Carbon Research

ORIGINAL ARTICLE

Open Access

Dynamic impacts of economic growth, renewable energy use, urbanization, industrialization, tourism, agriculture, and forests on carbon emissions in Turkey

Asif Raihan[1*] and Almagul Tuspekova[2]

Abstract

The present study examined the dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area in Turkey to accomplish environmental sustainability by lowering carbon dioxide emissions. The Dynamic Ordinary Least Squares method was used to analyze time series data from 1990 to 2020. The results disclosed that a 1% rise in economic growth, urbanization, industrialization, and tourism will raise carbon dioxide emissions by 0.39%, 1.22%, 0.24%, and 0.02% in Turkey, respectively. Furthermore, a 1% increase in renewable energy consumption, agricultural productivity, and forest area might result in reductions in carbon dioxide emissions of 0.43%, 0.12%, and 3.17%, respectively. This article made policy recommendations on low-carbon economies, renewable energy use, sustainable urbanization, green industrialization, eco-friendly tourism, climate-smart agriculture, and sustainable forest management, all of which could help to accomplish environmental sustainability by lowering emissions.

Highlights

- This study investigates the potential of emission reduction factors in Turkey.
- Dynamic Ordinary Least Squares method has been applied by using time series data.
- The outcomes shed new light on the potential of renewable energy, agriculture, and forests in Turkey.
- This article provides policy recommendations for sustainable development by reducing emissions.

Keywords: CO_2 emissions, Climate change, Environment, Carbon, Renewable energy, Sustainability

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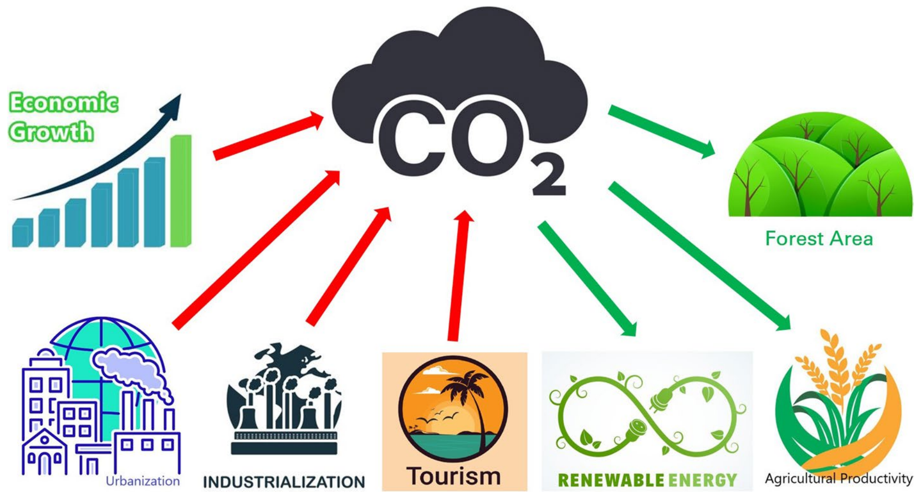
Graphical Abstract



1 Introduction

Due to anthropogenic emissions of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), which is mainly emitted by human-caused actions such as fossil fuel burning and deforestation. Global warming and climate change are prominent subjects in the twenty-first century (Raihan et al. 2018; Raihan et al. 2021a). Continuous increases in CO_2 emissions are expected to have devastating impacts on the global climate system and all parts of society (Raihan et al. 2022a). As a result, lessening CO_2 emissions and enhancing environmental conditions have become be global concerns in order to assure long-term growth and reduce climate change's detrimental consequences (Raihan and Tuspekova 2022a). However, Turkey has the world's 17th biggest economy and is the sixth-largest in Europe (World Bank 2022). The use of fossil fuel energy is expanding as a result of rapid economic expansion and greater energy needs, resulting in a significant increase in CO_2 emissions in the country. Turkey ranked 15th in the overall CO_2 emissions and 16th in per-capita CO_2 emissions amongst the top 20 countries that produced the most CO_2 in 2018 (World Bank 2022). As a result, the country is highly concerned about rising emission concentration, particularly in the energy sector. Therefore, it is critical if Turkey's economic progress accompanied by improved environmental sustainability.

Sustainable economic growth and its capacity to offset environmental costs are what ultimately define sustainable development and advancement. While the economy is growing, old, harmful methods are scrapped and replaced with newer, cleaner production, resulting in improved environmental quality. Changes in product structure, the adoption of cleaner technology, environmental regulation, and environmental responsibility all help to decouple economic expansion and environmental degradation (Raihan et al. 2022a). The importance of renewable energy has been emphasized in the context of energy shortage, global climate change, and the concept of sustainability has grown (Sohag et al. 2019; Sharif et al. 2021; Sohag et al. 2021). Renewable energy is widely acknowledged as a carbon-free source of energy with the capacity to address energy security concerns, and it is critical to meet the worldwide emission reduction ambition of 50% by 2050 (Raihan et al. 2022b). Turkey has rich renewable energy resources and has devised and implemented governmental frameworks to boost renewable energy. Thus, the potential of renewable energy for cutting carbon emissions in Turkey is a critical question.

Urban regions accounted for 76.1% of Turkey's total population in 2020 (World Bank 2022). Rapid urbanization poses a challenge to Turkey's long-term growth by increasing CO_2 emissions from household and commercial energy usage; infrastructure development; and forest conversions for urban growth. Furthermore, Turkey's industrialization has opened a new door in the fossil fuel-based economy, accounting for around 28% of the country's GDP in 2020 (World Bank 2022). As a result, one of the rising problems for accomplishing sustainability and emission reduction in Turkey is industrialization. The increasing level of urbanization and industrialization, on the other hand, results in better and more efficient utilization of urban infrastructure and industrial aggregation for cleaner production, which leads to less consequences on energy consumption and CO_2 emissions (Li and Lin

2015). Therefore, it is important to address whether urbanization and industrialization in Turkey is in line with environmental sustainability. Furthermore, with 52 million international tourists in 2019, the tourism sector contributed 11% to Turkey's GDP (World Bank 2022). However, tourism is related to a greater demand for energy for transportation systems, food, housing, services and facilities, and tourist site administration, which are often expected to deteriorate the ecosystem by increasing CO_2 emissions (Raihan et al. 2022c). Conversely, tourism-driven economic growth encourages countries to spend more on environmentally friendly cleaner production and cutting-edge innovative solutions to reduce emissions. Nonetheless, because of the general opinion that tourism significantly provides adequate economic progress, notably in Turkey, tourism expansion has been conspicuously ignored in emission modeling. Hence, a question arises about whether tourism contributes to improving Turkey's environmental quality.

Moreover, agriculture, forestry, and other land use (AFOLU); and land use, land-use change, and forestry (LULUCF) operations represent nearly one-fifth of worldwide annual CO_2 emissions, the second-largest producer of CO_2 emissions and contributing immensely to the global climate change (IPCC 2014). Agriculture contributed 7% to Turkey's GDP in 2020 (World Bank 2022). Agricultural productivity is tied to economic expansion, which boosts the need for cleaner production, healthier environments, goods, and services, and also the government's power to implement environmental laws (Raihan et al. 2022a). The yearly burning of fossil fuels in agriculture, on the other hand, releases billion of tons of GHGs into the atmosphere, resulting in global warming and climate change (Raihan and Tuspekova 2022a). Consequently, agriculture's influence on Turkey's environment has become a critical question to determine. Furthermore, the need for agriculture, mining, settlements, mass transport, and other infrastructures is increasing, causing forest cover loss (Jaafar et al. 2020) which triggers CO_2 emissions. Forests serve as both carbon sources and sinks, having a significant impact on the overall climate system (Raihan et al. 2021b). Forests help to slow the rate of climate change by absorbing atmospheric CO_2 and storing it in their biomass which is called carbon sequestration (Raihan et al. 2019). Forest areas trap around 300 billion tonnes of CO_2 every year, with an extra three billion tonnes of CO_2 predicted to escape into the atmosphere as a result of deforestation (Raihan et al. 2022a). Turkey's forest area accounts for about 30% of the total land mass (World Bank 2022), and it performs an essential role in the country's carbon stock. As a result, it is an urge to address the question of the forest's capacity for reducing CO_2 emissions in Turkey.

However, policymakers must acknowledge Turkey's potential to reduce emissions in order to achieve a balance between climate change mitigation and long-term growth. The question of how Turkey might cut emissions is critical and can be handled by assessing the impact of CO_2 emission drivers. Even though it has become a popular global issue, there is a paucity of studies investigating the association between CO_2 emission and emission reduction elements in Turkey employing econometric methodologies. To fill up the research gap, the current study used the Dynamic Ordinary Least Squares (DOLS) method to scrutinize the dynamic effects of economic growth, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions in Turkey. This research will be useful because it adds to the existing literature and policymaking in Turkey in a variety of ways. First, by providing fresh insights from a rigorous empirical estimation to investigate the association between CO_2 emissions and emission reduction components, this study fills a research need in the present academic literature. This study used the most up-to-date and comprehensive data over 31 years (1990–2020). Second, the assessment of the possible effects of renewable energy usage, agricultural productivity, and forest area on CO_2 emissions in Turkey is a pioneering attempt to demonstrate the connection between CO_2 emissions and emission reduction variables in the situation of Turkey. Finally, the article offers policymakers more reliable and detailed evidence for designing effective measures in the scopes of low-carbon economies, promoting renewable energy, sustainable urbanization, green industrialization, eco-friendly tourism, climate-smart agriculture, and sustainable forest management in Turkey. Furthermore, the findings of the study may guide other developing nations to implement effective environmental sustainability approaches while also increase climate change mitigation and adaptation measures.

2 Methodology

2.1 Data

The current study employed the DOLS approach of cointegration by Pesaran et al. (2001) to conduct an empirical analysis of the dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions in Turkey. The World Development Indicator (WDI) dataset was used to collect Turkey's time series data from 1990 to 2020. CO_2 emissions were used as a dependent variable in this study, with economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area serving as explanatory variables. To ensure that the data is normally distributed, the parameters were log-transformed. Table 1 lists the variables, along with their logarithmic versions, measurement units, and sources of data.

2.2 Summary statistics of the variables

Table 2 shows the results of the summary procedures among variables, together with the results of several normality tests (skewness, kurtosis, Jarque-Bera, and probability). Every single indicator had 31 samples of Turkey's annual data from 1990 to 2020. When the estimates of skewness are nearly zero, meaning that all of the variables are normally distributed. In addition, kurtosis was used to determine if the series was light-tailed or heavy-tailed when compared to a normal distribution. All the sets are platykurtic, according to the empirical observations, as their results are smaller than 3. Furthermore, all the variables are normal, according to the Jarque-Bera probability calculations.

2.3 Empirical model generation

Theoretically, CO_2 emission is associated with income. Assuming the market clearing condition, where CO_2 emissions equal economic growth, the following Eq. (1) is written within the framework of the standard Marshallian demand function (Friedman 1949) at time t as:

$$CO_{2t} = f\ (GDP_t) \tag{1}$$

where CO_{2t} is the CO_2 emissions at time t, and GDP_t is the economic growth at time t.

Furthermore, urbanization, industrialization, and tourism are associated with higher consumption of energy that triggers CO_2 emissions. On the other hand, renewable energy use helps to reduce the usage of fossil fuel energy sources and cut emissions. In addition, this study intends to estimate the potential of agricultural productivity and forest area to reduce emissions. Therefore, the dynamic effects of economic growth, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions were investigated using the following economic function:

Table 1 Variables with their logarithmic forms, units, and data sources

Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Kilotons (kt)	WDI
GDP	GDP	LGDP	Constant Turkish lira	WDI
RNE	Renewable energy use	LRNE	% of total final energy use	WDI
URB	Urbanization	LURB	Number of urban population	WDI
IND	Industrialization	LIND	Industry value added (% of GDP)	WDI
TR	International tourism	LTR	Number of tourist arrivals	WDI
AVA	Agricultural productivity	LAVA	Agricultural value added (% of GDP)	WDI
FA	Forest area	LFA	Square kilometers (sq. km)	WDI

Table 2 The statistical summaries of the variables

Variables	LCO2	LGDP	LRNE	LURB	LIND	LTR	LAVA	LFA
Mean	12.4115	27.5642	2.78781	17.6397	3.32673	16.6544	2.25074	12.2417
Median	12.3674	27.5623	2.73039	17.6456	3.32627	16.6787	2.19354	12.2364
Maximum	12.9382	28.2210	3.19911	17.9773	3.46827	17.7619	2.86084	12.3114
Minimum	11.8438	26.9635	2.43388	17.2789	3.17905	15.2733	1.75371	12.1952
Std. Dev.	0.34368	0.40928	0.26428	0.21072	0.08809	0.76136	0.34941	0.03609
Skewness	−0.03909	0.18300	0.31539	−0.04466	0.07209	−0.19189	0.38763	0.37092
Kurtosis	1.75911	1.73298	1.58722	1.82711	1.81453	1.65834	1.81974	1.82021
Jarque-Bera	1.99681	2.24660	3.09205	1.78723	1.84207	2.51533	2.57565	2.50873
Probability	0.36847	0.32520	0.21309	0.40918	0.39811	0.28432	0.27587	0.28526
Sum	384.758	854.491	86.4221	546.829	103.129	516.288	69.7729	379.492
Sum Sq. Dev.	3.54351	5.02538	2.09535	1.33208	0.23282	17.3904	3.66271	0.03907
Observations	31	31	31	31	31	31	31	31

$$CO_{2t} = f\,(GDP_t; RNE_t; URB_t; IND_t; TR_t; AVA_t; FA_t) \quad (2)$$

where RNE_t is the renewable energy use at time t, URB_t is the urbanization at time t; IND_t is the industrialization at time t; TR_t is the tourism at time t; AVA_t is the agricultural productivity at time t; and FA_t is the forest area at time t.

The empirical model is represented by the following equation:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 URB_t + \tau_4 IND_t + \tau_5 TR_t + \tau_6 AVA_t + \tau_7 FA_t \quad (3)$$

Equation (2) can also be used as an econometric model in the following way:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 URB_t + \tau_4 IND_t + \tau_5 TR_t + \tau_6 AVA_t + \tau_7 FA_t + \varepsilon_t \quad (4)$$

where τ_0 and ε_t stand for intercept and error term, respectively. In addition, τ_1, τ_2, τ_3, τ_4, τ_5, τ_6, and τ_7 denote the coefficients.

Furthermore, Eq. (3) can be arranged logarithmically as follows:

$$LCO2_t = \tau_0 + \tau_1 LGDP_t + \tau_2 LRNE_t + \tau_3 LURB_t + \tau_4 LIND_t + \tau_5 LTR_t + \tau_6 LAVA_t + \tau_7 LFA_t + \varepsilon_t \quad (5)$$

where $LCO2_t$ is the logarithmic form of CO_2 emissions at time t, $LGDP_t$ is the logarithmic form of economic growth at time t, $LRNE_t$ is the logarithmic form of renewable energy use at time t, $LURB_t$ is the logarithmic form of urbanization at time t, and $LIND_t$ is the logarithmic form of industrialization at time t, LTR_t is the logarithmic form of tourism at time t, $LAVA_t$ is the logarithmic form of agricultural productivity at time t, and LFA_t is the logarithmic form of forest area at time t.

2.4 Data stationarity methods

To prevent spurious regression, a unit root test is necessary. It estimates the regression equation using stationary procedures and verifies that the series are stationary (Raihan and Tuspekova 2022b). Before actually examining cointegration, the empirical evidence recognizes the need to establish the integration process (Raihan and Tuspekova 2022c). Since the effectiveness of unit root tests fluctuates with sample size, several studies proposed performing numerous unit root tests to assess the series integration sequence (Raihan and Tuspekova 2022d). To discover the autoregressive unit root, this work used the Augmented Dickey-Fuller (ADF) test suggested by Dickey and Fuller (1979), the Dickey-Fuller generalized least squares (DF-GLS) test developed by Elliott et al. (1996), and the Phillips-Perron (P-P) test introduced by Phillips and Perron (1988). The unit root test was used in this study to ensure that no variable exceeded the order of integration and to support the use of the DOLS technique over traditional cointegration methods.

2.5 ARDL bounds test for cointegration

This study applied the Autoregressive Distributed Lag (ARDL) bounds test proposed by Pesaran et al. (2001) to capture the cointegration amongst the series. The ARDL bounds test for cointegration valuation has many advantages over the other one-time integer methods. Firstly, it can be utilized when series have a mixed order of integration as the ARDL bounds test does not have obligatory assumptions, and all variables must be incorporated in the same order in the analysis. Secondly, it is significantly more reliable, particularly for a small sample size. Thirdly, it offers an accurate estimation for the long-term model. Therefore, the ARDL bounds testing approach can be used irrespective of whether the fundamental returning system is in sequence to a part in the I(2), and the cointegration order happens at I(0) or I(1). The ARDL bounds test is depicted as follows in Eq. (6):

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LRNE_{t-1} + \tau_4 LURB_{t-1} \\ & + \tau_5 LIND_{t-1} + \tau_6 LTR_{t-1} + \tau_7 LAVA_{t-1} + \tau_8 LFA_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1 \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LRNE_{t-i} \\ & + \sum_{i=1}^{q} \gamma_4 \Delta LURB_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LIND_{t-i} + \sum_{i=1}^{q} \gamma_6 \Delta LTR_{t-i} \\ & + \sum_{i=1}^{q} \gamma_7 \Delta LAVA_{t-i} + \sum_{i=1}^{q} \gamma_8 \Delta LFA_{t-i} + \varepsilon_t \end{aligned} \quad (6)$$

where Δ is the first difference operator and q is the optimum lag length in Eq. (6).

The F-distribution is followed by the ARDL bounds test, and its critical values were proposed by Pesaran and Timmermann (2005). The estimating technique starts with Eq. (6) and employs OLS to allow the F-test to evaluate the joint significance of the lagged variables' coefficients. The goal of this technique is to see if there is any long-term associations between the variables. The null hypothesis (H_0) reveals no cointegrating relationships among the regressors in this case. According to Pesaran et al. (2001), the F-statistics can be compared to the critical values of the upper and lower bounds. The null hypothesis is rejected if the F-statistics are higher than the upper critical value, indicating the existence of a long-term association between the variables. The null hypothesis, on the other hand, is accepted if the F-statistics are smaller than the lower critical value. The test is inconclusive if the F-statistics are observed within the lower and higher critical values.

2.6 The DOLS cointegration regression

To examine the time series data, the research studies used DOLS, which is an upgraded equation of ordinary least squares estimate. The DOLS cointegration test integrates explanatory factors as well as leads and lags of their baseline differential terms to control endogeneity and compute standard deviations utilizing a covariance matrix of errors that certainly is robust to serial correlation (Raihan et al. 2022e). The fact that the leads and lags of the individual terms are included indicates that the error term is orthogonalized. Since the DOLS estimator's standard deviations get a normal asymptotic distribution, it can be used to examine the statistical significance of parameters (Raihan and Tuspekova 2022f). The DOLS method is suitable for simply allowing factors in the cointegrated framework to be integrated when there is a combined order of integration by predicting the dependent parameter on explanatory factors in levels, leads, and lags (Begum et al. 2020). The fundamental advantage of the DOLS estimation is the presence of mixed-order integration of individual variables in the cointegrated outline. For example, one of the I(1) variables was regressed against other variables in DOLS estimation, some of which were I(1) variables with first difference leads (p) and lags (−p), while others were I(0) variables with a constant term (Raihan and Tuspekova 2022g). The DOLS assessment eliminates small sample bias, endogeneity, and autocorrelation by accumulating the leads and lags across independent parameters. However, after validating cointegration among the parameters, the study proceeded with the DOLS estimation of the long-run coefficient by using Eq. (6).

3 Empirical findings

3.1 Correlations between the variables

Correlation analysis results for linear relationships between the variables are presented in Table 3. The results revealed that all the variables are correlated to one another. LCO2, LGDP, LURB, LIND, and LTR had positive correlations with each other, meaning that when the value of one variable rises, the value of the other tends to rise as well and vice versa. However, LRNE, LAVA, and LFA show a negative correlation with LCO2, LGDP, LURB, LIND, and LTR which revealed that when the values of the LRNE, LAVA, and LFA rise, the values of LCO2, LGDP, LURB, LIND, and LTR tend to drop and vice versa. Furthermore, LRNE, LAVA, and LFA show positive correlations with each other which indicate that when the value of one variable rises, the value of the other variable tends to rise as well and vice versa.

3.2 Results of unit root tests

By ensuring that no parameter surpassed the integration order, the unit root test was used to demonstrate the feasibility of using the DOLS estimation model rather than just cointegration. The results of unit root testing utilizing the ADF, DF-GLS, and P-P tests are shown in Table 4. The variable is stationary at combined levels either in level or first-order integration, indicating that the DOLS technique is preferable to traditional cointegration approaches.

3.3 Results of ARDL bounds test

This research performed the ARDL bounds test for cointegration valuation after confirming the series' stationarity properties. This study used an appropriate lag duration to calculate the F-statistic, which was based on the lowest

Table 3 The results of the correlation analysis

	LCO2	LGDP	LRNE	LURB	LIND	LTR	LAVA	LFA
LCO2	1.0000	0.9906	−0.9586	0.9917	0.4258	0.9324	−0.9455	−0.9753
LGDP	0.9906	1.0000	−0.9303	0.9902	0.7581	0.9129	−0.9329	−0.9903
LRNE	−0.9586	−0.9303	1.0000	−0.9475	− 0.5817	−0.9521	0.9524	0.9091
LURB	0.9917	0.9902	−0.9475	1.0000	0.6594	0.9263	−0.9545	−0.9834
LIND	0.4258	0.7581	−0.5817	0.6594	1.0000	0.5360	−0.5569	−0.5439
LTR	0.9324	0.9129	−0.9521	0.9263	0.5360	1.0000	−0.9087	−0.8878
LAVA	−0.9455	−0.9329	0.9524	−0.9545	− 0.5569	−0.9087	1.0000	0.9133
LFA	−0.9753	−0.9903	0.9091	−0.9834	− 0.5439	−0.8878	0.9133	1.0000

Table 4 Results of unit root testing

Logarithmic form of the variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LCO2	−0.8518	−5.8362[a]	0.4716	−5.9345[a]	−1.1056	−7.4015[a]
LGDP	0.0882	−5.4307[a]	0.3511	−5.0666[a]	0.2985	−5.9801[a]
LRNE	−1.3354	−5.7201[a]	−0.6583	−6.9035[a]	−1.3152	−6.9518[a]
LURB	0.9526	−2.3993[b]	−0.1965	−2.2524[c]	−2.3510[c]	−2.9819[b]
LIND	−1.6179	−4.8257[a]	−1.3441	−4.7418[a]	− 1.6357	−4.8304[a]
LTR	−1.8901	−3.1253[b]	− 1.1419	−3.0592[a]	−1.9096	− 2.6043[c]
LAVA	−1.4868	−4.6284[a]	−0.4889	− 4.2526[a]	− 1.6182	− 4.6529[a]
LFA	0.5394	−2.1778[c]	0.4789	−2.0535[b]	0.4692	−2.1778[c]

[a, b] and [c] denote significance at the 1%, 5%, and 10% levels, respectively

values of Akaike's Information Criterion (AIC). Table 5 presents the results of the ARDL bounds test, which has been used to investigate the cointegration relationship between the variables. The results are presented in such a way that if the estimated value of the F-test is greater than the values of both limits, the existence of a long-run relationship between the parameters is confirmed (lower and upper bound). The findings revealed that the estimated F-statistic value (5.786135) is higher than 10%, 5%, 2.5%, and 1% of the crucial upper limit in the order zero and one which rejects the null hypothesis by indicating that a long-run relationship exists among the respective variables.

Table 5 Findings from cointegration with ARDL bounds testing

F-bounds test		Null hypothesis: No levels of relationship		
Test statistic	Value	Significance	I(0)	I(1)
F-statistic	5.786135	At 10%	1.92	2.89
K	7	At 5%	2.17	3.21
		At 2.5%	2.43	3.51
		At 1%	2.73	3.90

3.4 The results of the DOLS

The results of the DOLS evaluation are presented in Table 6. The anticipated long-run coefficient of LGDP is positively significant at a 5% level while other factors remain constant, meaning that a 1% increase in economic growth may lead to a 0.39% increase in CO_2 emissions. The result indicates that higher economic growth in Turkey is associated with a reduction in environmental sustainability by increasing carbon emissions. Greater social demands engendered by increased consumption of fossil

Table 6 DOLS results: LCO2 is a dependent variable

Variables	Coefficient	Standard Error	t-Statistic	*p*-value
LGDP	0.385137[b]	0.162866	2.364751	0.0269
LRNE	−0.426375[a]	0.079077	−5.391875	0.0000
LURB	1.215950[a]	0.204108	5.597381	0.0000
LIND	0.243104[b]	0.146353	1.661073	0.0113
LTR	0.020580[b]	0.015558	1.322824	0.0198
LAVA	−0.123736[a]	0.038620	−3.203927	0.0039
LFA	−3.173348[a]	0.851360	−3.727385	0.0011
C	19.63786	8.342592	2.353928	0.0275
R^2	0.994994			
Adjusted R^2	0.993470			
Standard error of the estimate	0.027772			
F-statistic	653.0204			
Prob (F-statistic)	0.000000			
Root mean square error (RMSE)	0.023922			
Mean Absolute Error (MAE)	0.018410			

[a, b] and [c] denote significance at the 1%, 5%, and 10% levels, respectively

fuels and development projects lead to an increase in pollution, garbage generation, and damage to the environment as a result of rising economic growth in Turkey. Thus, economic activities would be focused on emission reduction and environmental protection rather than constituting a danger to long-term environmental quality. Moreover, the estimated coefficient of renewable energy consumption is negative at a 1% significant level, suggesting that expanding renewable energy use by 1% is associated with a 0.43% reduction in CO_2 emissions in the long run. The result indicates that incorporating more renewable sources of energy into Turkey's total energy mix could help the nation reduce CO_2 emissions. As per the finding of the study, renewable energy use seems to have a vital role in controlling CO_2 emissions in Turkey. Turkey is an energy-dependent nation and its economic growth is crucial for providing the resources needed for continuous production. Enhancing renewable energy use instead of fossil fuels would not only promote Turkey's economic expansion and minimize environmental deterioration with cleaner production, but it would also give the country the chance to play a leading role in the global system and increase its competition with more advanced countries.

The predicted long-run coefficient of LURB is positively significant at a 1% level, implying that a 1% growth in urbanization results in a 1.22% rise in CO_2 emissions. This illustrates that the massive growth of the urban population is endangering the environment's long-term quality. According to the results of this study, Turkey's urbanization resulted in a rise in energy consumption bolstered by non-renewable fossil fuels, resulting in higher CO_2 emissions. It's not unexpected that CO_2 emissions respond so strongly when their sources are three channels: electronic component usage; construction, infrastructure development; and mass transport. Rapid urbanization raises energy needs, raises GHG emissions and wreaks havoc on the environment in urban regions (Raihan et al. 2022c). In addition, because the metropolitan zone is among the most electricity-intensive regions of the economic system, an increase in the need for electronic devices (conditioning, appliance, lights, refrigeration, and so on) leads to increased CO_2 emissions. Nevertheless, urbanization has a favorable effect on economic growth, which is related to CO_2 emissions (Raihan et al. 2022c).

Furthermore, at a 5% significance level, the projected long-run coefficient of LIND is significantly positive, implying that an increase of 1% in industry value added is associated with an increase of 0.24% in CO_2 emissions. The evidence revealed that growing emissions in Turkey are partly attributable to industrialization. Industrialization might generate emissions from industrial effluents, hazardous commodities, and heavy metals, damaging the atmosphere's performance while also increasing fossil fuel energy usage. At the beginning of industrialization, there was a shift from agricultural to resource-related heavy manufacturing, with adjustments mostly in the size and mix of production instead of the rate of technological advancement. Thus, the CO_2 emission rate was higher in the early stages of industrialization because of the high demand for energy and the lack of energy-saving equipment. This course of evolution may result in changes in industrialization, resulting in fewer polluting operations and cleaner production.

The estimated long-run coefficient of tourism is positive at a 5% significant level, implying that a 1% spike in the tourism industry causes a 0.02% rise in CO_2 emissions. The result indicates that increased tourism activities worsen air quality through accelerating environmental degradation in the country. According to the finding, growth in foreign visitor arrivals in Turkey boosts energy usage resulting in a negative impact on climate change. The tourist industry is among the prominent reasons for poor environmental quality, leading to CO_2 emissions from not only transportation but also heat and electricity generation (Raihan et al. 2022c). Deforestation is one of the most significant environmental consequences of widespread tourism expansion. Tourism events degrade the ecological landscape and detract from its allure. The accumulation of rubbish can turn a lovely spot into a landfill and increase emissions. Furthermore, airplanes, hotel accommodations, and motorized water supply activities all contribute to increased carbon emissions (Raihan et al. 2022c).

However, at a 1% significance level, the projected coefficient of agricultural productivity is significantly negative, implying that a 1% increase in agricultural productivity leads to a 0.12% decline in CO_2 emissions. Agricultural and environmental concerns are not always conflicting, according to the finding, instead, they are complementary, because increasing agricultural productivity and effectiveness also supports the protection of the environment in Turkey by reducing CO_2 emissions. Agricultural production benefits the environment by absorbing CO_2 from the atmosphere and storing it as biomass or soil carbon. According to the IPCC (2014), attaining the potential to cut GHG emissions from agriculture might not only lead to a clean and healthy environment but could also bring new revenue opportunities as more agricultural activities might be conducted. If appropriate treatment and technologies are applied, carbon released by agricultural activities can be retained. Carbon emitted by agricultural operations can be captured and used to reduce one's carbon footprint if treatment and technology are used appropriately. By developing organic and low-carbon agricultural practices, sustainable agriculture can cut emissions and improve carbon storage.

Moreover, at a 1% significance level, the long-run coefficient of forest area is significantly negative, indicating that growing forest area by 1% results in a 3.17% reduction in CO_2 emissions. Forest ecosystems enhance the level of Turkey's environment, according to this study, because forests capture CO_2 from the atmosphere and preserve it in forest vegetation and soil. In the long run, boosting forest carbon sinks via expanding forest reserves mitigates environmental deterioration, according to the empirical findings. Increasing forest carbon sequestration is by far the most cost-effective way of preventing environmental deterioration and mitigating global climate change (Raihan et al. 2019). Restoring, enhancing, and conserving forests is a critical goal for mitigating climate change, and this is a sticking point in today's climate science community. Additionally, forestry-based mitigation practices (e.g., forest protection, afforestation, natural regeneration) have multiple functions, such as carbon sequestration, biodiversity conservation, ecosystem rejuvenation, and societal production of products and services (Raihan and Said 2022). Through the extensive application of forestry-based mitigation strategies, Turkey's forestry sector has a significant ability to alleviate global climate change by lowering CO_2 emissions and improving forest biomass thereby expanding the country's carbon sink. In a nutshell, enhancing forest areas could be a good way to cut Turkey's carbon emissions.

The empirical findings reveal that economic expansion, urbanization, industrialization, and tourism degrade Turkey's environmental quality by increasing CO_2 emissions while rising renewable energy use, agricultural productivity, and forest area could assist Turkey to attain environmental sustainability by lowering emissions. Furthermore, from both a conceptual and a pragmatic viewpoint, the indications of the predicted coefficients are identical. The calculated model's goodness of fit was also evaluated using a range of diagnostic tests in this study. The R^2 and adjusted R^2 values, correspondingly, are 0.9949 and 0.9934, implying that the derived regression model fits quite well. This signifies the explanatory variables can describe 99% of the overall changes of the predictor variables. Second, the F- statistic demonstrates that the dependent and independent variables corroborate the DOLS model that has been established. With a *p*-value of 0.0000, the F- statistic indicates that the regression model is statistically significant. Third, model predictions were accurately estimated using the root mean square error (RMSE) and the mean absolute error (MAE). The RMSE and MAE figures are nearly zero and non-negative, showing that the DOLS modeling produced results that were an accurate match to the data. To validate the intensity of the cointegration valuation, this study used normality, heteroscedasticity, and serial correlation analysis. The diagnostic test findings are presented in Table 7. The model indicates normality and it also reveals that there is neither autocorrelation nor heteroscedasticity. We also used the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) tests to ensure the model's stability. Figure 1 depicts the CUSUM and CUSUMQ graphs at a significance level of 5%. The residual values are shown as blue lines, whereas the levels of confidence are shown as red lines. The calculated findings show that the analyzed residuals' values continue to stay inside the boundaries of confidence at a 5% significance level of significance, confirming the model's stability.

4 Discussion

4.1 Economic growth and emission reduction

The current study explored the link between economic growth and environmental damage in Turkey. The results revealed that economic growth causes environmental degradation by increasing CO_2 emissions in the long run. The finding is supported by other Turkish studies, for instance, Ozturk and Acaravci (2013), Yavuz (2014), Bölük and Mert (2015), Seker et al. (2015), Destek and Ozsoy (2015), Dogan (2016), Kizilkaya (2017), Katircioğlu and Taşpinar (2017), Cetin et al. (2018), Pata (2018), Oğuz et al. (2020), Eyuboglu and Uzar (2020), Malik (2021), and Karaaslan and Çamkaya (2022), found a positive association between GDP and CO_2 emissions. The outcomes of the current research recommended that Turkish authorities develop an environmental management system that minimizes CO_2 emissions while

Table 7 The outcomes of diagnostic testing

Diagnostic tests	Coefficient	*p*-value	Decision
Jarque-Bera test	0.697340	0.7056	Residuals are normally distributed
Lagrange Multiplier test	2.308274	0.1419	No serial correlation exits
Breusch-Pagan-Godfrey test	1.365371	0.2829	No heteroscedasticity exists

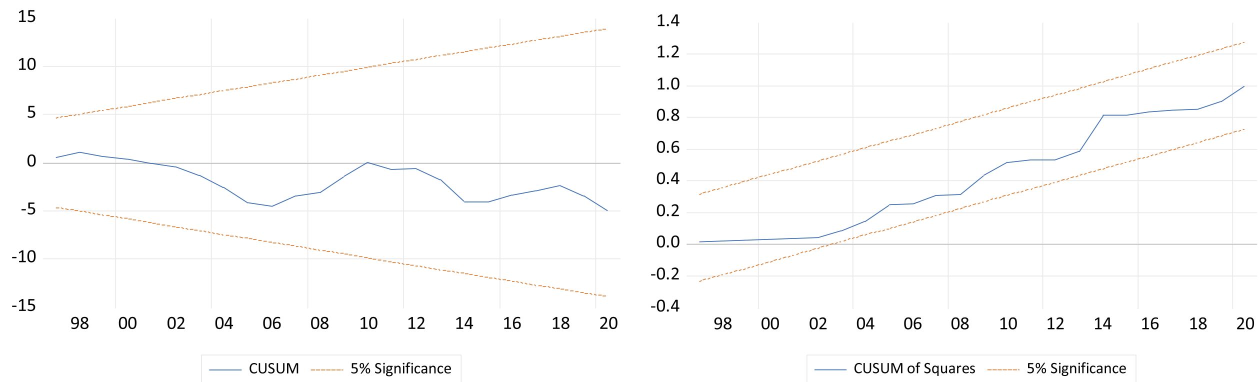


Fig. 1 The plots of the CUSUM and CUSUMQ tests (critical bounds at 5% significance level)

maintaining economic progress. In Turkey, the ultimate option for mitigating climate change is a low-carbon economy. To minimize contamination at its source, the "pollute first, then treat" policy and economic growth at the price of the environment might be modified. In this context, the study recommended that the administrations assist markets by establishing robust regulation that improves long-term emission reduction targets and continuously supports cleaner production with carbon-reducing technologies. The Turkish government can implement laws such as high carbon taxes, carbon capture and storage, and emission trading programs to limit CO_2 emissions through fossil fuel use across electricity production and industries. Furthermore, fostering the economic switch to renewables is crucial for mitigating the environmental effects of economic expansion. These steps would stimulate economic growth and increase the share of renewable energy usage in final energy consumption by substituting CO_2 -intensive traditional energy sources. Additionally, organizational coordination is essential to promote renewable energy use across all economic operations to ensure long-term economic growth.

4.2 Emission reduction through renewable energy use

This study investigated the possibility of using renewable resources to accomplish environmental sustainability in Turkey. According to the results, renewable energy use has a negative and significant correlation with CO_2 emissions. The finding of this study is consistent with Karaaslan and Çamkaya (2022) research, which showed that renewable energy helps Turkey's environment by lowering CO_2 emissions. As climate change plaguing, using renewable resources for power generation is vital for guaranteeing cleaner production, sustainable growth, and climate change mitigation (Raihan et al. 2022d). However, Turkish environmental policy includes sustainable development through the renewable energy sector, particularly for wind and geothermal power that can aid Turkey in resolving its energy problem. Amidst this, technological, organizational, societal, governmental, and financial barriers have hampered the acquisition and utilization of sustainable resources. Turkey could implement measures to decrease the price of renewable energy while preventing the consumption of fossil fuels in industry, businesses, and families. The government would encourage the use of energy-efficient residential equipment and more inexpensive renewable energies in the domestic sector. The government might formulate and maintain appropriate policies to promote investment in the development of renewable energy technology, resulting in increased renewable energy usage. Furthermore, Turkey would be successful in establishing technical cooperation partnerships with EU countries whilst still researching renewable energy technology proactively. The government may use media to spread its green living idea including low-carbon lifestyles and consumer behavior.

4.3 Emission reduction through sustainable and green urbanization

The influence of urbanization was analyzed by this study, and the findings demonstrated a positive and significant effect on Turkey's CO_2 emissions in the long run. The current study's finding on urbanization is compatible with those of other Turkish studies, such as Destek and Ozsoy (2015), Cetin et al. (2018), Pata (2018), Oğuz et al. (2020), and Malik (2021). Turkish authorities should set legislation to design and provide environmentally friendly urban and smart building technology. The Turkish administration must focus its attention on the development, enhancement, and support of sustainable and green urbanization, which will help to improve the performance and sustainability of economic growth while avoiding environmental mortification. Rapid urbanization degrades the ecosystem, necessitating urban development plans through improving energy efficiency, the deployment of technology innovation, and the promotion of sustainable lifestyles. As a result, authorities may promote sustainable and green urbanization to reduce the possibility of environmental degradation, and increase the role of renewables in following urbanization, such as the use of electric automobiles, solar lights, ethanol for vehicles, and so on. Furthermore, due to its capacity to absorb roughly 1000 kg of CO_2 per tree, green vegetation in the manner of planting trees is yet an alternative technique for reducing CO_2 emissions and decreasing urban heat. However, precautions are needed to preserve harmony between rural and urban populations to avoid migration to metropolitan areas and overburdening urban infrastructure. As a result, the government may encourage people to avoid megacities like Istanbul in favor of mid-sized and small cities (MSCs). Additionally, the government may stimulate industry development and job creation in rural areas. Such measures can increase overall economic growth in cities, alleviate the load on megacities, and boost the competitiveness of MSCs.

4.4 Emission reduction through green industrialization

The present analysis found a long-term positive and strong link between industrialization and CO_2 emissions. The finding of the study is corroborated by other research on Turkey, such as Pata (2018), who found a positive link between industrialization and CO_2 emissions. The current research's findings imply that industrialization is a major issue that should be prioritized when developing sustainability initiatives. The industrial framework must be properly altered and optimized to sustain economic growth through cleaner production while minimizing CO_2 emissions. Established industrial operations in Turkey that are liable for emissions and public health dangers must take adequate measures to prevent pollution. Moreover, foreign investors must comply with regulations and constraints to implement cleaner production and green industrialization plans. Energy usage and production must be sustainable for green industrialization, particularly renewable energy use increasing. Furthermore, the authority might use administrative means to strengthen the reformation of heavy- and high-emissions businesses while still encouraging zero- and low-emissions industries by supporting industrial diversification. The use of ecologically friendly techniques must be made compulsory for the entire industry sector, and the use of obsolete, polluting technologies must be forbidden for a cleaner production system. Furthermore, the government may assist firms in acquiring machinery to reduce emissions. If any industry does not adopt inclusive technologies, policymakers may consider imposing environmental levies. Additionally, governmental and non-governmental research and development organizations are necessary to limit contamination through advanced technologies, whilst encouraging the use of recycled industrial waste as a source of energy, resulting in lower emissions.

4.5 Sustainable tourism and emission reduction

This study observed a significant positive link between tourism and CO_2 emissions in Turkey. The finding of this study is aligned with Eyuboglu and Uzar (2020), who spotted a positive connection between the tourist industry and CO_2 emissions in Turkey. Therefore, in order to offset tourism's negative impacts on society, the environment, the climate, and the economy, sustainable tourism should be established. Tourism is unquestionably important for Turkey's economic growth and ought to be properly promoted and expanded. Turkey's focus on long-term tourism growth is crucial, as the nation is quickly discovering the need of understanding the interaction between progress and environmental protection, amidst worries that tourism is straining the nation's fragile ecosystem. The Turkish government could create a framework that makes locals, tourists, and other parties accountable for their behaviors regarding the natural ecosystem of Turkey's tourist attractions. Tourists would not only have a considerably better trip but also be better educated if all tourism businesses went green and embraced sustainability in their activities. In addition to information booklets and leaflets, government service disclosures with clear graphs and charts could be dispersed to the wider populace as regularly as needed, together with the latest update on the governments' continuous green attempts and improvement, inspiring people to be aware of the value of saving energy, environmental protection, and to adopt green practices even on holidays. Moreover, transportation technological progress, including the use of energy-efficient airplanes and high-speed trains, must be encouraged. CO_2 emissions can be lowered by modernizing the public transportation system and financing energy efficiency and waste disposal as a result of increasing tourism. Additionally, to conserve the ecosystem in tourist hotspots, the authorities may levy and implement environmental charges. Furthermore, the government could make it simpler for businesses to employ green and low-carbon technology and alternative energies for transportation systems, logistics, accommodation, and other tourism-related activities, decreasing CO_2 emissions and minimizing resource overexploitation. Turkey may enhance its current sustainability initiatives and shine a light on other nations where the tourist industry is degrading the environment.

4.6 Climate-smart agriculture to reduce emissions

This study revealed a negative relationship between agriculture production and CO_2 emissions in Turkey, which is supported by Dogan (2016). Agricultural production first improves the quality of the environment before harming the environment, rendering the agriculture industry a CO_2 emitter (Raihan et al. 2022d). Conventional farming techniques should be updated with new techniques, which might enhance agriculture productivity and cut emissions whilst assuring food and nutrition security for Turkey's rising population. For the transformation of the food and agricultural sectors to more ecologically friendly and climate-resilient methods, many worldwide organizations have recently created an initiative called climate-smart agriculture (CSA). The present research recommends Turkey's authorities develop effective strategies to enhance the environmental condition by enhancing agricultural productivity. The government may encourage the usage of clean renewable energy such as wind, solar, and biofuel, as it increases agricultural output while simultaneously aiding in the fight against global warming and climate change. Incentives for the use of renewable energy in farming would help the firm compete in global markets while releasing fewer pollutants. Other significant agricultural improvements include encouraging farmers to use solar tube wells for irrigation, organic farming, tunnel farming, transitioning from traditional tillage to no-till farming, and minimizing fertilizer use to reduce the environmental effect. These modern agricultural technologies can assist huge farms in reducing personnel, increasing output, and lowering emissions. Additionally, intensive farming investments in Turkey through increased international collaboration will help to reduce emissions from the Turkish agricultural sector while enhancing agricultural productivity.

4.7 Forest carbon sequestration to reduce emissions

This study found a negative association between forest areas and CO_2 emissions, which is supported by Begum et al. (2020), Raihan et al. (2022e), and Raihan and Tuspekova (2022g). Forest degradation has been viewed as a cause of the destruction of the environment since it is the second-largest emitter of CO_2 emissions in the world (IPCC 2014). As a result, limiting deforestation may be the most straightforward strategy to minimize CO_2 emissions. Moreover, the outcomes of this study recommended that Turkish policymakers formulate appropriate environmental and climate-resilient strategies, with a special focus on lowering CO_2 emissions via forest development. The Turkish government may increase investments while establishing strict forest rules aimed at reducing CO_2 emissions by enhancing forest biomass through forest protection and conservation. Additionally, the government may encourage private sector's participation in sustainable forest management by developing commercial forest plantation sections. Turkey may potentially collaborate with international organizations to attract more investment in CO_2 emission reduction initiatives through forestry sector development. Turkey can potentially increase its ability to mitigate climate change by enhancing forest carbon sinks by adopting a diverse range of forestry-based mitigation measures such as afforestation, reforestation, forest conservation, agroforestry, increased natural regeneration, and urban forestry.

5 Conclusions

By employing time series data from 1990 to 2020, this research examined the dynamic implications of economic growth, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions in Turkey. The ADF, DF-GLS, and P-P unit root tests were used in this study to determine the integration order of the dataset. In addition, the ARDL bounds test revealed evidence of cointegration among the variables in the long run. To assess the long-run effects of environmental factors, the DOLS model was utilized. The empirical outcomes revealed that a 1% rise in economic growth, urbanization, industrialization, and tourism will raise CO_2 emissions by 0.39%, 1.22%, 0.24%, and 0.02% in Turkey, respectively. Additionally, a 1% increase in renewable energy consumption, agricultural productivity, and forest area contribute to improved environmental quality by lowering CO_2 emissions by 0.43%, 0.12%, and 3.17%, respectively. The results provided insights into the possibility of renewable energy consumption, agricultural output, and forest areas to accomplish environmental sustainability in Turkey. Furthermore, the findings made recommendations regarding sustainable development in Turkey by building strong regulatory policy instruments to minimize environmental deterioration.

This research showed some major empirical results in the instance of Turkey, although the methodology had some shortcomings that could be addressed in future investigations. The scarcity of data on renewable energy consumption, tourism, and forest area outside its study period limited the analytical capacity of the econometric methodologies applied. Additional potential factors for reducing emissions and ecological sustainability, including recycling commodities, lowering water and electricity consumption, and switching to organic food, could be studied in future research. Furthermore, CO_2 was utilized as a measure of environmental pollution in this investigation. More exploration on consumption-based carbon pollution, as well as other emission measures such as methane (CH_4), nitrous oxide (N_2O), sulphur dioxide (SO_2), and short-lived climate forces (SLCF), is required. Although carbon emissions have been used as a proxy for environmental damage, it is not the only source of deteriorating environmental quality. Additional pollution measurements, such as water and land pollution, may be examined in the future.

Abbreviations

ADF: Augmented Dickey-Fuller; AFOLU: Agriculture, forestry, and other land use; AIC: Akaike's Information Criterion; ARDL: Autoregressive Distributed Lag; AVA: Agricultural productivity; CH_4: Methane; CO_2: CO_2 emissions; CSA: Climate-smart agriculture; CUSUM: Cumulative sum of recursive residuals; CUSUMQ: Cumulative sum of squares of recursive residuals; DF-GLS: Dickey-Fuller generalized least squares; DOLS: Dynamic Ordinary Least Squares; FA: Forest area; GDP: Gross domestic product; GHGs: Greenhouse gases; IND: Industrialization; IPCC: Intergovernmental Panel on Climate Change; LULUCF: Land use, land-use change, and forestry; MAE: Mean absolute error; MSCs: Mid-sized and small cities; N_2O: Nitrous oxide; P-P: Phillips-Perron; RMSE: Root mean square error; RNE: Renewable energy use; SLCF: Short-lived climate forces; SO_2: Sulphur dioxide; TR: International tourism; URB: Urbanization; WDI: World Development Indicator.

Acknowledgements

Not applicable.

Authors' contributions

AR and AT contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by AR. The first draft of the manuscript was written by AR and AT commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

Funding

No funding was received for this work.

Availability of data and materials

All data generated or analyzed during this study are available here: https://databank.worldbank.org/source/world-development-indicators

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

All the authors associated with this work declare that there is no conflict of interest.

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Received: 4 July 2022 Accepted: 6 September 2022
Published online: 26 September 2022

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