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Does Clean Energy Reduce Environmental Pollution under the Environmental Kuznets Curve Hypothesis in Sri Lanka?

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Abstract: This study explores the nexus among clean energy, economic growth, urbanization, trade openness, and carbon dioxide (CO_2) emissions nexus in an emerging economy, Sri Lanka. An autoregressive distributed lag (ARDL) econometric technique and different diagnostic tests are used to investigate the linkages. The pairwise Graner causality approach is applied to investigate the causality direction. The estimated results have confirmed that clean energy and urbanization reduce carbon emissions, whereas trade openness induces carbon emissions in the long run in Sri Lanka. The findings revealed the non-existence of the environmental Kuznets curve (EKC) hypothesis in Sri Lanka. In contrast, the pollution haven hypothesis (PHH) exists between trade openness and carbon dioxide emissions in Sri Lanka. Regarding causal relationships, there is bi-directional causality between clean energy and urbanization. This study reports a unidirectional causality from clean energy to CO_2 emissions, economic development to carbon emissions, urbanization and trade and CO_2 emissions to urbanization and trade. Based on the above findings, this study recommends some policy recommendations.

Keywords: clean energy; economic growth; urbanization; trade openness; CO_2 emission; environmental Kuznets curve; pollution haven hypothesis; emerging economies

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1. Introduction

People worldwide experience severe and frequent extreme weather conditions, such as heatwaves, floods, fires, and drought due to climate change. The recent report by the International Panel on Climate Change (IPCC) indicates that greenhouse emissions (GHEs) induced by 1.10 °C since before industrialization are set to reach 1.50 °C by 2020 arising from unsustainable energy use, manufacturing, and other factors within countries and between individuals [1]. Climate change harms humanity, and each country should take appropriate action to mitigate human-induced GHE. Many countries have converted unsustainable energy to alternative green energy sources to address this issue.

The existing literature examines the nexus between renewable energy use and economic growth; however, no consensus has yet been reached [2]. Dependence on non-renewable energy consumption, such as fossil fuel dependency, boosts economic growth and induces environmental problems in many South Asian countries [3]. On the other hand, renewable or clean energy consumption produces less or zero GHE, and governments need to warrant appropriate economic development. Clean energy supports sustainable development and helps environmental sustainability as it depends on non-carbohydrate energy sources, which do not generate GHE during production [4].

Previous studies on the nexus between CO_2 emissions, energy use, economic growth, urbanization, and trade openness found different findings due to varying control variables, data periods, econometric estimations, and the social-economic conditions of the country of study [5]. Therefore, individual countries reflecting on the association between clean energy and CO_2 emissions might provide different outcomes. For various reasons, this study selected Sri Lanka as an emerging country to explore the impact of clean energy, economic development, urbanization, and trade openness on carbon emissions. First, Sri Lanka is experiencing an energy shortage and mostly depends on fossil fuel energy which emits significant carbon emissions [6]. Sri Lanka concentrates on discontinuing the use of non-renewable energy by 2050 and is entirely dependent on 100% green energy sources to meet Sri Lankan energy needs by 2050 [7]. Second, to our knowledge, this is the first study investigating the clean energy–carbon emission nexus in Sri Lanka. These research findings might help policymakers in setting a sustainable energy plan to use green energy sources to mitigate environmental pollution.

This research uses data from 1971 to 2014 to see the impact of clean energy, economic development, urbanization, and trade openness on carbon emissions under the EKC hypothesis in an emerging market setting in Sri Lanka. This study adopts different time series econometric approaches: Augmented Dickey–Fuller test, Phillips–Perron test, autoregressive distribution lag bound test, and pairwise Granger causality test, with additional diagnostic tests adopted to find the results. This study explores the relationship between CO_2 emissions, clean energy, economic development, urbanization, and trade openness in Sri Lanka. Second, the study aims to see the direction of causality between CO_2 emissions, clean energy, economic development, urbanization, and trade openness in Sri Lanka. Finally, this study tests the validity of the environmental Kuznets curve (EKC) hypothesis and pollution haven hypothesis (PHH) in Sri Lanka.

The remaining study is structured as follows: Section 2 provides a brief literature survey on carbon emissions, clean energy, economic development, urbanization, and trade openness. The data and methodology are explained in Section 3. Section 4 reports empirical results and their discussion. Finally, a conclusion, policy recommendations, and limitations of the study are provided in Section 5.

2. Literature Review

Previous studies on the relationship between carbon emissions and economic growth in Sri Lanka have not considered clean energy and provided mixed results of the EKC hypothesis. Alabi et al. [8] examined the connection between CO_2 emissions, economic growth, the square of economic growth, energy use, tourism, urbanization, trade openness, and financial development in Sri Lanka. First, they found that the EKC hypothesis is invalid for Sri Lanka. Second, energy consumption and tourism increase environmental pollution, while urbanization reduces environmental degradation in Sri Lanka. Gasimli et al. [9] studied the nexus between energy use, trade, urbanization, and CO_2 emissions using the ARDL approach. They found that energy use and trade increase environmental degradation, but urbanization reduces pollution in Sri Lanka. Naradda Gamage et al. [10] examined the nexus between CO_2 emissions, economic growth, economic growth squares, energy use, and tourism using dynamic ordinary least squares (DOLS) data from 1974 to 2013. They found that energy use and tourism contribute to environmental pollution in Sri Lanka. However, they did not find validity in the EKC hypothesis in Sri Lanka.

Rahman and Alam [5] explored the connection between CO_2 emissions, clean energy, population density, urbanization, economic growth, and trade openness in Bangladesh using data from 1973 to 2014. Researchers employ the ARDL bound testing approach to investigate the long-run association and the Toda–Yamamoto Granger causality test to see the causal directions. They found that clean energy reduces environmental pollution, but population density, urbanization, and economic growth are stimulating environmental pollution in Bangladesh. Sun et al. [11] explored the association between economic growth squares, solar energy technology, and CO_2 emissions using the ARDL. They found that solar energy technology contributes a positive effect in reducing environmental pollution in China. They found validity in the EKC hypothesis in China.

Under the EKC framework, Jun et al. [12] investigated the association between CO_2 emission globalization, non-renewable energy use, and economic growth for selected South Asian countries using data from 1985 to 2018. First, they found that the EKC hypothesis was valid for South Asian economies. Second, globalization and non-renewable energy contribute to environmental damage in South Asia. Moreover, their findings indicate that the existence of the EKC framework in Sri Lanka suggests that when economic growth surges, environmental pollution also upsurges in the early stages of development, but after the threshold point, environmental pollution starts to decline with the rise in economic growth. There is a contradiction among the researchers' findings of the presence of the EKC hypothesis in Sri Lanka.

Ahmad et al. [13] examine the nexus between energy use, economic development, and carbon emissions in India using the ARDL model from 1971 to 2014. This study reports that the existence of the EKC framework is validated in the Indian economy. This research finds a positive association between energy use and carbon emissions. Using the environmental Kuznets curve (EKC) hypothesis, Sulaiman et al. [14] analyze the effect of electricity generated by consuming renewable energy sources on the environment and trade openness from 1980 to 2009, applying the ARDL approach in Malaysia. This study confirms the presence of the EKC hypothesis in Malaysia. In addition, they found that trade openness harms carbon emissions in the long run. Rahman and Kashem [15] investigate the relationship between carbon emissions, energy consumption, and industrial growth in Bangladesh from 1972 to 2011 using the ARDL bound testing methodology. The results indicate that industrial production and energy use have a significant positive effect on the carbon emissions in Bangladesh, but they did not investigate the EKC framework validity.

Uddin et al. [16] investigated the long-run causality relationship between energy use, economic growth, carbon emissions, and trade openness from 1971 to 2006 in Sri Lanka. The result revealed an unidirectional causality running from economic development to CO_2 emissions and energy use. Using time series data from 1960 to 2009 in Japan, Hossain [17] studied the dynamic casual association between CO_2 emissions, energy use, economic development, foreign trade, and urbanization. This research reports unidirectional causalities from energy use and trade openness to CO_2 emissions, trade openness to energy use, CO_2 emissions to economic development, and economic development to trade openness.

Shahbaz et al. [18] examined the relationship between economic growth, electricity consumption, urbanization, and environmental degradation in the United Arab Emirates (UAE) using the quarter frequency data from 1975 to 2011 and the ARDL bound testing model. This study found an inverted U-shaped association between economic development and carbon emissions. Electricity use decreases carbon emissions. In addition, this study reports a positive association between urbanization and carbon emissions. Using the EKC hypothesis by undertaking a comparative analysis between India and China over the period 1971–2012 by using the ARDL, Pal and Mitra [19] investigate the relationship between economic activity, energy consumption, trade openness, and CO_2 emissions. This study showed the long-run impact on economic activity and trade openness and the short-run effect on energy use on carbon emissions. Furthermore, this study reports the N-shaped association between carbon emissions and economic activity and fails to validate the EKC hypothesis.

Sani et al. [20] explored the link between economic growth, industrialization, energy use, and CO_2 emissions in Nigeria (1981–2019) using the ARDL method. The results reveal that economic development and energy use positively correlate with CO_2 emissions, while industrialization has an inverse relationship with CO_2 emissions. Ozgur et al. [21] analyzed the impact of nuclear energy use on carbon emissions. They tried to confirm the EKC hypothesis using the Fourier ARDL approach using data from 1970 to 2016 in India. This study demonstrates the validity of the EKC hypothesis in India. The negative association between nuclear energy use and CO_2 emissions suggests that nuclear power development is vital to reaching green and sustainable development in India. Xue et al. [4] probed the effects of clean energy on carbon emissions in France from 1987 to 2019, controlling urbanization, economic development, and policy uncertainty. The researchers found that clean energy does not contribute to carbon emissions, while economic growth and policy uncertainty induce carbon emissions in France.

Table 1 summarizes previous research findings related to the energy–income–emission nexus. Most of the research tested the EKC hypothesis and found contradictory mixed results. A few studies supported the EKC hypothesis [18,21,22]. Some other studies did not validate the EKC hypothesis [8,19,20]. Most importantly, Rahman and Alam [5] investigated the relationship between clean energy and carbon emissions using Bangladeshi data, but they did not test the EKC hypothesis. The above summary of findings indicates mixed results due to the selection of country, econometric methods, sample data selection period, and variables. Limited studies focus on clean energy, economic development, and carbon emission nexus. This study fills this research gap by examining the above nexus.

Table 1. Summary of the results of prior literature.

Author(s)	Time Span	Area of Study	Methodology	Findings
Alabi et al. [8]	1971–2014	Sri Lanka	ARDL bound testing approach	Energy use expands carbon emissions. The EKC hypothesis is not validated.
Gasimli et al. [9]	1978–2014	Sri Lanka	ARDL bound testing approach	Energy consumption raises carbon emissions. The EKC hypothesis is not found.
Naradda Gamage et al. [10]	1974–2014	Sri Lanka	DOLS	Energy use increases carbon emissions. The EKC hypothesis is not validated.
Rahman and Alam [5]	1973–2014	Bangladesh	ARDL bound testing approach	Clean energy reduces carbon emissions. The EKC hypothesis is not tested.
Shahbaz et al. [18]	1975–2011	United Arab Emirates	ARDL bound testing approach	Energy consumption increases CO_2 emissions; it supported the EKC hypothesis.
Pal and Mitra [19]	1971–2012	India and China	ARDL bound testing approach	There is an N-shaped association between carbon emissions and economic activity. The EKC hypothesis does not exist.
Sani et al. [20]	1981–2019	Nigeria	ARDL bound testing approach	Energy use increases CO_2 emissions; the EKC hypothesis is not supported.
Ozgur et al. [21]	1970–2016	India	ARDL bound testing approach	Energy consumption increases carbon emissions; the EKC hypothesis is not supported.
Nasreen et al. [22]	1980–2012	South Asian Economies	ARDL bound testing approach	The EKC hypothesis is validated in Pakistan, India, Bangladesh, and Sri Lanka, but not in Nepal.

Existing literature on the relationship between environmental degradation and economic development examined the EKC hypothesis presented by [23]. The EKC hypothesis indicates that initially, environmental degradation increases with the rise of economic growth until attaining a threshold level of economic development; however, after that point, ecological degradation decreases [24]. The EKC hypothesis proposes a connection between economic growth and environmental pollution in an inverted U-sharped curve [25]. In addition to the EKC hypothesis, this study adopts pollution haven hypothesis (PHH) to test the relationship between trade openness and CO_2 emissions.

The impact of trade openness on CO_2 emissions has sought more attention in recent years [5,26]. Trade openness plays a significant role in a country's economy, measured as the proportion of imports and exports to the country's GDP [27]. The import and export trading activities use natural resources that may harm the environment. Trade openness uses advanced technologies with dirty energy that improves economic growth and the standard of living and emits more carbon emissions in developing countries [26]. This confirms the existence of the PHH [28]. Recently, scholars tried to validate the PHH with the EKC hypothesis [29–33]. Liu et al. [34] investigated the relationship between energy use, economic growth, trade openness, foreign direct investment, and ecological footprint in Pakistan to test the validity of the EKC hypothesis and the PHH. The authors found support for both hypotheses. Dagar et al. [35] tested the PHH with the role of foreign direct investment, validating the PHH. Firoj et al. [31] investigated the EKC hypothesis with the PHH in Bangladesh and validated the EKC and invalidated the PHH. Another study from Bangladesh by Raihan [36] examined the EKC and the PHH and validated both. Ozturk et al. [37] investigated financial development and ecological footprint in South Asia, bridging the EKC and the PHH and supporting the EKC and the PHH for South Asian countries. Luo et al. [38] examined the EKC and the PHH in Asian economies and found support for both. Naqvi et al. [39] investigated the relationship between foreign direct investment, economic development, urbanization, natural resources, biomass energy usage, and ecological footprint in 87 middle-income countries and supported both hypotheses. Yilani et al. [28] investigated the PHH and the EKC hypothesis in Indonesia and provided evidence of the validity of both views.

Table 2 summarizes recent research findings on the validity of the PHH and the EKC hypotheses. Most previous researchers investigated the impact of foreign direct investment and economic growth on CO_2 emissions or ecological footprint to test the PHH and the EKC hypotheses. A country's trade openness significantly uses natural resources for international trade, contributing to environmental pollution [27]. In addition, mixed evidence is reported in the existing literature on the effect of trade openness on environmental pollution. Managi et al. [40] and Yilanci et al. [28] validated the PHH between trade openness and environmental pollution. Copeland and Taylor [41] and Kearsley and Riddel [42] found no relationship between trade openness and ecological impact. To the best of our knowledge, existing literature focused on environmental pollution studies and unexplored the validity of the EKC and the PHH hypotheses in the context of Sri Lanka. This study will try to fill this research gap.

Table 2. Summary of the results of prior literature on the EKC and the PHH.

Author/s	Sample	Economies	Variables	Techniques	Validity of EKC and PHH
Akram et al. [29]	1982–2018	China	CO_2 emissions, GDP, foreign direct investment, and international trade	Quantile ARDL	Validated both hypotheses
Bulut [30]	1970–2016	Turkey	Ecological footprint, GED, foreign direct investment, renewable energy use, and industrialization	ARDL bound test and DOLS	Validated EKC but not PHH
Dagar et al. [35]	1990–2014	Lower-middle-income, upper-middle-income, and high-income	Ecological footprint, economic growth, and foreign direct investment	PMG	Validated PHH but did not test the EKC hypothesis
Firoj et al. [31]	1986–2018	Bangladesh	CO_2, trade openness, financial development, foreign direct investment, capital formation, energy use, and urbanization	ARDL bound test	Validated the EKC but did not validate the PHH
Luo et al. [38]	2001–2019	Selected Asian countries	CO_2, green investment, technology innovation, and economic growth	FMOLS and DOLS	Validated both hypotheses
Naqvi et al. [39]	1990–2017	87 middle-income countries	Ecological footprint, economic growth, foreign direct investment, biomass energy consumption, natural resources, and urbanization	AMG	Validated both hypotheses
Ozturk et al. [37]	1971–2018	South Asian economies	Ecological footprint, GDP, energy consumption, financial development, and foreign direct investment	FMOLS, DOLS, and PMC	Validated both hypotheses
Rahman and Alam [43]	1960–2020	17 Asia-Pacific countries	CO_2, energy use, economic growth, trade openness, and financial development	Driscoll and Kraay's standard error and PCSE	Validated EKC but not PHH

Table 2. *Cont.*

Author/s	Sample	Economies	Variables	Techniques	Validity of EKC and PHH
Yilanci et al. [28]	1976–2018	Indonesia	Fishing footprint, fishery production, foreign direct investment, and GDP	ARDL bound test	Validated EKC but not PHH

3. Data and Methodology

3.1. Data

This study scrutinizes the link between clean energy, economic growth, the square of economic growth, urbanization, trade openness, and carbon emissions using annual data from 1971 to 2014 in Sri Lanka. This research employs carbon emissions (CO_2) per capita measured in metric tons as the proxy for environmental pollution. Clean energy is defined as alternative and nuclear energy as a fraction of total energy consumption. The variable definitions, abbreviations, and units of measure are specified in Table 3. All data were downloaded from the World Development Indicator (WDI), World Bank (WDI, World Bank (2022)).

Table 3. Description of variables.

Variables	Abbreviation	Definition	Unit of Measure
CO_2 emissions	CO_2	Quantity of CO_2 emissions	Metric tons per capita
Clean energy	CEN	Alternative and nuclear energy	Percentage of total energy use
Economic growth	GDP	GDP per capita	Constant 2015 USD
Urbanization	URB	Urban population (%)	Percentage of the total population
Trade openness	TRD	Trade	Percentage of GDP

3.2. Model Specification

The following multivariate model is used to explore the long- and short-run association between clean energy (CEN), economic growth (GDP), the square of economic growth (GDP^2), urbanization (URB), trade openness (TRD), and CO_2 emissions (CO_2).

$$CO_2 = \beta_0 + \beta_1 CEN + \beta_2 GDP + \beta_3 GDP^2 + \beta_4 URB + \beta_5 TRD + \varepsilon_t \quad (1)$$

where CO_2 is carbon emissions, CEN is clean energy, GDP is the GDP per capita, GDP^2 is the square of GDP per capita, β_0 is the constant term, and ε is the error term. B_1 to β_5 indicate the coefficients of the independent variables.

Equation (1) is converted to a natural logarithm format as follows:

$$\ln CO_2 = \beta_0 + \beta_1 \ln CEN + \beta_2 \ln GDP + \beta_3 \ln GDP^2 + \beta_4 \ln URB + \beta_5 \ln TRD + \varepsilon_t \quad (2)$$

where ln indicates the natural logarithm and others are as mentioned in Equation (1).

3.3. Unit Root Tests

This research uses augmented Dickey–Fuller (ADF) [44]) and Phillips and Perron [45] to verify whether the variables are stationary or not. The Fisher test of unit root using ADF estimates the regression equation as follows:

$$\Delta Y_t = \alpha + \beta_t \; + \theta y_{t-1} + \sum_{j=1}^{n} \mu_i \Delta_{Y_{t-1}} + e_t \quad (3)$$

where α is the intercept, β is the coefficient on the time trend T, μ is the coefficient on the lagged dependent variable, n is the number of lags, and e is random error.

Phillips and Perron [45] suggest the following unit root test:

$$\Delta Y_t = \alpha + \beta_t + \theta y_{t-1} + e_t \quad (4)$$

3.4. Autoregressive Distributed Lag (ARDL) Bound Test

Prior research tested the co-integration relationship between the studied variables employing Engle and Granger [46], Phillips and Hansen [47], and Johansen and Juselius [48] co-integration tests, which have some drawbacks of estimation about the series of integration. Pesaran et al. [49] introduce the ARDL bound test to investigate the long-run co-integration association, which is superior in comparison with the co-integration tests introduced by Engle and Granger [46], Phillips and Hansen [47], and Johansen and Juselius [48]. First, the ARDL bound test investigates the long-run association among variables, whether the underlying repressors are integrated of order I(0), I(1), or marginally integrated. Second, this ARDL test is an efficient estimator even if there is a small sample size. Third, this approach provides reasonable estimations of the long-run model and accurate statistics, even if some of the repressors are endogenous. Fourth, these procedures assess long- and short-run parameters simultaneously. Finally, this test incorporates a dynamic error correction model [50], which is deduced by a linear transformation [51].

$$\begin{aligned}\Delta lnCO2_t = \beta_0 &+ \sum_{i=1}^{p_1} \beta_{1i}\Delta lnCO2_{t-1} + \sum_{i=1}^{p_2} \beta_{2i}\Delta lnCEN_{t-1} + \sum_{i=1}^{p_3} \beta_{3i}\Delta lnGDP_{t-1} \\ &+ \sum_{i=1}^{p_4} \beta_{4i}\Delta GDP^2{}_{t-1} + \sum_{i=1}^{p_5} \beta_{5i}\Delta lnURB_{t-1} + \sum_{i=1}^{p_6} \beta_{6i}\Delta lnTRD_{t-1} + \beta_7 lnCO2_{t-1} \\ &+ \beta_8 lnCEN_{t-1} + \beta_9 GDP_{t-1} + \beta_{10} GDP^2{}_{t-1} + \beta_{11} URB_{t-1} + \beta_{12} TRD_{t-1} + \varepsilon_t\end{aligned} \quad (5)$$

where Δ and ε indicate the first difference and the error term, respectively and the p_1, p_2, p_3, p_4, p_5, and p_6 are the number of lags based on the Akaike information criterion (AIC). Pesaran et al. [49] develop the lower critical bound (LCB) and upper critical bound (UCB) and F-statistic, which checks that the null hypothesis is H_0: $\beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = 0$ of taking no co-integration between the variables in Equation (5) and the alternative hypothesis of the long-run co-integration is H_1: $\beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq \beta_{11} \neq \beta_{12} = 0$.

4. Results and Discussion

Table 4 reports the summary statistics of the variables in the original value. The mean CO_2 emission in metric tons is 0.415, which ranges between the minimum and maximum values of 0.200 and 0.847, with a standard deviation of 0.206. The average clean energy value is 3.163, between 1.473 and 5.400, with a variability value of 0.952. The average value of GDP per capita is USD 1655.27, which ranges between USD 712.84 and 3694.30 with a standard deviation of USD 830.84. On average, trade (% of GDP) has a mean value of 67.51% and the lowest and highest values of 46.21% and 88.64%, respectively. The average percentage of the urban population is 18.36%, which falls between 17.697% and 18.676%, with variability scores of 0.255.

Table 4. Description statistics.

Variable	Mean	Median	Standard Deviation	Minimum	Maximum	N
CO_2 emissions	0.415	0.303	0.206	0.200	0.847	44
Alternative and nuclear energy	3.163	3.011	0.952	1.473	5.400	44
GDP per capita	1655.270	1376.004	830.839	726.787	3694.300	44
Urban	18.360	18.388	0.225	17.697	18.676	44
Trade	67.505	68.002	11.661	46.225	88.636	44

Figure 1a shows the trends of CO_2 emissions in Sri Lanka that have significantly increased since 1971 and dropped in 2009, then increased until 2012 and again dropped in 2013, and again started to increase. Figure 1b reports alternative and nuclear energy trends in Sri Lanka. There is a more fluctuating trend in clean energy. Figure 1c shows an upward trend in GDP per capita. Figure 1d presents that the urban population increased from 1971 to 1983 and sharply dropped until 2013. Figure 1e shows year-by-year fluctuation in trade openness throughout the studied period.

The unit root test results of the examined variables using the ADF and the PP are presented in Table 5. The variables of $lnCO_2$, lnCEN, lnGDP, and lnTRD have unit roots at the level but no unit roots at their first difference under the indicated ADF and PP unit root tests. They are stationary at the first difference I(1). The variable of lnURB has no unit root test at the level and unit root test at their first difference under ADF and PP unit root tests. It is stationary at level I(0). Therefore, the selected variables have fallen as either I(1) or I(0) but not I(2). As a result, this study could adopt the ARDL bound testing approach to explore the long-run relationship among the variables.

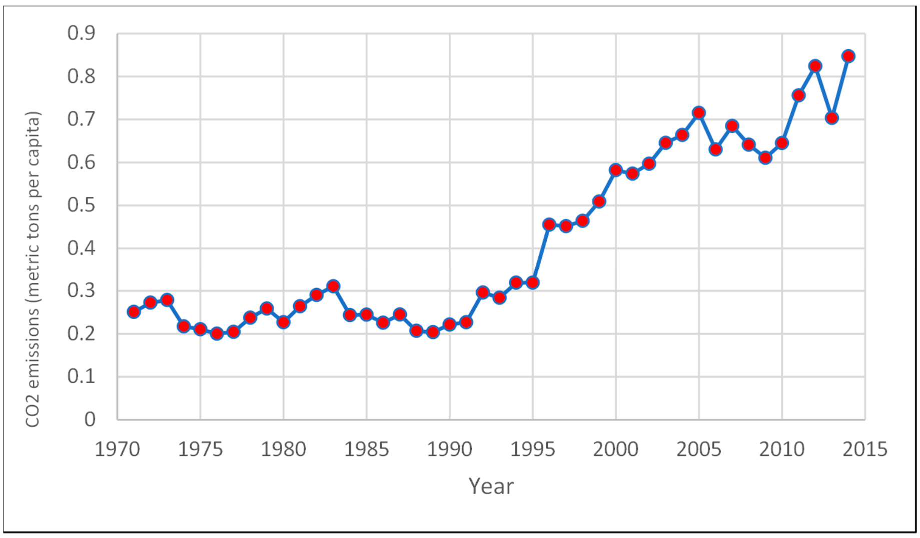
Table 5. The results of the unit root test.

	ADF Test		PP Test	
	Constant and Trend		Constant and Trend	
	Level	First Difference	Level	First Difference
$lnCO_2$	−2.330	−7.460 ***	−2.248	−7.465 ***
lnCEN	−3.068	−8.917 ***	−2.884	−9.876 ***
lnGDP	−0.709	−6.455 ***	−0.804	−6.434 ***
lnURB	−6.995 ***	−0.743	−4.642 ***	−1.023
lnTRD	−1.441	−5.855 ***	−1.474	−5.845 ***

Notes: *** indicate statistical significance at 1%.

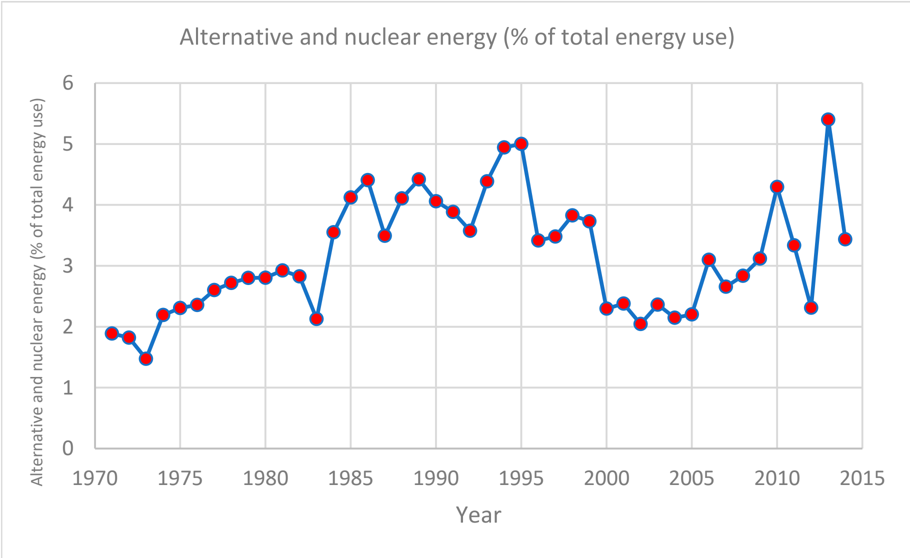
Following Jayanthakumaran et al. [52], Ahmed et al. [53], and Wang [54], this study selects a lag length of four based on AIC.

Table 6 shows the ARDL bound test results (1, 0, 0, 1, 0, 4). The calculated F-statistic of 9.123 is larger than the upper value of 4.15 and statistically significant at 1% level, revealing that long-run co-integration between the studied variables is present.

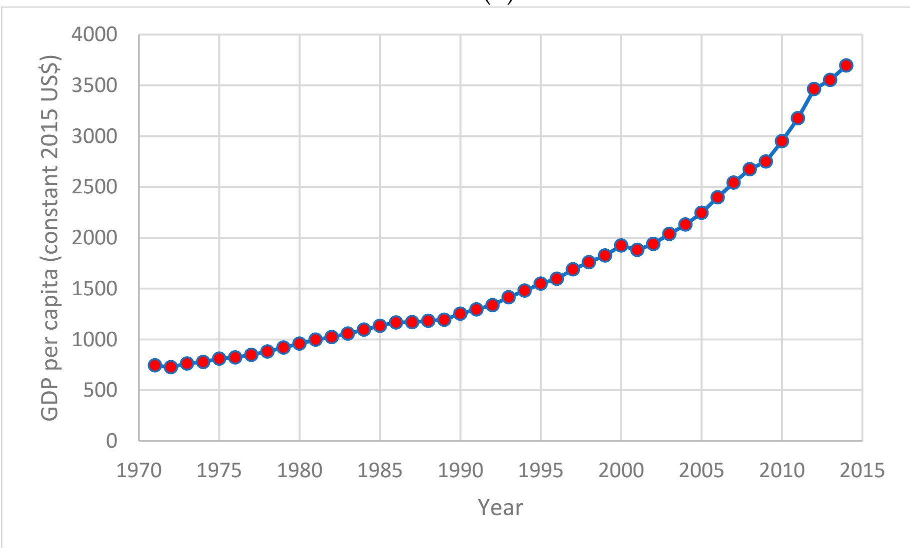


(**a**)

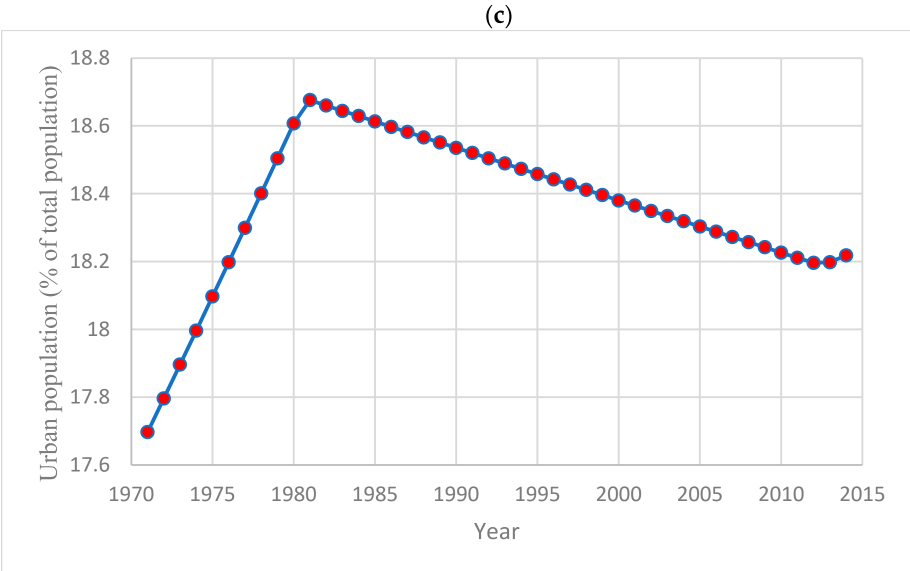
Figure 1. *Cont.*



(**b**)

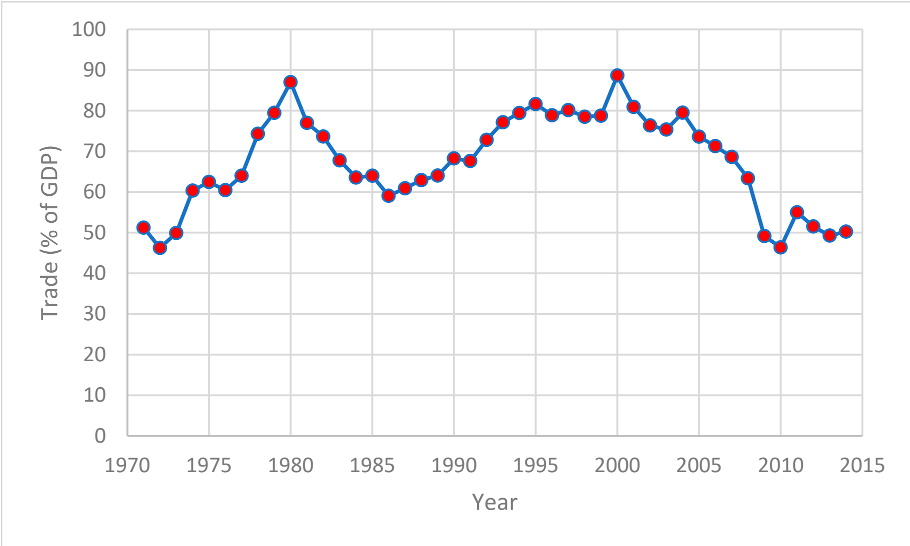


(**c**)



(**d**)

Figure 1. *Cont*.



(**e**)

Figure 1. (**a**) CO_2 emissions (metric tons per capita). (**b**) Alternative and nuclear energy (% of total energy use). (**c**) GDP per capita (constant 2015 USD). (**d**) Urban population (% of total population). (**e**) Trade (% of GDP).

Table 6. The results of the bound test.

Critical Value	F-Statistic: 9.123	
	Lower Bound 0(1)	**Upper Bound 1(1)**
1%	3.06	4.15
5%	2.39	3.38
10%	2.08	3.00

Table 7 displays the results of the long-run relationship among the studied variables. The coefficient of CEN is −0.210, negative, and statistically significant at a 1% level, demonstrating that clean energy use mitigates environmental pollution in Sri Lanka. This finding shows that a 1% increase in clean energy use in Sri Lanka contributes to a 0.21% reduction in carbon dioxide emissions. This evidence is supported by Rahman and Alam [5] for Bangladesh but contradicted by Xue et al. [4] for France, who finds an insignificant negative impact of clean energy on carbon emissions. The GDP and square of GDP coefficients are −8.255 and 0.625, which are negative and positive, respectively, implying that this study found no support for the KEC framework in Sri Lankan economy. This evidence is supported by the previous Sri Lankan studies of Alabi et al. [8], Gasimli et al. [9], and Naradda Gamage et al. [10] but contradicted by Nasreen et al. [22], who document the existence of the KEC hypothesis for Sri Lanka. This study finds a negative and significant association between urbanization and carbon emissions in Sri Lanka. This finding is consistent with a previous study on Sri Lanka [9]. The coefficient of trade openness is positive and significant, implying that trade openness induces CO_2 emissions in Sri Lanka, validating the PHH. The findings confirm that a 1 percent change in trade openness causes a 1.44 percent increase in CO_2 emissions in Sri Lanka. The results are consistent with those of Dou et al. [55], Chhabra et al. [26], Managi et al. [40], and Yilanci et al. [28], who validated the PHH between trade openness and environmental pollution. Copeland and Taylor [41] and Kearsley and Riddel [42] found no relationship between trade openness and ecological impact.

Table 7. The results of the long-run relationship.

Variable	Coefficient	Standard Error	*t*-Statistic	Prob.
Constant	40.519 ***	9.609	4.217	0.000
lnCEN	−0.210 ***	0.063	−3.332	0.002
lnGDP	−8.255 ***	1.929	−4.278	0.000
lnGDP^2	0.625 ***	0.130	4.811	0.000
lnURB	−7.035 ***	2.175	−3.235	0.003
lnTRD	1.435 ***	0.187	7.693	0.000

Notes: *** indicate statistical significance at 1%.

This study gives evidence in support of the invalidity of the EKC and the validity of the PHH. These findings are consistent with Nawaz [33] for South Asia and Bakirtas and Cerin [56] for Mexico, Indonesia, Korea, Turkey, and Australia. The non-existence of the EKC in Sri Lanka could be due to the country's initial stage of development, the role of technological innovation, environmental and economic policies of the government [33]. In addition, the impact of trade openness on CO_2 emissions in Sri Lanka is positive and supports the PHH. In the future, the existence of the EKC can be possible if Sri Lanka uses more clean energy than fossil-fuel energy for their international trading activities. Clean international trading activities could lead to sustainable economic growth. Dong et al. [57] and Dong [58] found evidence that a country using renewable energy consumption can reduce environmental pollution and helps in supporting sustainable economic growth.

The results from short-run error correction methods are stated in Table 8. The short-run coefficient of the square of GDP is 0.619, which is positive and significant at the 1% level. The short-run coefficient of the first difference of trade openness is 0.589, which is positive and significant at a 1% level. Nonetheless, the first lag of the first difference, the second lag of the first difference, and the third lag of the first difference of trade openness are −0.964, −0.718, and −0.389, respectively, which are negative and statistically significant. The assessed lagged error correction term (ECT_{t-1}) is −1.086, which is negative and statistically significant at a 1% level, suggesting that there are long-run associations between clean energy, economic growth, the square of economic growth, urbanization, trade openness, and carbon emissions and every year 108.6% error will be adjusted toward the long-run equilibrium.

Table 8. The ARDL co-integrating short-term error-correction model (1, 0, 0, 1, 0, 4).

Variable	Coefficient	Standard Error	*t*-Statistic	Prob.
Constant	44.014 ***	13.393	3.286	0.003
D(lnGDP^2)	0.619 ***	0.065	9.494	0.000
D(lnTRD)	0.589 ***	0.138	4.280	0.000
D(lnTRD)(−1)	−0.964 ***	0.182	−5.286	0.000
D(lnTRD)(−2)	−0.718 ***	0.135	−5.296	0.000
D(lnTRD)(−3)	−0.389 **	0.155	−2.507	0.018
ECT(−1)	−1.086 ***	0.123	−8.806	0.000

Notes: ** and *** indicate statistical significance at 5%, and 1%, respectively. The maximum lag to be used is four. Akaike information criterion chooses the optimal lag structure.

Table 9 reports the results of diagnostic tests of serial correlation tests, heteroskedasticity, and normality. This study finds no serial correlation or heteroskedasticity and the residuals are normally distributed. This study also finds that both CUSUM and CUSUMSQ are well within critical bounds, as shown in Figures 2 and 3.

Table 9. Diagnostic tests.

Test	F-Statistics (Prob.)	Finding
Breusch–Godfrey serial correlation LM test	0.104 (0.902)	There is no serial correlation
Breusch–Pagan–Godfrey heteroskedasticity test	0.390 (0.949)	There is no heteroskedasticity
Jarque–Bera normality test	2.337 (0.311)	Residuals are normally distributed

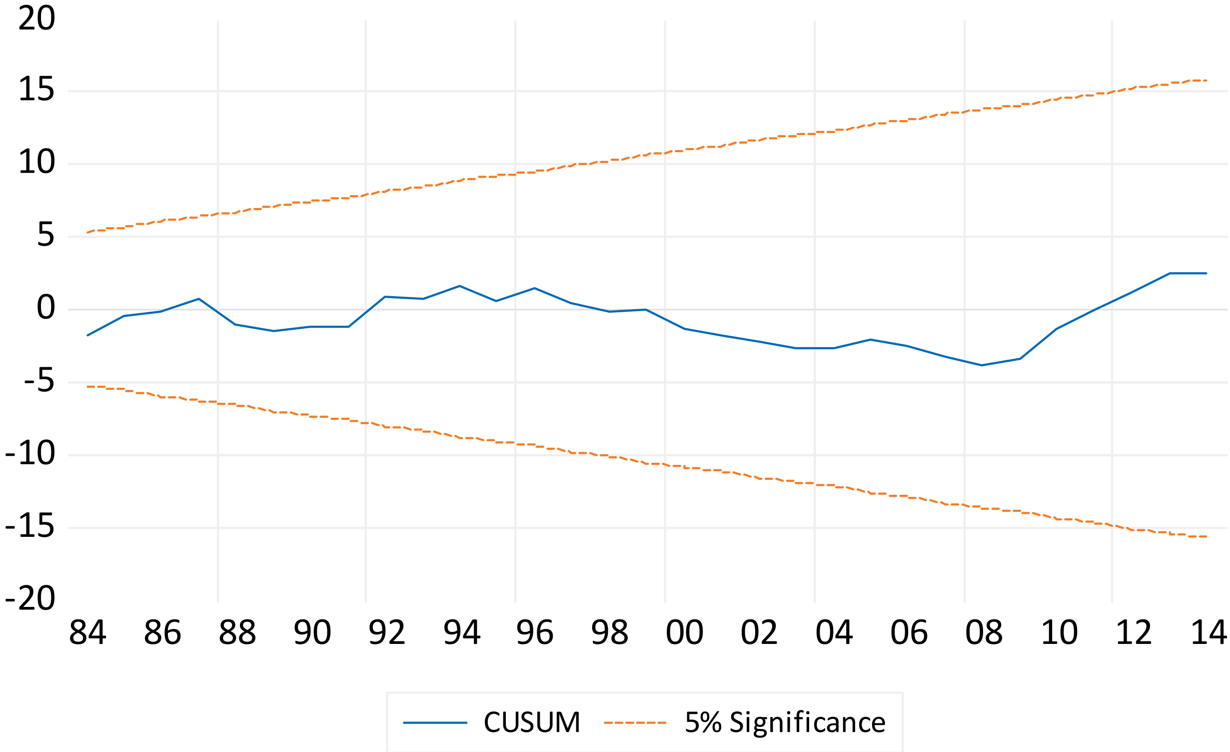


Figure 2. The plot of the cumulative sum of recursive residuals.

This study uses a pairwise Granger causality test to examine the connection between the studied variables. Table 10 reports the results of pairwise Granger causality test. The findings reveal unidirectional causality running from clean energy to carbon emissions, economic growth to carbon emissions, carbon emissions to urbanization, carbon emissions to trade openness, economic growth to urbanization, and economic growth to trade openness. There is evidence of bidirectional causality between urbanization and clean energy.

Table 10. The results of pairwise Granger causality test.

Null Hypothesis:	F-Statistic	Causality
$CE \rightarrow CO_2$	11.948 ***	$CE \rightarrow CO_2$ (unidirectional causality)
$CO_2 \rightarrow CE$	0.045	
$GDP \rightarrow CO_2$	5.702 **	$GDP \rightarrow CO_2$ (unidirectional causality)
$CO_2 \rightarrow GDP$	0.060	
$URB \rightarrow CO_2$	0.308	$CO_2 \rightarrow URB$ (unidirectional causality)
$CO_2 \rightarrow URB$	47.300 ***	
$TRD \rightarrow CO_2$	0.906	$CO_2 \rightarrow TRD$ (unidirectional causality)
$CO_2 \rightarrow TRD$	4.093 **	

Table 10. *Cont.*

Null Hypothesis:	F-Statistic	Causality
GDP→CE	0.225	-
CE→GDP	0.159	
URB→CE	3.775 *	URB↔CE (bidirectional causality)
CE→URB	3.433 *	
TRD→CE	0.090	-
CE→TRD	0.654	
URB→GDP	0.067	GDP→URB (unidirectional causality)
GDP→URB	62.303 ***	
TRD→GDP	0.000	GDP→TRD (unidirectional causality)
GDP→TRD	3.892 *	
TRD→URB	0.166	-
URB→TRD	0.048	

Notes: ***, **, and * denotes significant level at 1%, 5%, and 10%, respectively.

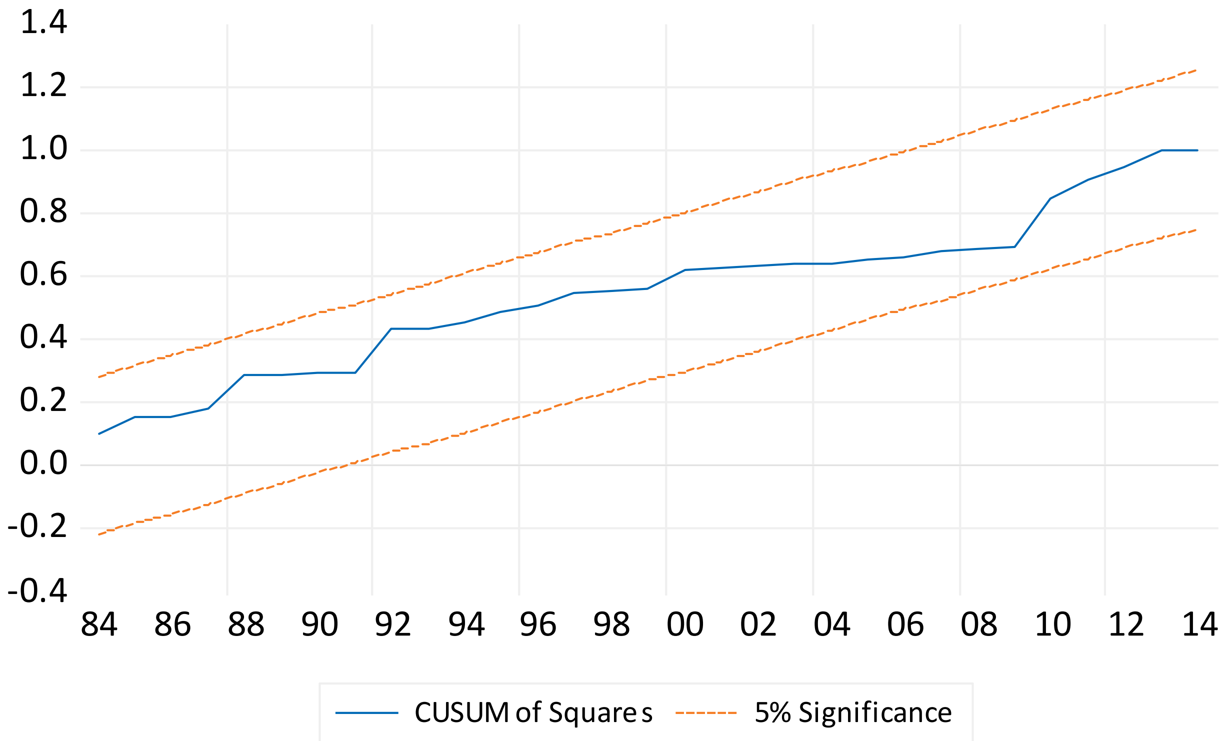


Figure 3. The cumulative sum of squares of recursive residuals plot.

5. Conclusions and Policy Implications

This study explores the impact of clean energy, economic growth, the square of economic growth, urbanization, and trade openness on carbon emissions using time series data from 1971 to 2014 in Sri Lanka. This research adopts various econometric techniques associated with time series data, such as unit root tests of ADF and PP, ARDL bound testing approach, error correction method, and Granger causality test to achieve the results. This ARDL bound testing method study finds short-run and long-run co-integration between carbon emissions, economic growth, the square of economic growth, urbanization, and trade openness. The finding confirms that clean energy use contributes to carbon dioxide emission reduction in Sri Lanka in the long run. This finding indicates that a 1%

increase in clean energy use contributes to a 0.21% reduction in carbon dioxide emissions. This evidence is supported by Rahman and Alam [5] for Bangladesh but contradicted by Xue et al. [4] for France, who found an insignificant negative impact of clean energy on carbon emissions.

Economic growth is negatively associated with carbon dioxide emissions, whereas economic growth squared has a positive association with carbon dioxide emissions in Sri Lanka. These findings did not validate the inverted U-shape relationship between economic growth and carbon dioxide emissions, implying that this study finds no support for the KEC framework in Sri Lanka in the long run. These findings are consistent with Alabi et al. [8], Gasimli et al. [9], and Naradda Gamage et al. [10]. Urbanization improves the environmental quality in the long run in Sri Lanka. One of the reasons for reducing carbon dioxide emissions is a decrease in the percentage of the urban population in Sri Lanka since 1982. This finding is supported by Gasimli et al. [9]. Trade openness is positively correlated with carbon dioxide emissions and is significant, implying that trade openness induces environmental degradation in Sri Lanka in the long run supporting the PHH. This finding is supported by Naradda Gamage et al. [10] and Rahman and Alam [5] for Bangladesh. Using the PHH hypothesis, Copeland and Taylor [41], and Kearsley and Riddel [42] found no relationship between trade openness and environmental impact. Managi et al. [40] and Yilanci et al. [28] validated the PHH between trade openness and environmental impact. The import and export sectors in Sri Lanka did not use environmentally friendly technology to mitigate carbon dioxide emissions [10].

The current research findings would help policymakers in making an effective decision related to environmentally friendly energy consumption. First, policymakers should make an appropriate green energy policy to look for alternative energy sources to mitigate carbon emissions, as it is sharply increasing in Sri Lanka. Second, policymakers should consider incentives for the users of clean energy. For this purpose, the government and the banking sector should jointly undertake initiatives. Third, the government should consider imposing a carbon tax on international traders who use fossil-fuel-generated energy for their international trading activities. Finally, policymakers should implement a policy encouraging import and export traders to use green energy.

This study has several limitations. First, this study considers only an emerging country, Sri Lanka. Therefore, the obtained findings may not apply to developed countries. Second, this study includes carbon emissions as an independent variable. There are other types of GHE variables, such as ecological footprint, sulfur dioxide emission, and deforestation rate. Finally, the unavailability of data for some essential variables is another limitation of this study. This study examines the relationship between trade openness and CO_2 to validate the PHH. Future research should consider other variables, such as foreign direct investment and ecological footprint to test the PHH with other econometric methods for proper policy implementation.

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