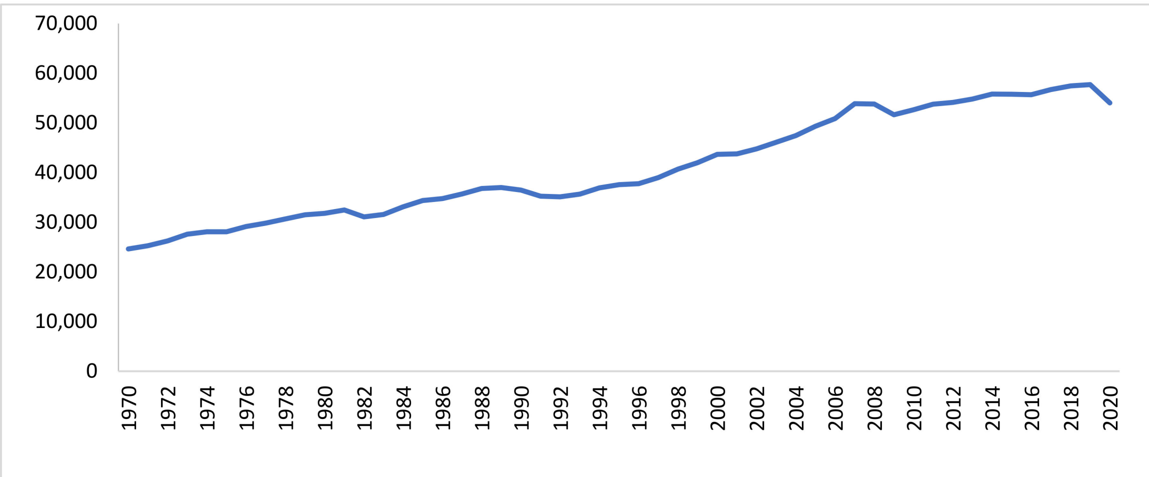

Figure 1. GDP per capita in Canada (constant at local currency units).

Economic growth brings some negative implications in addition to positive effects. Canada is no exception. GHGs emissions increased because of growth in the economy. Approximately, the agriculture sector emits 55–65% of total global N_2O emissions [16,40]. Duxbury et al. [41] stated that out of total agriculture-induced GHG emissions, N_2O is the highest contributor, with its share of 92 percent followed by methane (65%), while the share of carbon dioxide is only one-fourth of the total emissions. Though per capita total N_2O emissions fell by 34% in Canada from 1990 and 2009, its progress was ranked below 12 of the 17 peer countries (see Figure 2).

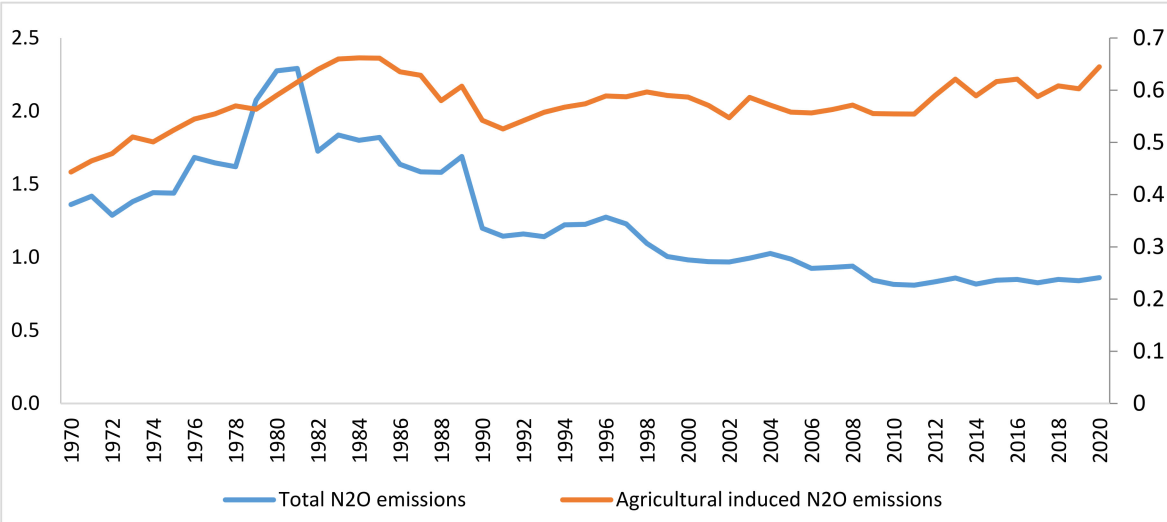

Figure 2. N_2O emissions and agriculturally induced N_2O emissions per capita (right axis) in Canada.

Despite a decrease in total N_2O emissions per capita (thousand metric ton of CO_2 equivalent), the agricultural induced N_2O emissions are showing a gradual upward trend. N_2O emissions from agriculture in Canada are higher than other gases. In 2009, share of agriculture in total GHGs emissions was roughly eight percent, of which one-third came from N_2O. To mitigate the challenges of food and energy security, emissions from agriculture are expected to increase in the future. Under an international agreement, all major GHG emitter countries including Canada recognize the importance of the agriculture sector and believe that agriculture-induced emissions can be reduced by improving the efficiency of the sector.

The use of fertilizers in agriculture is to boost production results in GHGs. Since 1961, use of nitrogen has increased ten-fold. The agriculture sector was revolutionized by nitrogen fertilizers at the beginning of the 20th century. It resulted in greater food production, but produced large amounts of N_2O emissions. However, despite its severe consequences for the environment, use of nitrogen fertilizer is rising in the world (Figure 3) which is taken from Drescher et.al [42]. The results of the calculations for the total fertilizer consumption in 2050 based on the formula of T&L [43] show that because cereal production is projected to increase, the global demand for fertilizer nutrients will also increase. According to T&L [43], global demand for fertilizer was 188 million Mt in 2015, and it is expected to reach about 223 million Mt in 2030 and 324 million Mt in 2050. Agriculture is responsible for emissions of all three GHGs: CO_2, methane (CH_4), and N_2O. How different sources from agriculture contribute to GHGs in Canada excluding CO_2 can be seen in Figure 4. It is evident that N_2O is the second-highest gas emitted from agriculture after methane.

Land use patterns and conversion of forest to arable lands have changed across the world over the last few decades in the context of achieving a high level of economic growth. By modifying land emission, changes in land-use practices influence nitrogen oxide concentration in the atmosphere [15]. Currently, agriculture and land-use change are responsible for about one-third of global emissions. Projections show no immediate slowing down of emissions from agriculture and land-use change (deforestation). Per capita agricultural land use (hectare) is on a continuous decline since 1970 (Figure 5).

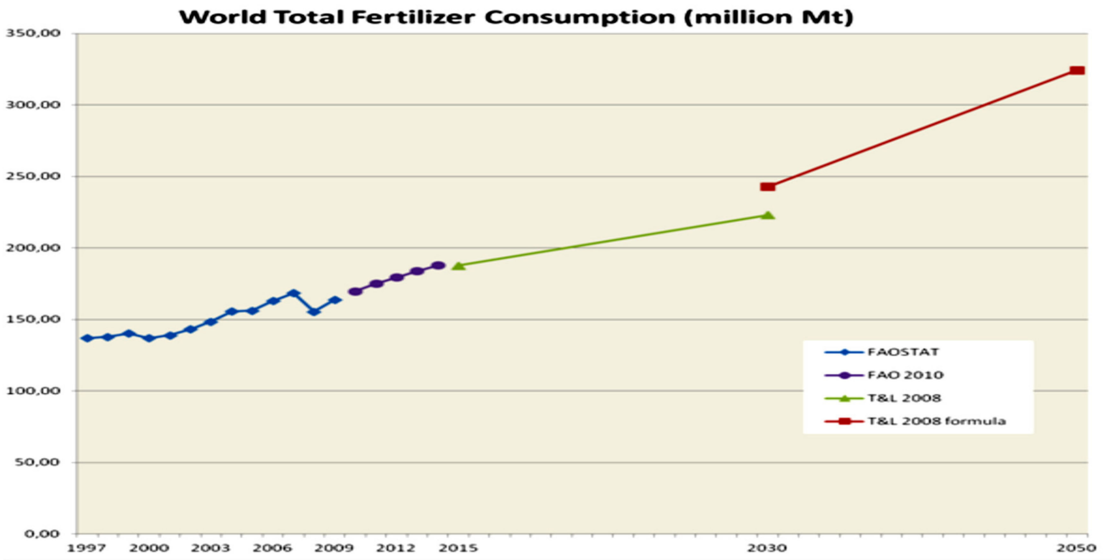

Figure 3. World total fertilizer consumption (million Mt). Data sources [42–44], calculations based on T&L [44] formula).

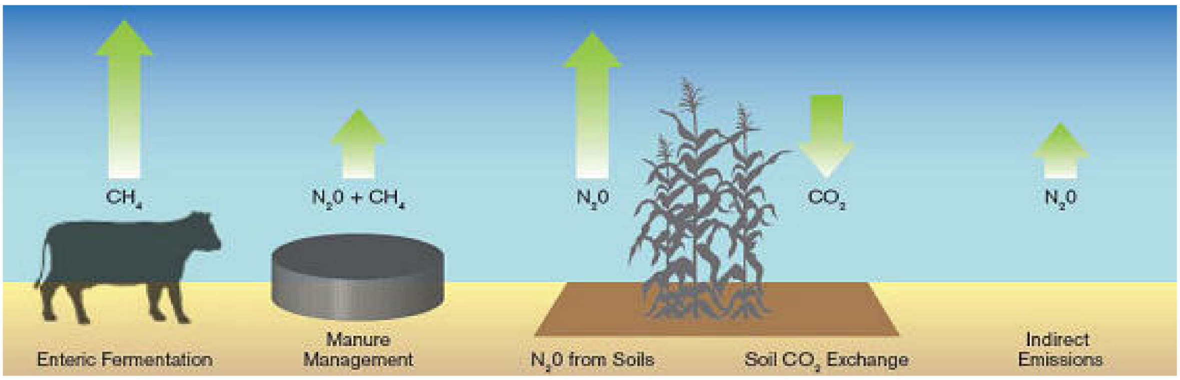

Figure 4. Relative size of agriculture induced GHGs emissions. Note: Sources of greenhouse gas emissions from Canadian agriculture excluding CO_2 emissions associated with energy use. The size of the arrow indicates the relative magnitude of the emission or amount sequestered. Available online: https://www.agr.gc.ca/eng/agriculture-and-agri-food-canada/?id=1395690825741 (accessed on 19 December 2020).

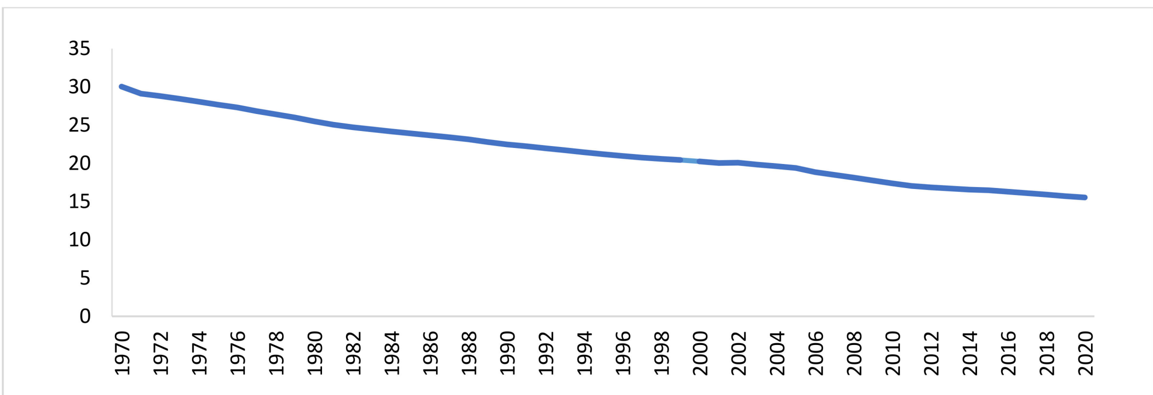

Figure 5. Agriculture land use per capita in Canada.

Exports are a key to economic growth, and Canada's exports were at a peak in 2001 and then started gradually decreasing. However, since 2010, exports have been gaining momentum, but again start decreasing since 2018 (Figure 6).

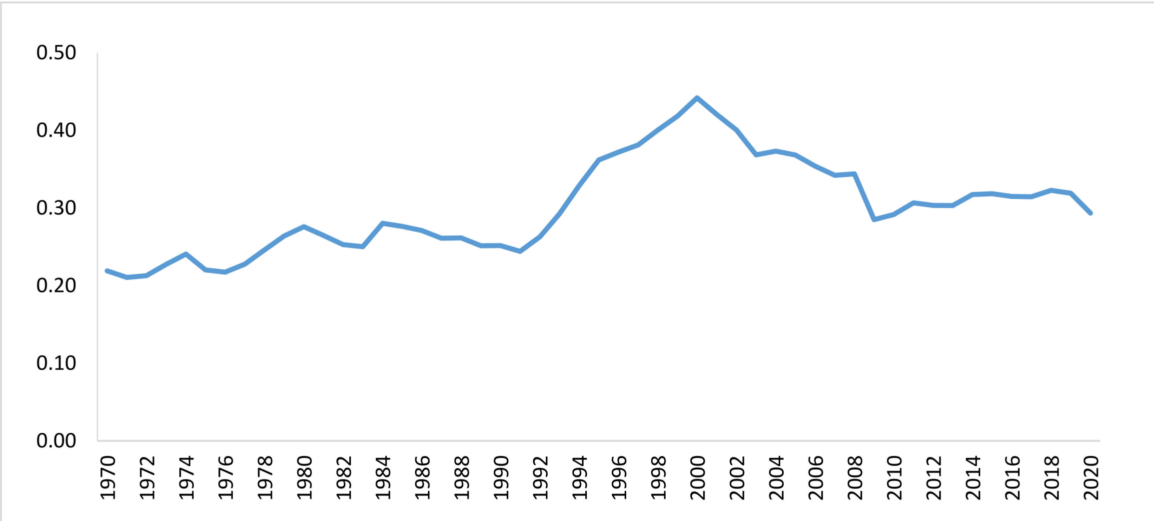

Figure 6. Exports as a percentage of GDP in Canada.

2. Literature Review

Testing the EKC has been a fascinating topic for researchers over the last three decades. The first to test this hypothesis include Grossman and Krueger [45], Shafik and Bandyopadhyay [46], and Panayotou [47]. The studies on EKC use different measures of environmental state while relating it to economic growth. In addition, this hypothesis has been explored by using various estimation methodologies and data time periods for different countries and regions (for detail, see Husnain et al. [21]). For instance, the inverted U-shaped relationship found between economic growth and different measures of pollution indicators using a random-effects model as indicated by Grossman and Krueger [45]. With the help of a set of panel regression models, Shafik and Bandyopadhyay [46] examined the link between 10 measures of pollution and income and found mixed results. While a study conducted by Panayotou [47] reported an inverted U-shaped relationship between pollution and income using cross-section data of 68 countries. Similar studies conducted on the EKC hypothesis by a group of countries and a single country can be found in Table 2.

Table 2. A summary review of studies validating/invalidating the EKC hypothesis.

Reference	Location	Time Frame	Methodology	Variables Used	Conclusions
Acaravci and Ozturk [48]	19 European countries	1960–2005	ARDL	CO_2 emissions, energy use, GDP	EKC hypothesis not confirmed
Ahmad and Long [49]	Pakistan	1971–2008	ARDL	CO_2 emissions, energy use, GDP, trade	EKC hypothesis confirmed
Shahbaz et al. [24]	Pakistan	1971–2009	Cointegration, Granger causality	CO_2 emissions, GDP, trade	EKC hypothesis confirmed
Cho et al. [50]	22 OECD countries	1971–2000	FMOLS	GHGs, GDP, Energy use	EKC hypothesis confirmed
Apergis and Ozturk [51]	14 Asian countries	1990–2011	GMM	CO_2 emissions, GDP, Land	EKC hypothesis confirmed

Table 2. *Cont.*

Reference	Location	Time Frame	Methodology	Variables Used	Conclusions
Alam et al. [52]	Brazil, China, India, Indonesia	1970–2012	ARDL	CO_2 emissions, GDP, energy consumption	Mixed findings
Shahbaz et al. [26]	Next 11 countries	1972–2013	Time varying Granger causality	CO_2 emissions, GDP, energy consumption	Mixed findings
Rafindadi [53]	Japan	1961–2012	ARDL	Energy use, CO2 emissions, GDP	EKC hypothesis confirmed
Apergis et al. [54]	48 states of USA	1960–2010	Common correlated effects	CO_2 emissions, GDP	Mixed findings
Balsalobre-Lorente et al. [55]	EU-5 countries	1985–2016	Panel least square	CO_2 emissions, GDP, trade, electricity	EKC hypothesis not confirmed
Barra and Zotti [56]	120 countries	2000–2009	GMM	CO_2 emissions, per capita GDP	EKC hypothesis confirmed
Sinha and Shahbaz [7]	India	1971–2015	ARDL	CO_2 emission, GDP, trade	EKC hypothesis confirmed
Shahbaz et al. [33]	86 countries	1970–2015	Cross-correlation	Globalization, energy use, GDP	Mixed findings
Liu et al. [57]	Chinees provinces	1996–2015	Fixed effect	CO_2 emissions, GDP, FDI, trade	EKC hypothesis confirmed
Aydin et al. [58]	26 countries of the EU	1990–2013	PSTR	Ecological footprint, GDP	Mixed findings
Shahbaz et al. [59]	Sweden	1850–2008	MARS	CO_2 emission, GDP	EKC hypothesis confirmed
Haider et al. [60]	33 countries	1980–2012	PMG	N_2O emissions, GDP, exports, land use	EKC hypothesis confirmed
Ng et al. [61]	76 countries	1971–2014	CCEMG, AMG, PMG	CO_2 emissions, GDP, energy consumption	Mixed findings
Mania [62]	98 countries	1995–2013	GMM, PMG	CO_2 emissions, GDP, export diversification	Augmented EKC hypothesis confirmed
Destek et al. [63]	G-7 countries	1800–2010	Bootstrap-rolling window	CO_2 emissions, GDP	Mixed findings
Shahbaz et al. [34]	China	1980–2018	Nonparametric Cointegration test	Energy consumption, GDP	Mixed findings
Haider et al. [64]	Pakistan	1971–2012	ARDL	Agricultural land use, N_2O emissions	N shaped ECK confirmed
Tenaw and Beyene [65]	SSA countries	1990–2015	CCE-PMG	Economic Growth, Environmental Quality	A modified EKC

While studying EKC, most of the empirical studies usually take CO_2 emissions for the environmental degradation [27–32], which is not surprising as CO_2 constitutes 82% of total GHGs emissions. Studies also focused on N_2O emissions in verifying the EKC hypothesis, but their number is very small. An empirical study conducted by Zambrano-Monserrate and Fernandez [66] confirmed the EKC hypothesis in the case of Germany using the N_2O emissions as a pollution indicator by the ARDL method. The agricultural land use and exports as the additional explanatory variables were included in the estimated model. Using data from 39 countries, Fujii and Managi [67] found an EKC relationship for CO_2 emissions and an N-shaped relationship for nitrogen oxide and methane. The unidirectional causality was detected by Menyah and Wolde-Rufael [68], running from environmental pollutants to economic growth without any feedback. Employing data from nineteen European countries for the period 1960–2005, Acaravci and Ozturk [48] reported mixed results. The unidirectional, bidirectional, and neutrality results were found for these countries. The study by Soytas et al. [69] establishes that energy consumption Granger causes income, but income does not cause Granger energy consumption. Zafeiriou et al. [70] use ARDL method to examine the relationship between economic performance and agriculturally induced carbon emissions in Hungry, the Czech Republic and Bulgaria. Their findings show the existence of the long-run EKC for the case of the Czech Republic and Bulgaria, while in the short-run, the EKC is only validated for the case of the Czech Republic. By applying conventional and GMM estimator on a single country regional panel dataset, Coderoni and Esposti [71] investigate the long-run relationship between productivity growth and agricultural greenhouse gases and found no evidence for the presence of the EKC across the different specifications.

The EKC is a standard framework to analyze the major global concern, i.e., the relationship between environment and economic growth. The EKC is based on the idea "grow first and clean up later" argument. Therefore, with the help of the EKC framework, we test the environmental-growth nexus for the case of Canada by constructing the following hypotheses.

H1: *Is economic growth associated with N_2O emissions?*

H2: *Is economic growth related to agriculture-induced N_2O emissions?*

H3: *Is there any relationship between agriculture land use and N_2O emissions and agriculture induced N_2O emissions?*

H4: *Are exports linked with N_2O emissions and agriculture induced N_2O emissions?*

3. Data and Methodology

To establish the nature of the relationship between N_2O emissions and economic growth, two separate models are estimated: the first with total N_2O emissions and the second with agriculturally induced N_2O emissions taken as a dependent variable. All data is collected from the World Development Indicators (WDI) 2022 except for total N_2O emissions and agricultural induced N_2O emissions because limited data is available for the agriculturally induced N_2O emissions in WDI. To update the data for N_2O emissions, we used the Environment and Climate Change Canada dataset for 1990–2020 to make it consistent with WDI data that is available from 1970–2012. The following two separate models are used to test the validity of the EKC, which is represented by Equations (1) and (2) as follows:

$$\text{Model-1} \;\; N_2O = f(GDP, GDP^2,\; ALU, EXP) \tag{1}$$

$$\text{Model-2} \;\; N_2OA = f(GDP, GDP^2,\; ALU, EXP) \tag{2}$$

where N_2O and N_2OA represent the total nitrous oxide emissions and agricultural induced nitrous oxide emissions, respectively, which is measured in thousands of metric tons of CO_2 per capita. While the GDP is gross domestic product at constant 2000 USD prices, which is also measured in terms of per capita and similarly GDP square term. Agricultural land use (ALU) is taken in per capita and is the share of land area that is arable, under permanent pasture and crop as defined by the WDI (2019). While the Exports (EXP) of goods and services are measured as a percent of GDP.

In the context of the present analysis, it is paramount important to include some control variables to overcome the problem of the misspecification bias. Based on the empirical literature and evidence from the recent studies, agricultural land use and exports are selected for the analysis as discussed by the study of Zambrano-Monserrate and Fernandez [66]. Conversions of land use into and out of agriculture can impact atmosphere [72] and land use associated activities form 25–45% of anthropogenic emissions [73]. Furthermore, agricultural soils lead to N_2O emissions [74]. Like agriculture land use, exports may influence N_2O emissions. According to Kearsley and Riddel [75], exports may not be associated with N_2O emissions, but can be linked with EKC in the context of a Pollution Heaven Hypothesis (PHH) such as Cole [76], which states that pollution occurs in developing countries due to lax environmental regulations. For economic growth, we used the per capita income as it was used by many previous studies [25–27]. To obtain more efficient results, we first transform the model into a natural log form as according to Shahbaz et al. [24], which also helps to induce stationarity. The econometrics models used for the estimations are expressed by Equations (3) and (4) for both models:

$$\mathrm{lnN_2O_t} = \beta_0 + \beta_1\mathrm{lnGDP_t} + \beta_2\mathrm{lnGDP^2}_t + \beta_3\mathrm{lnALU_t} + \beta_4\mathrm{lnEXP_t} + \varepsilon_t \quad (3)$$

$$\mathrm{lnN_2OA_t} = \beta_0 + \beta_1\mathrm{lnGDP_t} + \beta_2\mathrm{lnGDP^2}_t + \beta_3\mathrm{lnALU_t} + \beta_4\mathrm{lnEXP_t} + \varepsilon_t \quad (4)$$

where β_1, β_2, β_3, and β_4 are the estimated coefficients for all the independent variables that correspond to the elasticity estimates as the functional form is logarithmic for both models.

Estimation Strategy

Time series variables are prone to having characteristics of non-stationarity which, if they exist, may lead to spurious results. Therefore, it is mandatory to check the order of the integration, apply the unit root test before making further analysis. To test the order of the integration, a series of unit root tests are available in the literature such as Augmented Dicky Fuller (ADF), Philips Perron (PP), etc., which are called first-generation tests and are unreliable when there is a structural break in the data. Then it is better to apply any second-generation unit root tests such as those developed by Zivot and Andrews [77], which is applicable in the presence of any structural break in the time series data. For the present study, to test the stationarity properties of the time series variables, we applied a structural break unit test developed by Zivot and Andrews [77], which is more reliable than the first-generation tests.

After identifying the order of the integration, we apply the ARDL bounds testing approach to cointegration as follows the work by Pesaran et al. [78]. The ARDL method is the most popular for testing the long-run relationship between variables [78] because it addresses the problems faced by other methods such as Engle and Granger [79], and Johansen and Juselius [80]. The ARDL bounds test is applied to the parameters validated by a unit root test with structural breaks. This approach has many advantages [81]. First, the ARDL method is appropriate when the selected variables are I (1) or I (0); in contrast, the Johansen cointegration procedure demands that all variables be of the same order. Second, it is an effective estimator in the presence of endogeneity, and it is also valid and more efficient in case of small samples. Third, the ARDL method is flexible in terms of the lag selection of variables. Finally, the ARDL method evaluates the long-run relationship using a single reduced-form equation, in contrast to other cointegration methods that require a system of equations. However, a disadvantage of the ARDL approach is that it cannot be applied in the case of I (2) variables. The bounds test, an F-test, is applied on Equations (3) and (4) to test cointegration under the null hypotheses given below:

$$\mathrm{H0:}\ \beta 1 = \beta 2 = \beta 3 = \beta 4 = 0 \qquad \mathrm{Ha:\ At\ least\ one\ of\ the}\ \beta i \neq 0.$$

We used the critical values developed by Narayan [82] as the critical values generated by Pesaran et al. [78] are downward biased due to the small sample. After establishing the cointegration relationship, the modified Equations (3) and (4) are estimated to capture the long run and short-run dynamics by the Error Correction Model (ECM) as follows:

$$\begin{aligned}\Delta \ln \mathrm{N_2O_t} = \beta_0 + \beta_1\mathrm{lnGDP_t} + \beta_2\mathrm{lnGDP^2}_t + \beta_3\mathrm{lnALU_t} + \beta_4\mathrm{lnEXP_t} \\ + \sum_{i=1}^{p}\gamma_{1i}\Delta\mathrm{lnN_2O_{t-i}} + \sum_{j=0}^{q}\gamma_{2j}\Delta\mathrm{lnGDP_{t-1}} \\ + \sum_{k=0}^{m}\gamma_{3k}\Delta lnGDP^2{}_{t-k} + \sum_{r=0}^{z}\gamma_{5r}\Delta\mathrm{lnALU_{t-r}} \\ + \sum_{w=0}^{s}\gamma_{6w}\Delta\mathrm{lnExp_{t-w}} + \theta\mathrm{ECT_{t-1}} + \varepsilon_t\end{aligned}$$

Similarly, for Equation (4):

$$\begin{aligned}\Delta \ln N_2OA_t = \ & \beta_0 + \beta_1 \ln GDP_t + \beta_2 \ln GDP^2{}_t + \beta_3 \ln ALU_t + \beta_4 \ln EXP_t \\ & + \sum_{i=1}^{p} \gamma_{1i} \Delta \ln N_2OA_{t-i} + \sum_{j=0}^{q} \gamma_{2j} \Delta \ln GDP_{t-1} \\ & + \sum_{k=0}^{m} \gamma_{3k} \Delta \ln GDP^2{}_{t-k} + \sum_{r=0}^{z} \gamma_{5r} \Delta \ln ALU_{t-r} \\ & + \sum_{w=0}^{s} \gamma_{6w} \Delta \ln Exp_{t-w} + \theta ECT_{t-1} + \varepsilon_t\end{aligned}$$

where β_i, and γ_i are captured the long-run and short-run elasticities coefficients, respectively. While the Error Correction Term (ECT) shows the speed of adjustment, which indicates how quickly the variables (in the given model) converge to their equilibrium in case of one-time shock in the model, its coefficient should be negative and statistically significant with a magnitude less than or equal to one.

After estimating the long-run and short-run coefficients, it is important to find out the tipping points that tell us whether the Canadian economy is on the decreasing or increasing portion of EKC in both models. For this purpose, we take the first derivative with respect to the GDP of estimated models and set it equal to zero, to get the threshold level of income after which the N_2O emissions will start to decrease or increase depending on the relationship found as U-shaped or inverted U-shaped.

$$\frac{\partial \ln N_2O_t}{\partial \ln GDP_t} = \beta_1 \left(\frac{1}{GDP_t}\right) + 2\beta_2 \left[\ln GDP_t\right] \left(\frac{1}{GDP_t}\right) = 0$$

$$\left[\ln GDP_t\right] = \frac{-\beta_1}{2\beta_2} \ \text{ and } \ GDP_t = \exp\left(\frac{-\beta_1}{2\beta_2}\right)$$

After finding the threshold level of income per capita, we applied different diagnostic tests to verify the estimated models and coefficients are efficient, and stable, such as for stability, we apply the CUSUM and CUSUMSQ tests as developed by Brown et al. [83]. The next step is to check the direction of the variables, which means causation between the variables. For this purpose, we used the Granger [84] causality tests under the Vector Error Correction (VEC) representation, which is as follows:

$$\begin{bmatrix}\Delta \ln N_2O_t \\ \Delta \ln GDP_t \\ \Delta \ln GDP^2{}_t \\ \Delta \ln ALU_t \\ \Delta \ln Exp_t\end{bmatrix} = \begin{bmatrix}\mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5\end{bmatrix} + \begin{bmatrix}\gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55}\end{bmatrix} \times \begin{bmatrix}\Delta \ln N_2O_{t-1} \\ \Delta \ln GDP_{t-1} \\ \Delta \ln GDP^2{}_{t-1} \\ \Delta \ln ALU_{t-1} \\ \Delta \ln Exp_{t-1}\end{bmatrix} + \begin{bmatrix}\pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \\ \pi_5\end{bmatrix} ECT_{t-1} + \begin{bmatrix}e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t}\end{bmatrix}$$

while the VECM model for Equation (4) is as follows:

$$\begin{bmatrix}\Delta \ln N_2OA_t \\ \Delta \ln GDP_t \\ \Delta \ln GDP^2{}_t \\ \Delta \ln ALU_t \\ \Delta \ln Exp_t\end{bmatrix} = \begin{bmatrix}\mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5\end{bmatrix} + \begin{bmatrix}\gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55}\end{bmatrix} \times \begin{bmatrix}\Delta \ln N_2OA_{t-1} \\ \Delta \ln GDP_{t-1} \\ \Delta \ln GDP^2{}_{t-1} \\ \Delta \ln ALU_{t-1} \\ \Delta \ln Exp_{t-1}\end{bmatrix} + \begin{bmatrix}\pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \\ \pi_5\end{bmatrix} ECT_{t-1} + \begin{bmatrix}e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t}\end{bmatrix}$$

There are two types of Granger causality relationships (long-run as well as short-run) that exist under the VEC representation. The long-run causality is determined by the significance of the ECT coefficient using the *t*-test, while the short-run causality is determined by the Wald test [25].

4. Results and Discussion

To present data in a meaningful and summarized way is to provide descriptive statistics. The detailed outlay of descriptive statistics is presented in Table 3. The minimum (0.81) and maximum (2.29) values of N_2O emissions per capita with a standard deviation of (0.40) show relatively high variations in total N_2O emissions per capita when compared with agricultural induced N_2O emissions per capita (min: 0.44; max: 0.66; SD: 0.05). Huge variations in GDP per capita are evident from a large value of (SD: 10401), meaning a rapid increase in the per capita GDP of Canada over the years. The behavior of the agricultural land use variable is also volatile, with a standard deviation of (4.10) showing different rates of deforestation in the country. Exports remained stable and sustainable with a small standard deviation of (0.06).

Table 3. Descriptive statistics.

	N_2O	N_2OA	GDP	ALU	Exports
Mean	1.26	0.58	40,964	21.70	0.30
Maximum	2.29	0.66	57,685	30.04	0.44
Minimum	0.81	0.44	24,628	15.54	0.21
Std. Dev	0.40	0.05	10,401	4.10	0.06

To detect structural breaks in the data, we employed the Zivot–Andrew structural break unit root test, and the results are reported in Table 4. Zivot–Andrew has based on the null hypothesis that all series are non-stationary in their levels except the agricultural land use. Results show that structural break exists in N_2OA emissions in the year 2011, while ALU suffered a structural break in 2005.

Table 4. Zivot–Andrew structural break unit root test.

Variables	At Level		At Ist Difference	
	T-Stat	Time Break	T-Stat	Time Break
Ln $N2O_t$	−3.631	1989	−8.535 *	1982
Ln $N2OA_t$	−3.424	2011	−8.229 *	1983
Ln GDP_t	−3.754	1996	−5.020 *	2019
Ln GDP_t^2	−3.701	1996	−5.608 *	2019
Ln ALU_t	−5.557 *	2005	−6.079 *	2006
Ln $Exports_t$	−3.311	1991	−5.620 *	2000
1% critical value: −4.95				
5% critical value: −4.44				
10% critical value: −4.19				

Note: * significant at 1% level of significance.

Table 5 shows the signs of parameters used in different models that determine the nature of the relationship between the variables as described by Dinda [85]. The first model, the simplest one, reveals that no specific trend exists between the variables. The second and third models are linear monotonically increasing and decreasing, respectively. Models four and five include quadratic terms and describe the nonlinear relationship. The relationship in model four is U-shaped, as the quadratic term has a positive sign while the intercept is negative. On the other hand, model five depicts an inverted U-shaped relationship as the quadratic term becomes negative while the intercept assumes a positive value. To find more than one bump or giggle cubic term is included in models six and seven. Both models show an N-type relationship, but inverse to each other. In model six, the intercept and quadratic terms are positive while the quadratic term has a value less than zero, meaning an there is an N-type relationship between the variables. The intercept and cubic terms become negative while the quadratic term is negative in model seven, ensuring that the nature of the relationship is inverted N-shaped.

Table 5. Possible shapes of the curve regarding nexus between income and environment.

Model	Value of βi	Forms of the Curve
Model 1	β1 = β2 = β3 = 0	No relationship
Model 2 (linear)	β1 > 0, β2 = β3 = 0	Linear monotonically increasing
Model 3 (linear)	β1 < 0, β2 = β3 = 0	Linear monotonically decreasing
Model 4 (quadratic)	β1 < 0, β2 > 0, β3 = 0	U-shaped relationship
Model 5 (quadratic)	β1> 0, β2 < 0, β3 = 0	Inverted U-shaped relationship
Model 6 (cubic)	β1 > 0, β2 < 0, β3 > 0	N-type relationship
Model 7 (cubic)	β1 < 0, β2 > 0, β3 < 0	Inverted N-type relationship

Table 6 contains the results of the Wald tests (bound-testing approach). The value of the F-statistic in both models is significant at a 5 percent level of significance and greater than the upper limits (4.9725 > 3.97 & 4.0311 > 3.97). In the model where N_2O emissions and agriculture induced N_2O emissions are dependent variables, the computed value of F-statistic surpasses the upper bound of 5%, therefore, the null hypothesis of no cointegration among the variables is rejected and we conclude the non-existence of a long-run relationship between N_2O emissions and their determinants. Likewise, agriculture-induced N_2O emissions have a similar relationship with economic growth, exports, and agricultural land use.

Table 6. Bounds testing to cointegration ARDL.

Statistics	Total N_2O	Agricultural N_2O
Optimal Lag Structure	(3,1,4,0,4)	(2,4,2,2,4)
F-Statistics	4.9725 **	4.0311 **
Lower bounds	3.05	3.05
Upper bounds	3.97	3.97
AIC	−2.281404	−4.0358
Log-Likelihood	71.60830	109.8423

Critical Values: ** significant at 5%. Based on the Akaike information criterion. Critical values bounds are from Narayan [82]. Case IV-restricted intercept and no trend.

After establishing a long-run relationship, we estimate the conditional ARDL long-run model by using Equation (2) to obtain the long-run dynamics [86]. The estimated long-run and short-run elasticities are reported in Tables 7 and 8, respectively. In both models, the quadratic term, i.e., GDP^2, is negative and significant while GDP has a positive sign verifying the existence of EKC. Agriculture land use appears with a positive sign in the total N_2O emissions model, but negative and insignificant when agricultural N_2O emissions is the dependent variable. It shows a positive relationship between agricultural land use and pollution indicators (N_2O). However, exports are negatively and significantly associated with environmental degradation measures used in the analysis, which has striking results that lead to a conclusion that Canadian environmental laws are more stringent in case of the Canadian economy. A 1% increase in exports leads to a 0.46% and 0.13% decrease in total N_2O and agriculture-induced N_2O emissions, respectively.

Table 7. Long-run analysis.

	Dependent_Ln(N_2O)		Dependent_Ln(N_2OA)	
Variable	Coefficient	t-Statistic	Coefficient	t-Statistic
ln GDP_t	41.6239 *	4.3390	18.2060 *	4.1628
ln $GDP^2{}_t$	−1.9563 *	−4.3643	−0.8615 *	−4.2155
ln ALU_t	1.3234 **	2.2048	−0.3205	−1.1710
ln $Exports_t$	−0.4594 *	−2.6653	−0.1284 ***	1.7055
Constant	−225.7087 *	−4.3491	−95.8651 *	−4.0517
Diagnostic Tests				
R-squared	0.7905	-	R-squared	0.6199
Adjusted R-squared	0.7723	-	Adjusted R-squared	0.4361
F-statistic	43.39616 [0.000]	-	F-statistic	3.3713 [0.002]
Jarque-Bera Normality Test	3.62838 [0.1562]	-	Jarque-Bera Normality Test	0.5306 [0.7606]
Serial Correlation LM	1.53997 [0.2326]	-	Serial Correlation LM	2.0744 [0.1485]
Heteroscedasticity (ARCH)	8.14293 [0.0865]	-	Heteroscedasticity (ARCH)	8.1317 [0.0869]
Ramsey RESET Test	2.16149 [0.1028]	-	Ramsey RESET Test	2.0824 [0.1109]
CUSUM & CUSUMSQ	Stable	-	CUSUM & CUSUMSQ	Stable

Note: *, ** and *** significant at 1%, 5% and 10% level of significance, respectively. Values in brackets are *p*-values.

Table 8. Short-run analysis (Dependent_Ln (N_2O)).

Variable	Coefficient	t-Statistic	Prob.
ΔlnN_2O_{t-1}	−0.3925 **	−3.0245	0.0052
ΔlnN_2O_{t-2}	−0.2361 ***	−1.9445	0.0616
$\Delta lnGDP_t$	89.6556 *	5.0532	0.0000
$\Delta lnGDP^2{}_t$	−4.1423 *	−4.9719	0.0000
$\Delta lnGDP^2{}_{t-1}$	−0.1045 *	−3.3782	0.0021
$\Delta lnGDP^2{}_{t-2}$	−0.1177 *	−3.0456	0.0049
$\Delta lnGDP^2{}_{t-3}$	−0.1054 **	−2.7253	0.0108
$\Delta lnEXP_t$	0.1351	0.5188	0.6078
$\Delta lnEXP_{t-1}$	0.8672 *	3.2621	0.0028
$\Delta lnEXP_{t-2}$	1.1608 *	4.0107	0.0004
$\Delta lnEXP_{t-3}$	0.9634 *	3.3468	0.0023
Constant	−36.9108 *	−5.9194	0.0000
ECT_{t-1}	−0.2066 *	−6.0140	0.0000
Diagnosis Tests			
R-squared	0.6484	B.G Serial Correlation LM	1.4964 [0.2413]
Adjusted R-squared	0.5242	Heteroscedasticity (ARCH)	0.0755 [0.7834]
F-statistic	5.2241	Ramsey RESET Test	0.05295 [0.8196]
Prob.(F-statistic)	0.0001	CUSUM & CUSUMSQ	Stable

Note: *, ** and *** significant at 1%, 5% and 10% level of significance, respectively. Values in brackets are *p*-values.

Different diagnostics tests were applied to have reliable results in both models. In the case of the Jarque-Bera test null hypothesis of data, normality cannot be rejected, indicating normality in the data. Sufficient evidence is available to reject the null hypothesis that "there is no serial correlation of any order". The heteroscedasticity test reveals an absence of heteroscedasticity as we are unable to reject the null hypothesis of "there is no heteroscedasticity". Ramsey Reset test verifies the correct specification of both models as the *p*-value is insignificant. CUSUM and CUSUMSQ tests conclude that both the models are stable. A short-run relationship may or may not confirm long run results. Table 8 reports short-run elasticities for model 1. All coefficients in the short run are statistically significant except exports. Coefficients signs of difference GDP and difference GDP^2 imply the existence of EKC in the short run. Though the coefficient of difference exports has an expected positive sign and significace, which conclude that more stringent environmental laws do not exist in the case of the Canadian economy in the short-run.

The lagged time difference coefficients portray signs that are not justifiable at least in the short run. The estimated coefficients of error correction term (ECTt-1) assume the desired negative sign, meaning the restoration of equilibrium in the model at the speed of 21% per year. The diagnostic tests state that the model is stable and has no problem with serial correlation or heteroscedasticity.

In model 2, all the estimated coefficients appear significant except for the export. The lagged difference coefficient of the dependent variable is negative and significant as expected, simply meaning a strong relationship, in the short-run, between the variables (see Table 9). However, the error correction term has a negative sign and is significant at a 1% level showing the convergence nature of the model. The model restores its disturbed equilibrium at 29% per year. Again, diagnostic tests reveal the appropriateness and significance of the model. Figure 7 shows plots of Cumulative Sum and Cumulative Sum of Squares of Recursive Residuals for both models.

Table 9. Short-run analysis (Dependent_Ln (N_2OA)).

Variable	Coefficient	t-Statistic	Prob.
ΔlnN_2OA_{t-1}	−0.3682 *	−2.8986	0.0074
$\Delta lnGDP_t$	15.4765 ***	1.8874	0.0699
$\Delta lnGDP_{t-1}$	−16.6311 ***	−2.0314	0.0522
$\Delta lnGDP_{t-2}$	−0.6177 ***	−1.8909	0.0694
$\Delta lnGDP_{t-3}$	−1.4771 *	−4.1760	0.0003
$\Delta lnGDP^2{}_t$	−0.7315 ***	−1.9003	0.0681
$\Delta lnGDP^2{}_{t-1}$	0.7812 ***	2.0177	0.0537
$\Delta lnALU_t$	−2.7046 **	−2.3074	0.0289
$\Delta lnALU_{t-1}$	2.0469 ***	1.7219	0.0965
$\Delta lnEXP_t$	0.0165	0.1356	0.8931
$\Delta lnEXP_{t-1}$	−0.3293 **	−2.5144	0.0182
$\Delta lnEXP_{t-2}$	0.2334 **	2.2939	0.0298
$\Delta lnEXP_{t-3}$	0.2281 **	2.2641	0.0318
Constant	72.7276 *	5.3533	0.0000
ECT_{t-1}	−0.2909 *	−5.3540	0.0000
	Diagnosis Tests		
R-squared	0.6199	B.G Serial Correlation LM	0.8985 [0.4186]
Adjusted R-squared	0.4537	Heteroscedasticity (ARCH)	0.2912 [0.9780]
F-statistic	3.7229	Ramsey Reset Test	0.1443 [0.7067]
Prob. (F-statistic)	0.0010	CUSUM & CUSUMSQ	Stable

Note: *, ** and *** significant at 1%, 5% and 10% level of significance, respectively. Values in brackets are *p*-values.

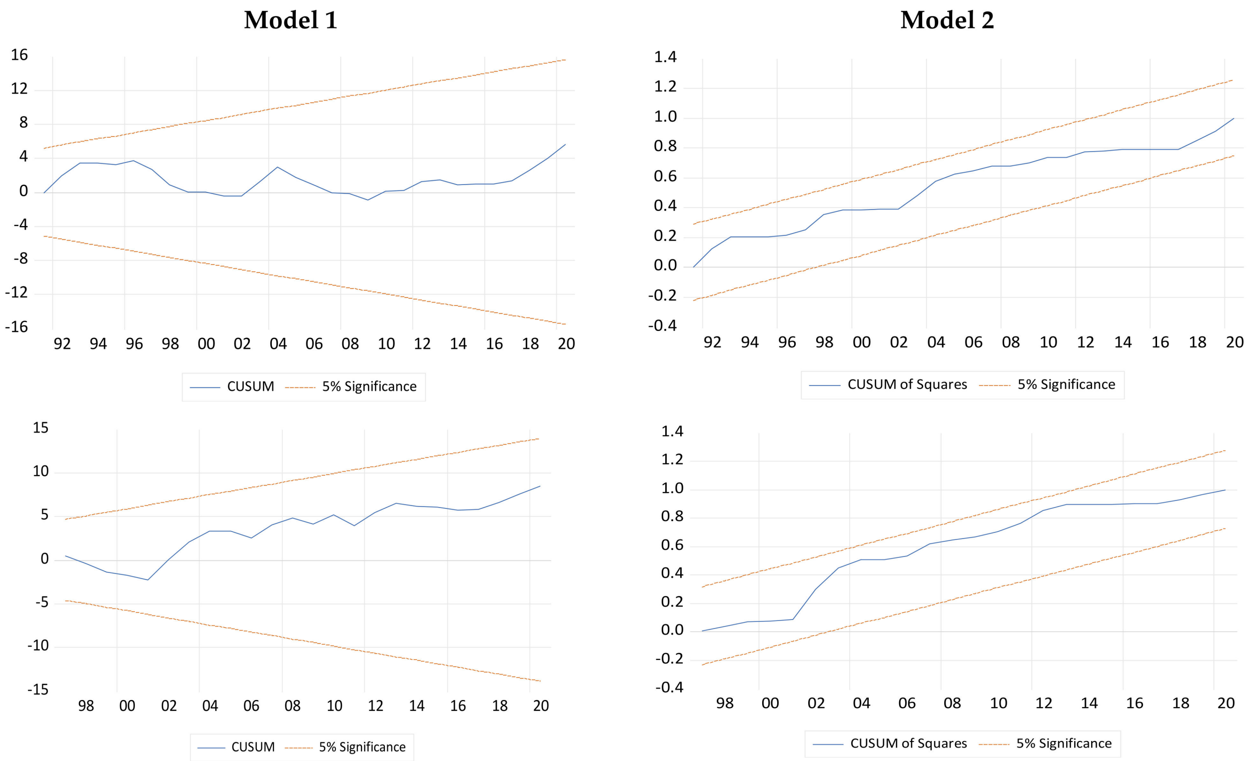

Figure 7. Plots of CUSUM and CUSUMSQ.

The estimated tipping point of GDP per capita for total N_2O emissions is $41718 while for agricultural induced N_2O emissions it is $38825. Canada is on the decreasing portion of EKC in both cases of total N_2O emissions and agriculturally induced N_2O emissions. However, agriculture-induced N_2O emissions have just started declining, while total N_2O emissions are on the decline for many years. The variables may cause each other in the short-run as well as in the long run. Granger causality test is applied on both models to see the direction of the relationship among the variables and the results of the Granger Causality test for both models can be found in Tables 10 and 11.

Table 10. Granger causality analysis for total N_2O emissions.

Dependent Variable	**Short Run Causality**					**Long-Run Causality**
	F-Statistics (*p*-Value)					**[t-Statistics]**
	$\Delta\ln N_2O_t$	**$\Delta\ln GDP_t$**	**$\Delta\ln GDP^2{}_t$**	**$\Delta\ln ALU_t$**	**$\Delta\ln EXP_t$**	**ECT_{t-1}**
$\Delta\ln N_2O_t$	-	1.87651	1.84776	0.66747	0.30977	−0.028883 **
	-	(0.1652)	(0.1696)	(0.5181)	(0.7352)	[−1.94405]
$\Delta\ln GDP_t$	2.69480 ***	-	0.20397	6.98450 *	0.16101	0.000842
	(0.0787)	-	(0.8163)	(0.0023)	(0.8518)	[0.20205]
$\Delta\ln GDP^2{}_t$	2.66522 ***	0.17947	-	6.93087 *	0.16101	0.012336
	(0.0808)	(0.8363)	-	(0.0024)	(0.8452)	[0.13893]
$\Delta\ln ALU_t$	3.40478 **	0.29224	0.28922	-	0.35320	0.000227
	(0.0422)	(0.7480)	(0.7503)	-	(0.7044)	[0.36268]
$\Delta\ln EXP_t$	3.02655 ***	1.736606	1.77408	0.15122	-	0.015678 *
	(0.0587)	(0.1880)	(0.1816)	(0.8601	-	[2.32136]

Note: *, **, *** significant at 1%, 5% and 10% level of significance.

Table 11. Granger causality analysis for agriculturally induced N_2O emissions.

Dependent Variable	Short Run Causality					Long-Run Causality
	F-Statistics (*p*-Value)					[t-Statistics]
	$\Delta \ln N_2O_t$	$\Delta \ln GDP_t$	$\Delta \ln GDP^2{}_t$	$\Delta \ln ALU_t$	$\Delta \ln EXP_t$	ECT_{t-1}
$\Delta \ln N_2O_t$	-	0.55943	0.58337	0.27156	1.14854	−0.29243 *
	-	(0.8156)	(0.7971)	(0.9762)	(0.3710)	[−2.34904]
$\Delta \ln GDP_t$	4.02855 *	-	0.36609	1.92368 ***	2.70420 **	−0.03048
	(0.0033)	-	(0.9397)	(0.0992)	(0.0262)	[−0.35291]
$\Delta \ln GDP^2{}_t$	3.99364 *	0.35952	-	2.07215 ***	2.76590 **	−0.05977
	(0.0035)	(0.9429)	-	(0.0766)	(0.0236)	[−0.32419]
$\Delta \ln ALU_t$	0.63563	0.46215	0.48693	-	1.15736	−0.001589
	(0.7553)	(0.8849)	(0.8684)	-	(0.3658)	[−1.17678]
$\Delta \ln EXP_t$	1.68875	1.58433	1.58501	0.85301	-	−0.048628 *
	(0.1492)	(0.1787)	(0.1785)	(0.5776)	-	[−3.40867]

Note: *, **, *** significant at 1%, 5% and 10% level of significance.

The results of Granger causality movements are summarized in Table 12. In the short run, the agricultural land use Granger causes total N_2O emissions and this relationship is unidirectional. Similarly, the total N_2O emissions Granger causes GDP, $GDP^{2,}$ and exports, while GDP and GDP^2 Granger cause ALU; however, there is no other short-run causality exists between the variables. Unidirectional causality is detected from GDP, GDP^2, and agricultural land use to total N_2O emissions while bidirectional causality exists between total N_2O emissions and exports in the long run. For the agriculturally induced N_2O emissions, in the short-run, only agricultural land used and exports Granger cause GDP and its square term, which is a unidirectional relationship while GDP and GDP^2 Granger cause ALU; however, no other short-run causality exists between the variables. Unidirectional causality is found from GDP, GDP^2, and agriculture land use to agriculturally induced N_2O emissions in the long-run while bidirectional causality exists between agriculturally induced N_2O emissions and exports.

Table 12. Direction of Granger Causality Test for both specifications.

Total N_2O Emissions		Agricultural Induced N_2O Emissions	
Short-Run	**Long-Run**	**Short-Run**	**Long-Run**
$N_2O \rightarrow$ GDP, GDP^2, ALU, Exp **GDP, $GDP^2 \rightarrow$ ALU**	GDP $\rightarrow N_2O$, Exp $GDP^2 \rightarrow N_2O$, Exp EXP $\rightarrow N_2O$ ALU $\rightarrow N_2O$, Exp $N_2O \rightarrow$ Exp	$N_2O \rightarrow$ GDP, GDP^2 GDP, $GDP^2 \rightarrow$ ALU, Exp	GDP $\rightarrow N_2O$, Exp $GDP^2 \rightarrow N_2O$, Exp EXP $\rightarrow N_2O$ ALU $\rightarrow N_2O$, Exp $N_2O \rightarrow$ Exp

Studying GHGs is important, as they impact human life, climate, and the environment [87]. In addition, the study of N_2O is much more important due to its 300 times greater warming potential than CO_2 [9]. This research examines the long-run and the causal nexus of economic growth, exports, and agricultural land use with total N_2O emissions and agricultural induced N_2O emissions for Canada using data from 1970 to 2020 by applying the ARDL bounds testing technique. The empirical findings show a significant impact of independent variables (economic growth, exports) on agriculturally induced N_2O emissions, while agricultural land use shows an insignificant result, whereas economic growth, agricultural land use and exports significantly impact total N_2O emissions. The nature of the relationship is nonlinear, which confirms the EKC hypothesis, as many previous studies reported a non-linear relationship between various indicators of economic growth and different measures of pollution indicators [21]. Jiang et al. [88] employ panel data from thirty provinces of China over the period of 2002–2015 and taking CO_2 as a pollution indicator confirmed EKC for all provinces. Grossman and Krueger [45] empirically found the non-linear relationship between sulfur dioxide and fine smoke. Shafik [89] found that the EKC was valid for 149 countries only for SO_2. In contrast, studies are available that deny the existence of the EKC hypothesis. Using N_2O, CH_4, and CO_2 as proxies of pollution indicators, Tamang [90] empirically estimated the EKC hypothesis for eleven high and eight low-income countries and found no support in favor of the EKC hypothesis, while Haider et al. [60], using data from 15 developed and 18 developing countries, and Haider et al. [64], using N_2O emissions as a pollution indicator, confirmed the EKC hypothesis in the respective countries studied. Using panel data for OECD countries, Georgiev and Mihaylov [91] examined the EKC hypothesis for two global air pollutants and found that the inverse U-shaped association between income and pollution is non-existent for all gases. Using the GMM approach, Abdouli et al. [92] validate EKC for the BRICS countries. Other than inverted U-shaped EKC (Jalil and Mahmud [29], Pao and Tsai [93]), some other shapes have also been found: no shape [48], N-shaped [94], and inverted N-shaped [38,95].

The inverse U-shaped association between economic growth and pollution guarantees the happening of a turning point, which means a shift toward environmental improvement from environmental deterioration [96]. The turning point of per capita income for total N_2O emissions is \$41,718, whereas it is \$38,825 for agriculturally induced N_2O emission. This conveys that EKC exists in the context of total N_2O emissions and agricultural induced N_2O emissions. The close threshold level of per capita income in the case of total and agricultural induced N_2O emissions conveys that the relative size of N_2O emissions from the agriculture sector is moderate in Canada, while the total N_2O emissions have decreased significantly over the years. It is evident that Canada has just passed the turning point of EKC when analyzed in the context of agriculture-induced emissions. This estimated tipping point is not significantly different from the findings of Zambrano-Monserrate and Fernandez [66], who estimate the threshold level of income at \$27,880 in the case of Germany. Canada is a developed economy and over the years has shifted from an agriculture-based economy to a service-oriented country. The heterogeneity in threshold level of income in the contest of EKC can be attributed to the choice of pollution indicators, the difference in estimation methods, and the period of study. Moosa [97] estimated the tipping points of GDP from \$20,250 to \$50,000 depending on the model specification and source of CO_2 emissions for Australia. Countries differ in terms of the speed to reach the turning point. Industrialized countries reach a turning point 1.96 times slower than the deindustrializing countries. Technological progress, among others, is one of the key factors that increase the speed to reach the turning point [96]. According to Sarkodie and Strezov [98], the average threshold level of income is \$8910, while low-income and middle-income economies are found below the turning point while high-income countries are found above. Yaduma et al. [99] also found a tipping point of income correspondence to the level of pollution emissions.

Land-use policies are important in the context of deforestation, change in land use, and arable and permanent cropland areas. These policies are closely linked with sustainable management of forests, environmental degradation, and biodiversity loss. Sustainable development and sustainable agriculture are highly prone to a degree of land degradation, as it causes poverty in the countries with an agrarian economy. We find that agricultural land use significantly impacts total N_2O emissions, whereas there is insignificant impact in case of agriculture-induced N_2O emissions. This result is in line with the previous empirical literature. For instance, Zambrano-Monserrate and Fernandez [66] also found a direct positive effect of agricultural land use on N_2O emissions in Germany, and similar results were found in the case of Pakistan by Haider et al. [64]. To increase production intensive use of fertilizer is common that is linked to nitrate contamination of water supply and the excessive use of pesticides in agriculture poses environmental challenges [100]. An inverted U-shaped relationship is found by Barbier and Burgess [101] between economic development and agricultural land use, which varies across countries. Likewise, Chiu [102] reported an inverted U-shaped between economic growth and deforestation using data from 52 countries.

Canadian exports negatively affect total N_2O emissions as well as agricultural induced N_2O emissions, and this result is in line with the study conducted by Zambrano-Monserrate and Fernandez [66] for Germany. According to Solarin et al. [103], lax environmental regulations encourage developed nations to establish pollution-intensive industries in poor countries. This shift in trade patterns damages the environment in developing countries [104]. However, mixed results can be found in the literature on the nexus between exports and N_2O emissions. Exports negatively affect N_2O emissions in Germany [66] while a report by the OECD [105] finds no evidence of a decrease in exports in countries where environmental laws are very strict. This difference of opinion may be attributed to the production processes involved in exports in different countries. The countries where efficient and environmentally friendly production procedures are employed may not report a positive effect of exports on N_2O emissions while countries with less efficient and polluted production systems may have a positive effect of exports on N_2O emissions especially in case of developing countries [64].

5. Conclusions and Policy Implications

The objective of this research was to examine the existence of EKC in Canada by using N_2O emission as a proxy for pollution and including exports and agricultural land use as control variables in the model. The ARDL approach was applied to infer conclusions on the Canadian data spanning from 1970–2020. Two models were estimated. N_2O emissions and agricultural induced N_2O emissions were taken as dependent variables in the first and second model, respectively. The outcomes of the study show a non-linear long-run association between economic growth and both indicators (total N_2O emissions and agricultural induced N_2O emissions) of environmental state. This provides sufficient support for the presence of EKC in Canada. Further, results show that Canada is on the declining segment of EKC in term of total N_2O emissions meaning economic growth in Canada is improving its environmental state instead of destructing it. The turning points are $41,718 and $38,825 per capita income for total N_2O emissions and agricultural induced N_2O emissions respectively. The behavior of control variables is according to the prior expectations. For instance, agricultural land use does have a positive effect on total N_2O emissions, while a negative and insignificant effect on agriculturally induced N_2O emissions. Canadian exports are negatively associated with total N_2O emissions as well as agriculturally induced N_2O emissions.

Based on the findings, we report some of the policy implications. First, the export production processes seem efficient and non-polluting, which concludes that even though Canada does have some more restrictive environmental laws for exports, it requires more stringent laws to curb N_2O emissions-oriented exports to keep the ecosystem in balance and intends to meet its 2030 target of reducing emissions by up to 45% compared to 2005 levels as it progresses towards Canada’s 2050 net-zero ambition. Second, careful selection of nitrogen fertilizers in agriculture crops could reduce N_2O emissions significantly. Instead of short-run policies based on economic returns from agricultural production, long-run policies need to be perused to control environmental damage. To encourage the farmer to adopt some mitigative measures it must be ensured they do not face losses in their revenue. Integrated modeling of agriculture activities could be a viable solution where environmental and economic indicators are estimated simultaneously. Currently, a model called CRAM exists for agricultural planning that can be further extended for developing mitigating policies to reduce GHGs emissions. The adoption of precision farming can optimize the yield by suggesting ways to fine-tune location and machine-led fertilizer spread. Finally, the land being a limited natural resource has encouraged production systems that emit high-level GHGs, particularly N_2O emissions [106]. Land-use policies in Canada need to align in such a way that land use does not cause N_2O emissions.

To conclude this study, we propose a few future research dimensions. First, considering the vastness of Canada and huge variations in biodiversity and climate in its various parts, it is more interesting to study the EKC hypothesis at the state/province level. In this way, more accurate and appropriate policy formulation is ensured. Second climatic variables, like temperature and precipitation, may be included in the estimation model, as GHGs emissions ultimately lead to a climatic variation that in turn affects economic activities. Finally, a comparative study is required at least among the top largest and smallest economies of the world for the adaptability and universality of the inferences drawn in this research.

Author Contributions: A.H. and F.S., conceptual framework, data analysis, and investigation, methodology, software, validation, visualization, writing—original draft preparation; M.I.u.H., analyzed and interpreted the results, writing, literature review, and review and editing the final draft; W.R., supervision, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the World Bank Dataset, World Development Indicators https://databank.worldbank.org/reports.aspx?source=2&series=SH.UHC.NOP1.ZG# (accessed on 1 July 2022).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Knox, S.H.; Sturtevant, C.; Matthes, J.H.; Koteen, L.; Verfaillie, J.; Baldocchi, D. Agricultural peatland restoration: Effects of land-use change on greenhouse gas (CO_2 and CH_4) fluxes in the Sacramento-San Joaquin Delta. *Glob. Change Biol.* **2014**, *21*, 750–765. [CrossRef] [PubMed]
2. Kaivo-oja, J.; Vehmas, J.; Luukkanen, J. Trend analysis of energy and climate policy environment: Comparative electricity production and consumption benchmark analyses of China, Euro area, European Union, and United States. Renew. *Sustain. Energy Rev.* **2016**, *60*, 464–474. [CrossRef]
3. IPCC. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Pachauri, R.K., Meyer, L.A., Eds.; Core Writing Team; IPCC: Geneva, Switzerland, 2014; p. 151.
4. Cook, J.; Oreskes, N.; Doran, P.; Anderegg, W.; Verheggen, B.; Maibach, E.; Carlton, J.; Lewandowsky, S.; Skuce, A.; Green, S.; et al. Consensus on consensus: A synthesis of consensus estimates on human-caused global warming. *Environ. Res. Lett.* **2016**, *11*, 048002. [CrossRef]
5. Chen, Z.; Ma, W.; Li, S.; Wu, J.; Wei, K.; Yu, Z.; Ding, W. Influence of carbon material on the production process of different electric arc furnaces. *J. Clean. Prod.* **2018**, *174*, 17–25. [CrossRef]
6. Ochuodho, T.O.; Lantz, V.A. Economic impacts of climate change in the forest sector: A comparison of single-region and multiregional CGE modeling frameworks. *Can. J. For. Res.* **2014**, *44*, 449. [CrossRef]
7. Sinha, A.; Shahbaz, M. Estimation of environmental Kuznets curve for CO_2 emission: Role of renewable energy generation in India. *Renew. Energy* **2018**, *119*, 703–711. [CrossRef]
8. Del Grosso, S.J.; Parton, W.J. Climate change increases soil nitrous oxide emissions. *New Phytol.* **2012**, *196*, 327–328. [CrossRef]
9. Solomon, S.D.; Qin, D.; Manning, M.; Averyt, K.; Marquis, M. (Eds.) *Climate Change 2007-the Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC*; Cambridge University Press: Cambridge, UK, 2007; Volume 4.
10. Kinzig, A.P.; Socolow, R.H. Human impacts on the nitrogen cycle. *Phys. Today* **1994**, *47*, 24–31. [CrossRef]
11. Ravishankara, A.R.; Daniel, J.S.; Portmann, R.W. Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. *Science* **2009**, *326*, 123–125. [CrossRef]
12. Sinha, A.; Bhattacharya, J. Environmental Kuznets curve estimation for NO_2 emission: A case of Indian cities. *Ecol. Indic.* **2016**, *67*, 1–11. [CrossRef]
13. Husnain, M.I.; Subramanian, A.; Haider, A. Robustness of Geography as an Instrument to Assess Impact of Climate Change on Agriculture. *Int. J. Clim. Change Strateg. Manag.* **2018**, *10*, 654–669. [CrossRef]
14. Smith, K.A.; McTaggart, I.P.; Dobbie, K.E.; Conen, F. Emissions of N_2O from Scottish soils, as a function of fertilizer N. *Nutr. Cycl. Agroecosystems* **1998**, *52*, 123–130. [CrossRef]
15. Kroeze, C. Nitrous oxide and global warming. *Sci. Total Environ.* **1994**, *143*, 193–209. [CrossRef]
16. Mosier, A.; Kroeze, C.; Nevison, C.; Oenema, O.; Seitzinger, S.; van Cleemput, O. Closing the Global N_2O Budget: Nitrous Oxide Emissions Through the Agricultural Nitrogen Cycle. *Nutr. Cycl. Agroecosystems* **1998**, *52*, 225–248. [CrossRef]
17. Thomson, A.J.; Giannopoulos, G.; Pretty, J.; Baggs, E.M.; Richardson, D.J. Biological sources and sinks of nitrous oxide and strategies to mitigate emissions. *Philos. Trans. R. Soc. B* **2012**, *367*, 1157–1168. [CrossRef] [PubMed]

18. Miah, M.D.; Masum, M.F.H.; Koike, M. Global observation of EKC hypothesis for CO_2, SOx and NOx emission: A policy understanding for climate change mitigation in Bangladesh. *Energy Policy* **2010**, *38*, 4643–4651. [CrossRef]
19. Isermann, K. Agriculture's share in the emission of trace gases affecting the climate and some cause-oriented proposals for reducing this share. *Environ. Pollut.* **1994**, *83*, 95–111. [CrossRef]
20. Eichner, M.J. Nitrous oxide emissions from fertilized soils: Summary of available data. *J. Environ. Qual.* **1990**, *19*, 272–280. [CrossRef]
21. Husnain, M.I.; Haider, A.; Khan, M.A. Does the environmental Kuznets curve reliably explain a developmental issue? *Environ. Sci. Pollut. Res.* **2021**, *28*, 11469–11485. [CrossRef]
22. Kijima, M.; Nishide, K.; Ohyama, A. Economic models for the environmental Kuznets curve: A survey. *J. Econ. Dyn. Control.* **2010**, *34*, 1187–1201. [CrossRef]
23. Carson, R.T. The environmental Kuznets curve: Seeking empirical regularity and theoretical structure. *Rev. Environ. Econ. Policy* **2009**, *4*, 3–23. [CrossRef]
24. Shahbaz, M.; Lean, H.H.; Shabbir, M.S. Environmental Kuznets curve hypothesis in Pakistan: Cointegration and Granger causality. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2947–2953. [CrossRef]
25. Shahbaz, M.; Khraief, N.; Uddin, G.S.; Ozturk, I. Environmental Kuznets curve in an open economy: A bounds testing and causality analysis for Tunisia. *Renew. Sustain. Energy Rev.* **2014**, *34*, 325–336. [CrossRef]
26. Shahbaz, M.; Solarin, S.A.; Ozturk, I. Environmental Kuznets curve hypothesis and the role of globalization in selected African countries. *Ecol. Indic.* **2016**, *67*, 623–636. [CrossRef]
27. Ahmad, A.; Zhao, Y.; Shahbaz, M.; Bano, S.; Zhang, Z.; Wang, S.; Liu, Y. Carbon emissions, energy consumption and economic growth: An aggregate and disaggregate analysis of the Indian economy. *Energy Policy* **2016**, *96*, 131–143. [CrossRef]
28. Xu, B.; Lin, B. Reducing carbon dioxide emissions in China's manufacturing industry: A dynamic vector autoregression approach. *J. Clean. Prod.* **2016**, *131*, 594–606. [CrossRef]
29. Jalil, A.; Mahmud, S.F. Environment Kuznets curve for CO_2 emissions: A cointegration analysis for China. *Energy Policy* **2009**, *37*, 5167–5172. [CrossRef]
30. Ozatac, N.; Gokmenoglu, K.K.; Taspinar, N. Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: The case of Turkey. *Environ. Sci. Pollut. Res.* **2017**, *24*, 16690–16701. [CrossRef]
31. Haseeb, A.; Xia, E.; Baloch, M.A.; Abbas, K. Financial development, globalization, and CO_2 emission in the presence of EKC: Evidence from BRICS countries. *Environ. Sci. Pollut. Res.* **2018**, *25*, 31283–31296. [CrossRef]
32. Shahbaz, M.; Sinha, A. Environmental Kuznets curve for CO_2 emissions: A literature survey. *J. Econ. Stud.* **2019**, *46*, 106–168. [CrossRef]
33. Shahbaz, M.; Haouas, I.; Van Hoang, T.H. Economic growth and environmental degradation in Vietnam: Is the environmental Kuznets curve a complete picture? *Emerg. Mark. Rev.* **2019**, *38*, 197–218. [CrossRef]
34. Shahbaz, M.; Khraief, N.; Mahalik, M.K. Investigating the environmental Kuznets's curve for Sweden: Evidence from multivariate adaptive regression splines (MARS). *Empir. Econ.* **2020**, *59*, 1883–1902. [CrossRef]
35. Adom, P.K.; Bekoe, W.; Amuakwa-Mensah, F.; Mensah, J.T.; Botchway, E. Carbon dioxide emissions, economic growth, industrial structure, and technical efficiency: Empirical evidence from Ghana, Senegal, and Morocco on the causal dynamics. *Energy* **2012**, *47*, 314–325. [CrossRef]
36. Khalil, M.A.K.; Rasmussen, R.A. The global sources of nitrous oxide. *J. Geophys. Res. Atmos.* **1992**, *97*, 14651–14660. [CrossRef]
37. Mundaca, L.; Markandya, A. Assessing regional progress towards a green energy economy. *Appl. Energy* **2016**, *179*, 1372–1394. [CrossRef]
38. Sinha, A.; Shahbaz, M.; Balsalobre, D. Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. *J. Clean. Prod.* **2017**, *168*, 1217–1229. [CrossRef]
39. The Work of a Nation. the Center of Intelligence, Central Intelligence Agency (CIA). Available online: http://www.cia.gov/library/publications/download/download-2017/index.html (accessed on 15 December 2020).
40. Olivier, J.G.J.; Bouwman, A.F.; Van Der Hoek, K.W.; Berdowski, J.J.M. Global Air Emission Inventories for Anthropogenic Sources of NOx, NH_3 and N_2O in 1990. *Environ. Pollut.* **1998**, *102*, 135–148. [CrossRef]
41. Duxbury, J.M.; Harper, L.A.; Mosier, A.R. *Contributions of Agroecosystems to Global Climate Change, in Agricultural Ecosystem Effects on Trace Gases and Global Climate Change*; ASA Special Publication Number 55: Madison, WI, USA, 1993; pp. 1–18.
42. Drescher, A.; Glaser, R.; Clemens, R.; Karl-Rainer, N. Demand for key nutrients (NPK) in the year 2050. Draft report 2011 by University of Freiburg, Department of Geography. Available online: https://esdac.jrc.ec.europa.eu/projects/NPK/Documents/Freiburg_Demand_for_key_nutrients_in_2050_Drescher.pdf/ (accessed on 20 June 2022).
43. Tenkorang, F.; Lowenberg-Deboer, J. *Forecasting Long-Term Global Fertilizer Demand*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2008.
44. FAO. *Current World Fertilizer Trends and Outlook to 2014*; FAO: Rome, Italy, 2010.
45. Grossman, G.M.; Krueger, A.B. *Environmental Impacts of a North American Free Trade Agreement*; Natl. Bur. Econ. Res. Working Paper No. 3914; NBER: Cambridge, MA, USA, 1991.
46. Shafik, N.; Bandyopadhyay, S. *Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence*; World Bank Publications: Washington, DC, USA, 1992.

47. Panayotou, T. *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development*; ILO Working Papers No. 238; International Labor Office: Geneva, Switzerland, 1993.
48. Acaravci, A.; Ozturk, I. On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy* **2010**, *35*, 5412–5420. [CrossRef]
49. Ahmed, K.; Long, W. Environmental Kuznets curve and Pakistan: An empirical analysis. *Procedia Econ. Financ.* **2012**, *1*, 4–13. [CrossRef]
50. Cho, C.H.; Chu, Y.P.; Yang, H.Y. An environment Kuznets curve for GHG emissions: A panel cointegration analysis. *Energy Sources Part B Econ. Plan. Policy* **2014**, *9*, 120–129. [CrossRef]
51. Apergis, N. Environmental Kuznets curves: New evidence on both panel and country-level CO_2 emissions. *Energy Econ.* **2016**, *54*, 263–271. [CrossRef]
52. Alam, M.M.; Murad, M.W.; Noman, A.H.M.; Ozturk, I. Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. *Ecol. Indic.* **2016**, *70*, 466–479. [CrossRef]
53. Rafindadi, A.A. Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: Empirical evidence from Japan. *Energy Policy* **2016**, *94*, 274–284. [CrossRef]
54. Apergis, N.; Christou, C.; Gupta, R. Are there environmental Kuznets curves for US state-level CO_2 emissions? *Renew. Sustain. Energy* **2017**, *69*, 551–558. [CrossRef]
55. Balsalobre-Lorente, D.; Shahbaz, M.; Roubaud, D.; Farhani, S. How economic growth, renewable electricity and natural resources contribute to CO_2 emissions? *Energy Policy* **2018**, *113*, 356–367. [CrossRef]
56. Barra, C.; Zotti, R. Investigating the non-linearity between national income and environmental pollution: International evidence of Kuznets curve. *Environ. Econ. Policy Stud.* **2018**, *20*, 179–210. [CrossRef]
57. Liu, J.; Qu, J.; Zhao, K. Is China's development conforms to the environmental Kuznets curve hypothesis and the pollution haven hypothesis? *J. Clean. Prod.* **2019**, *234*, 787–796. [CrossRef]
58. Aydin, C.; Esen, Ö.; Aydin, R. Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach. *Ecol. Indic.* **2019**, *98*, 543–555. [CrossRef]
59. Shahbaz, M.; Shafiullah, M.; Khalid, U.; Song, M. A nonparametric analysis of energy environmental Kuznets Curve in Chinese Provinces. *Energy Econ.* **2020**, *89*, 104814. [CrossRef]
60. Haider, A.; Bashir, A.; Husnain, M.I. Impact of agricultural land use and economic growth on nitrous oxide emissions: Evidence from developed and developing countries. *Sci. Total Environ.* **2020**, *741*, 140421. [CrossRef]
61. Ng, C.F.; Choong, C.K.; Lau, L.S. Environmental Kuznets curve hypothesis: Asymmetry analysis and robust estimation under crosssection dependence. *Environ. Sci. Pollut. Res.* **2020**, *27*, 1–14. [CrossRef] [PubMed]
62. Mania, E. Export diversification and CO_2 emissions: An augmented environmental Kuznets curve. *J. Int. Dev.* **2020**, *32*, 168–185. [CrossRef]
63. Destek, M.A.; Shahbaz, M.; Okumus, I.; Hammoudeh, S.; Sinha, A. The relationship between economic growth and carbon emissions in G-7 countries: Evidence from time-varying parameters with a long history. *Environ. Sci. Pollut. Res.* **2020**, *27*, 29100–29117. [CrossRef] [PubMed]
64. Haider, A.; ul Husnain, M.I.; Rankaduwa, W.; Shaheen, F. Nexus between Nitrous Oxide Emissions and Agricultural Land Use in Agrarian Economy: An ARDL Bounds Testing Approach. *Sustainability* **2021**, *13*, 2808. [CrossRef]
65. Tenaw, D.; Beyene, A.D. Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110897. [CrossRef]
66. Zambrano-Monserrate, M.A.; Fernandez, M.A. An Environmental Kuznets Curve for N_2O emissions in Germany: An ARDL approach, Natural Resources Forum. *Wiley Online Libr.* **2017**, *41*, 119–127.
67. Fujii, H.; Managi, S. Economic development and multiple air pollutant emissions from the industrial sector. *Environ. Sci. Pollut. Res. Int.* **2016**, *23*, 2802–2812. [CrossRef]
68. Menyah, K.; Wolde-Rufael, Y. CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy* **2010**, *38*, 2911–2915. [CrossRef]
69. Soytas, U.; Sari, R.; Ewing, B.T. Energy consumption, income, and carbon emissions in the United States. *Ecol. Econ.* **2007**, *62*, 482–489. [CrossRef]
70. Zafeiriou, E.; Sofios, S.; Partalidou, X. Environmental Kuznets curve for EU agriculture: Empirical evidence from new entrant EU countries. *Environ. Sci. Pollut. Res.* **2017**, *24*, 15510–15520. [CrossRef]
71. Coderoni, S.; Esposti, R. Is there a long-term relationship between agricultural GHG emissions and productivity growth? A dynamic panel data approach. *Environ. Resour. Econ.* **2014**, *58*, 273–302. [CrossRef]
72. Abraha, M.; Gelfand, I.; Hamilton, S.K.; Chen, J.; Robertson, G.P. Legacy effects of land use on soil nitrous oxide emissions in annual crop and perennial grassland ecosystems. *Ecol. Appl.* **2018**, *28*, 1362–1369. [CrossRef] [PubMed]
73. Smith, K.A. The impact of agriculture and other land uses on emissions of methane and nitrous and nitric oxides. *Environ. Sci.* **2005**, *2*, 101–108. [CrossRef]
74. Wang, C.; Amon, B.; Schulz, K.; Mehdi, B. Factors that influence nitrous oxide emissions from agricultural soils as well as their representation in simulation models: A review. *Agronomy* **2021**, *11*, 770. [CrossRef]

75. Kearsley, A.; Riddel, M. A further inquiry into the Pollution Haven Hypothesis and the Environmental Kuznets Curve. *Ecol. Econ.* **2010**, *69*, 905–919. [CrossRef]
76. Cole, M.A. Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecol. Econ.* **2004**, *48*, 71–81. [CrossRef]
77. Zivot, E.; Andrews, D.W. Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *J. Bus. Econ. Stat.* **1992**, *10*, 251–270.
78. Pesaran, M.H.; Shin, Y.; Smithc, R.J. Bounds testing approaches to the analysis of level relationships. *J. Appl. Econ.* **2001**, *16*, 289–326. [CrossRef]
79. Engle, R.F.; Granger, C.W.J. Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* **1987**, *55*, 251. [CrossRef]
80. Johansen, S.; Juselius, K. Maximum likelihood estimation and inference on cointegration with applications to the demand for money. *Oxf. Bull. Econ. Stat.* **2009**, *52*, 169–210. [CrossRef]
81. Pesaran, M.; Shin, Y. *An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis. iç. Econometrics and Economic Theory in the Twentieth Century: The Ragnar Frisch Centennial Symposium*; Strøm, S., Ed.; Erişim Tarihi: 11.08. 2010; Cambridge University Press: Cambridge, UK, 1999; Available online: http://www.econ.cam.ac (accessed on 23 December 2020).
82. Narayan, P.K. The saving and investment nexus for China: Evidence from cointegration tests. *Appl. Econ.* **2005**, *37*, 1979–1990. [CrossRef]
83. Brown, R.L.; Durbin, J.; Evans, J.M. Techniques for Testing the Constancy of Regression Relationships. *J. R. Stat. Soc. Ser. B* **1975**, *37*, 149–163.
84. Granger, C.W.J. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica* **1969**, *37*, 424. [CrossRef]
85. Dinda, S. Environmental Kuznets Curve Hypothesis: A Survey. *Ecol. Econ.* **2004**, *49*, 431–455. [CrossRef]
86. Bouznit, M.; Pablo-Romero, M. CO_2 emissions and economic growth in Algeria. *Energy Policy* **2016**, *96*, 93–104. [CrossRef]
87. Abbas, M.; Dalia, S.; Fausto, C.; Nanthakumar, L.; Masoumeh, K. Carbon dioxide (CO_2) emissions and economic growth: A systematic review of two decades of research from 1995 to 2017. *Sci. Total Environ.* **2019**, *649*, 31–49.
88. Jiang, L.; Zhou, H.F.; Bai, L.; Zhou, P. Does foreign direct investment drive environmental degradation in China? An empirical study based on air quality index from a spatial perspective. *J. Clean. Prod.* **2018**, *176*, 864–872. [CrossRef]
89. Shafik, N. Economic development and environmental quality: An econometric analysis. *Oxf. Econ. Pap.* **1994**, *46*, 757–773. [CrossRef]
90. Tamang, P. Reexamining the environmental Kuznets curve: Evidence from time series. *Financ. Quant. Anal.* **2013**, *1*, 30–42. [CrossRef]
91. Georgiev, E.; Mihaylov, E. Economic growth and the environment: Reassessing the environmental Kuznets curve for air pollution emissions in OECD countries. *Lett. Spat. Resour. Sci.* **2015**, *8*, 29–47. [CrossRef]
92. Abdouli, M.; Kamoun, O.; Hamdi, B. The impact of economic growth, population density, and FDI inflows on CO_2 emissions in BRICTS countries: Does the Kuznets curve exist? *Empir. Econ.* **2018**, *54*, 1717–1742. [CrossRef]
93. Pao, H.T.; Tsai, C.M. Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): Evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy* **2011**, *36*, 685–693. [CrossRef]
94. Zhou, Y.; Fu, J.; Kong, Y.; Wu, R. How Foreign Direct Investment influences carbon emissions, based on the empirical analysis of Chinese urban data. *Sustainability* **2018**, *10*, 2163. [CrossRef]
95. Stern, D.I.; Common, M.S. Is there an environmental Kuznets curve for sulfur? *J. Environ. Econ. Manag.* **2001**, *41*, 162–178. [CrossRef]
96. Du, X.; Xie, Z. Occurrence of turning point on environmental Kuznets curve in the process of (de)industrialization. *Struct. Change Econ. Dyn.* **2020**, *53*, 359–369. [CrossRef]
97. Moosa, A.I. The econometrics of the environmental Kuznets curve: An illustration using Australian CO_2 emissions. *Appl. Econ.* **2017**, *49*, 4927–4945. [CrossRef]
98. Sarkodie, S.A.; Strezov, V. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. *Sci. Total Environ.* **2019**, *646*, 862–871. [CrossRef]
99. Yaduma, N.; Kortelainen, M.; Wossink, A. The environmental Kuznets curve at different levels of economic development: A counterfactual Quantile regression analysis for CO_2 emissions. *J. Environ. Econ. Policy* **2015**, *4*, 278–303. [CrossRef]
100. Asantewaa, O.P.; Asumadu-Sarkodie, S. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Eng.* **2016**, *3*, 1. [CrossRef]
101. Barbier, E.B.; Burgess, J.C. The economics of tropical deforestation. *J. Econ. Surv.* **2001**, *15*, 413–433. [CrossRef]
102. Chiu, Y.B. Deforestation and the Environmental Kuznets Curve in Developing Countries: A Panel Smooth Transition Regression Approach. *Can. J. Agric. Econ.* **2012**, *60*, 177–194. [CrossRef]
103. Solarin, A.S.; Al-Mulali, U.; Ozturk, I. Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renew. Sustain. Energy Rev.* **2017**, *80*, 1578–1587. [CrossRef]
104. Sun, J.; Mooney, H.; Wu, W.; Tang, H.; Tong, Y.; Xu, Z.; Huang, B.; Cheng, Y.; Yang, X.; Wei, D. Importing food damages domestic environment: Evidence from global soybean trade. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 5415–5419. [CrossRef] [PubMed]

105. OECD. Tougher Environmental Laws Do Not Hurt Export Competitiveness—OECD Study. 2016. Available online: https://www.oecd.org/newsroom/tougher-environmental-laws-do-not-hurt-export-competitiveness.htm (accessed on 15 June 2021).
106. Henseler, M.; Dechow, R. Simulation of regional nitrous oxide emissions from German agricultural mineral soils: A linkage between an agro-economic model and an empirical emission model. *Agric. Syst.* **2014**, *124*, 70–82. [CrossRef]