Received: 27 September 2022 | Revised: 21 October 2022 | Accepted: 22 November 2022
https://doi.org/10.56946/jeee.v1i2.486
Journal of Environmental and Energy Economics

Research Article

Nexus Between Agriculture, Economy, Energy Use, and Ecological Footprint Toward Sustainable Development in Bangladesh

Md. Shoaibur Rahman[1], Mohammad Ridwan[2], Asif Raihan[3*], Khayruzzaman[3], Tipon Tanchangya[4], Junaid Rahman[4], Md. Zia Uddin Foisal[5], Babla Mohajan[6], Samanta Islam[7]

[1]Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur 5200, Bangladesh.
[2]Department of Economics, Noakhali Science and Technology University, Noakhali 3814, Bangladesh.
[3]Institute of Climate Change, National University of Malaysia, Bangi 43600, Malaysia.
[4]Department of Finance, University of Chittagong, Chittagong 4331, Bangladesh.
[5]Department of Statistics and Data Science, Jahangirnagar University, Dhaka 1342, Bangladesh.
[6]Department of Land, Environment, Agriculture and Forestry, University of Padua, Padova PD 35122, Italy.
[7]Department of Environmental Science and Engineering, Jatiya Kabi Kazi Nazrul Islam University, Mymensingh 2220, Bangladesh.

*Corresponding author: Asif Raihan, Email: asifraihan666@gmail.com

Abstract

The primary endeavor of this research is to empirically explore the implication of agriculture, economic growth, and energy usage on the ecosystem damage in Bangladesh from 1971 to 2022. In light of this, we tested the agriculture-induced environmental Kuznets curve (EKC) hypothesis incorporating ecological footprint (EF) rather than emissions because EF better illustrates environmental degradation. Our findings from the dynamic ordinary least squares (DOLS) estimation confirm the validity of the EKC framework for Bangladesh. Consequently, ecological damage intensifies with economic development and is enhanced by an elevated gross domestic product (GDP). Moreover, a boost in both the agricultural value added and power consumption upsurges EF. To put it another way, utilization of energy and crop production are significant factors that affect the state of the planet. Consequently, the government ought to formulate strategies that foster long-term prosperity by promoting renewable power usage and climate-smart agriculture.

Keywords: Environmental degradation, ecological footprint, agriculture, economic growth, energy use, sustainability.

Introduction

Concerns around rising energy prices and volatility (energy security), as well as pollution and/or loss of biodiversity, have grown to be global issues recently [1]. Subsequent to the agricultural and industrial explosions, nations have intensified economic operations across several sectors (e.g., manufacturing, energy, transportation, and agriculture) to attain economic growth and advancement [2]. Nevertheless, these actions require significantly greater energy and exert strain on the ecosystem. International initiatives to address rising greenhouse gas (GHG) emissions include the Kyoto Protocol, which was established in 1987, and the Paris Agreement, which was enacted in 2015. By 2050, we anticipate a doubling of the world's economy, with robust GDP and population growth driving an almost 50% increase in energy demand [3]. Furthermore, with the exception of the COVID-19-related decline in 2020, worldwide pollutants have risen annually since 2015, the year of the Paris Conference of Parties. Energy conservation and alternative power resources serve as options to alleviate biodiversity loss and promote a green economy [2]. Within such structure, numerous governments have enacted incentive strategies, including feed-in tariffs, subsidies, mortgages, tenders, and taxes, to expedite the integration of clean energy supplies into their energy consumption.

Similar to energy, the demand for crop products has escalated to satisfy the requirements of the expanding world population. Figures recommend that the global population will attain 9 billion by 2050, a 34% increase from current figures, with 70% of individuals living in urban areas, approximately 49% more than currently [4]. Projections indicate that food production must rise by around 70% to satisfy the demands of the global population by 2050 [5]. Nevertheless, the global community views agriculture as a significant contributor to ecosystem pollution and deterioration. The augmentation of crop production results in heightened use of energy (particularly fossil fuels), fertilizers, and pesticides, which in turn generate CO_2 emissions and/or pollutants that contribute to environmental issues [6]. Furthermore, progressive agricultural practices necessitate the expansion of arable land, resulting in deforestation [7]. Agricultural practices, including the application of pesticides and herbicides, land reclamation, and bush burning, can lead to substantial environmental issues such as water and soil contamination, excessive water resource utilization, habitat destruction, GHG emissions, acid rain, and ozone depletion [8].

Approximately 25% of the released GHGs originate from agriculture, making it the second largest contributor to GHG emissions [7]. Moreover, agricultural activities, including growing crops, raising animals, irrigation, and the transportation of harvests, utilize over 70% of freshwater and account for around 5% of global energy consumption [9]. The increasing global need for food extends the agribusiness area, degrades the soil's regenerative capacity, and adversely impacts the sustainability of the next generation [6]. The United Nations (UN) devised 17 sustainable development goals (SDGs) to direct national policies towards sustainable development. The accomplishments of no poverty (SDG 1), zero hunger (SDG 2), positive health and well-being (SDG 3), gender equality (SDG 5), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8), sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), climate action (SDG 13), and life on land (SDG 15) are completely or in part interrelated with the connection between agricultural production and environmental quality [10]. The goal of zero hunger (SDG 2) has a direct link with agricultural efficiency.

Moreover, technology innovations like blockchain provide a safe means for enhancing agricultural productivity and food security by creating online personas and facilitating effective collaboration and ownership rights in farming operations [11]. Blockchain technology has the capacity to enhance sustainable agriculture, augment the role of women in the agricultural system, facilitate their empowerment, and improve their educational and health status [12]. Consequently, the agriculture industry, increasingly utilizing blockchain and information and communication technologies (ICTs), has emerged as a pivotal domain in forging the connection between technologies and the social aspect of long-term viability, as outlined by SDG 5. Consequently, the interplay among the agricultural sector, economy, energy consumption, and ecosystem has garnered the attention of scholars and policymakers to attain sustainable economic development [8].

The environmental Kuznets Curve (EKC) concept serves as the theoretical foundation for the economy-environment relationship, based on the seminal research of Grossman and Krueger [13], which offers viable remedies for environmental degradation. If the EKC holds true, then ecological issues will decrease as living standards rise. The EKC hypothesis posits that income growth has inverse consequences during the early phases of economic expansion, as the production framework predominantly relies on polluting technology. The EKC theory posits that environmental deterioration initially intensifies with rising affluence before subsequently improving with economic advancement, forming an inverted U-shaped correlation. The EKC relationship between GDP growth and the quality of the environment arises from the effects of size, technology, and composition. Numerous studies have examined the validation of the EKC and explored the relationship between GDP development and environmental damage, incorporating various control variables such as energy usage, renewable and fossil energy utilization, foreign direct investment (FDI), urbanization, industrialization, globalization, trade, financial growth, inequality in income, cost of electricity, ICT, and economic complexity [14-16].

In prior research, ecological damage has predominantly been characterized by CO_2 emissions. Consequently, as greenhouse gas emissions represent the sole atmospheric component of the destruction of the ecosystem, this methodology faces significant criticism within the fields of energy and environmental economics. Few EKC studies have adopted the ecological footprint (EF), a more comprehensive metric of environmental deterioration compared to emissions [17,18]. The EF is a comprehensive environmental metric that aggregates the effects of human behavior on air, water, and soil. We assess the impacts using six components: carbon, farmland, pastures, built-up land, fishing grounds, and forest footprints [19]. Consequently, researchers regard EF as a more potent predictor of sustainability. Nevertheless, a handful of research papers have investigated the implication of agricultural activity on ecological variables within the EKC literature, especially concerning rising nations such as Bangladesh. Figure 1 presents a categorization of EF by land type in Bangladesh.

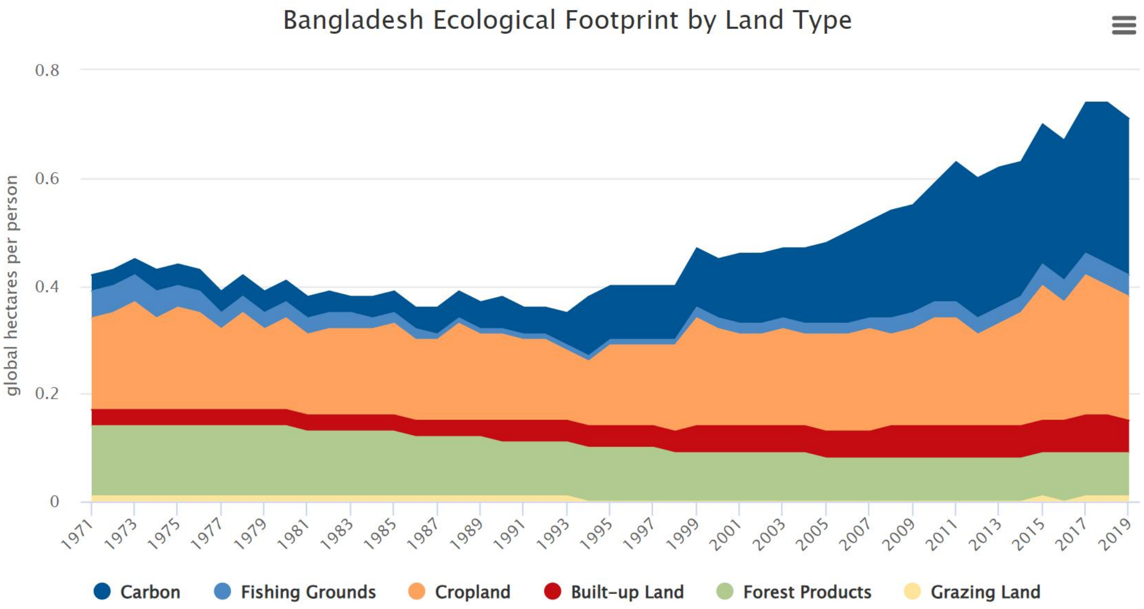

Figure 1. Ecological footprint by land type in Bangladesh [20].

The farming sector is crucial to Bangladesh in both financial and societal dimensions [6]. The agriculture industry represented 11% of Bangladesh's GDP and employed 37% of the entire labor force. The agriculture and energy sectors exhibit significant inter-industrial connections, with agriculture being the primary income-generating sector in Bangladesh's economy [6]. Energy consumption in Bangladesh's agriculture industry has risen markedly during the past 30 years, corresponding with the growth in agricultural production and exports. In 1990, the energy use in Bangladesh's agricultural industry was 11 petajoules (PJ), escalating to 52 PJ by 2018, indicating a significant reliance on energy within this sector [6]. Furthermore, the application of herbicides and fertilizers has escalated significantly during the past 50 years. In Bangladesh, fertilizer consumption rose from 13 kg per hectare of cultivable land in 1971 to 382 kg/hectare in 2021 [21].

Agriculture is the leading contributor of GHG emissions in Bangladesh, representing over 30% of total pollutants [6]. Despite the potential adverse effects of the agriculture sector on the country's environmental quality, both directly and indirectly, there have been limited studies investigating its influence on CO_2 emissions under the EKC framework in Bangladesh. These studies, however, concentrate solely on CO_2 emissions and neglect the effects of agricultural practices on EF. Moreover, these inquiries disclose contentious findings about the legitimacy of the EKC theory and the interaction between agriculture and the natural world. Furthermore, prior research offers less insight into the link between GDP growth, the agricultural sector, and environmental health, as it predominantly concentrates on air pollution. Using DOLS methodology and EF, this study is the first to assess the reliability of the agriculture-induced EKC hypothesis in Bangladesh from 1971 to 2022.

This study's contributions are as follows: Initially, the researchers employed the EF, a robust and comprehensive metric for assessing ecosystem health and sustainability in green economics, to analyze agriculture's impact on the planet. Secondly, we concentrate on Bangladesh, as there is no empirical study examining the role of agriculture on the EF in the country. Third, we utilized a multivariate model incorporating energy as an endogenous factor, as a bivariate model may yield biased outcomes. The exclusion of energy from the EKC modeling, given its strategic importance in the inverted U-shaped connection, results in conflicting outcomes. Fourth, we utilized a comprehensive and contemporary array of datasets covering the period from 1971 to 2022 (52 years). Fifth, our findings yielded significant results for the formulation of effective policies in the agriculture and power industries aimed at continuous prosperity in Bangladesh. Moreover, the examination of EF in agri-food production holds significant relevance for sustainable farming and long-term food safety.

Literature Review

The EKC literature has given rise to two primary study strands that examine the relationship between GDP, agriculture, and the state of the planet. The initial strand examines the relationship among GHG emissions (specifically CO_2 emissions), agriculture, and GDP. Although GHGs include CO_2, methane, nitrous oxide, and fluorinated gases, EKC modeling studies often use CO_2, as it accounts for approximately 76% of total GHG emissions. The second aspect of the EKC hypothesis examines the connection among agriculture, GDP, and EF, as EF serves as a more holistic indication than air pollution.

Agriculture and carbon emission

Despite numerous EKC evaluations incorporating various independent factors since the seminal work of Grossman and Krueger [13], the exploration of the link between farming and the planet commenced in the 2000s. Agboola and Bekun [22] used data from 1981 to 2014 and cointegration techniques in Nigeria to check the existence of an agriculture-induced EKC and look at how agriculture, FDI, trade liberalization, and electricity use affect CO_2 emissions. Their findings validated the presence of the EKC theory in Nigeria. Furthermore, the study revealed that, although agriculture and consumption of energy elevate pollutants, FDI inflow alleviates the release of CO_2. Moreover, Cetin et al. [8] used dynamic panel data with DOLS and FMOLS estimates to test the idea that farming caused EKC in 47 countries from 1976 to 2017. Their research confirmed the validity of the EKC concept in relation to GDP and CO_2 emissions, as well as the detrimental impacts of agriculture on the environment.

Doğan [23] looked at the influence of agriculture and GDP on CO_2 releases, supporting the inverted U-shaped relationship and the negative impacts of farming output on the natural world in China. Volkan et al. [24] examined the consequences of monetary sectors, including agriculture, electricity, waste, and manufacturing, on pollution in Turkey within the context of the EKC concept utilizing the ARDL approach. The analysis found no proof to support the EKC hypothesis or a significant correlation between CO_2 emissions in the farming and industrial sectors. Vlontzos et al. [25] employed the Eco-efficiency Index for agriculture and data from 1999 to 2002 to explore the inverted U-shaped link among EU regions. The analysis identified an N-shaped association between variables, indicating that agriculture is significantly unsustainable. Using the ARDL model and data from 1971 to 2014, Gokmenoglu et al. [26] proved that the EKC hypothesis was correct and found that agriculture, GDP, and energy use all have negative effects on China's GHG emissions.

Selcuk et al. [27] looked into how farming affects the release of CO_2 and tested the EKC hypothesis. They did this by looking at control variables like FDI, commerce, and power adoption for the Next Eleven (N-11) countries. The study, employing the panel cointegration approach and data from 1991 to 2019, yielded conflicting results. For instance, the agricultural sector reduces CO_2 emissions in Bangladesh and Turkey, whereas it exacerbates air pollution in Mexico. Furthermore, only Bangladesh, Mexico, Nigeria, and Turkey have validated the EKC. Parajuli et al. [28] conducted an analysis utilizing dynamic panel data from 1990 to 2014 to examine the influence of agriculture and forest areas on CO_2 outputs across 86 nations. Their findings indicated that an expansion of forested regions reduces emissions, whereas the agricultural sector exacerbates CO_2 pollution. Kara et al. [29] assessed the impact of agricultural land use on several agricultural goods in Turkey from 1988 to 2019. The research indicated that applying farmland for olive cultivation and fallow land elevates emissions while engaging farmland for fruits, drinks, and vineyards reduces CO_2 emissions in this country.

Ehigiamusoe et al. [30] examined the influence of three primary sectors on the ecology in Malaysia. The study, employing the ARDL technique, revealed that the banking sector reduces CO_2 emissions, but agriculture, industry, and other financial industries exacerbate them. Khan et al. [31] used panel quantile regression to look into the role of the agriculture sector, which included feed crops, along with control variables such as manufacturing capacity, green power, GNP, and foreign trade in thirteen developed countries and nine emerging countries. The research revealed that agricultural practices increase CO_2 emissions, and only high-quantile states confirm the EKC.

In contrast, certain research identified a beneficial effect of agriculture on the condition of the air. Gurbuz et al. [32] employed the ARDL technique and analyzed data from 1992 to 2014 to explore the influence of agriculture, energy usage, and GDP on the release of CO_2 in Azerbaijan. The findings validated the EKC hypothesis and reduced the influence of the farming industry on air quality in this nation. Ridzuan et al. [33] used the ARDL method to look at how agriculture, clean energy, urbanization, and GDP affected CO_2 emissions in Malaysia from 1978 to 2016. They found that the agricultural sector had a moderating effect on CO_2 emissions. Liu et al. [34] analyzed the impact of agriculture, green electricity, and GDP on CO_2 releases in four ASEAN nations from 1970 to 2013. Their findings did not corroborate the EKC hypothesis but highlighted the beneficial effect of agriculture on pollutants. Bas et al. [35] investigated the relationship between farm value-added, merchandise value-added, and export value-added concerning pollutants in Turkey from 1991 to 2019. The results corroborated the EKC concept and the reduction of CO_2 emissions from farming.

Agriculture and ecological footprint

Usman and Makhdum [36] employed dynamic panel data to examine the influence of agriculture, both sustainable and non-sustainable electricity, forest area, monetary growth, and GDP on environmental footprint in BRICS-T nations from 1990 to 2018. The research indicated that a rise in agricultural value adds to the EF. Furthermore, the results demonstrated the reciprocal influence of agricultural, financial expansion, and environmental factors in these nations. Alvarado et al. [37] examined the relationship among economic factors, research and development, agriculture, and global trade across 77 nations from various areas throughout the period from 1996 to 2016, employing the FMOLS methodology. The results demonstrated that agricultural value-added and trade openness contribute to elevated environmental degradation, as measured by the EF, across North America, Europe, and Central Asia. The research identified a causal link between agriculture and liberalization in commerce in these nations.

From 1975 to 2016, Udemba [38] used linear and nonlinear ARDL to examine the effects of FDI, agriculture, energy use, population, and GDP on India's ecology. The research identified unidirectional causal links among agriculture, FDI, electricity usage, and people with respect to EF. Moreover, Olanipekun et al. [39] substantiated the negative effects of agricultural practices on EF across 11 Central and West African nations. Muoneke et al. [9] examined the effects of farming and globalization on the environment, utilizing two distinct indicators (EF and CO_2) alongside control variables like fossil energy use, GDP, urban residents, and financial growth in the Philippines. The study provided evidence supporting the agriculture-induced EKC, positing that ecosystem damage initially escalates before subsequently improving as farming advances. Pata [19] examined the interplay between clean energy, globalization, and agriculture in relation to environmental harm, as evidenced by both EF and CO_2

emissions in the BRIC nations. The empirical data indicated that crop production is a significant contributor to ecological issues in these economies.

Soltani et al. [40] conducted an assessment and comparison of the resource footprints of various agricultural products using the "system for combined evaluation for water, land, food, and environment-SEA model" and data from 31 Iranian provinces over the 2013–2017 time frame. The study revealed that the generation of oilseeds had the biggest energy footprint compared to others. Furthermore, although cattle and poultry production exhibit the highest environmental footprint, wheat production represents the greatest consumption of water, energy, and other resources. Salari et al. [41] examined the influence of clean energy utilization, globalization, agriculture, and trade liberalization on the EF in 21 rising nations, utilizing a panel fixed-effect quantile regression model. The analysis revealed that, with the exception of globalization, several independent factors adversely affect the ecological condition in these 21 growing nations.

In contrast, some studies have identified a beneficial consequence of agriculture on economic growth. Aziz et al. [42] analyzed the effects of farming, both green and fossil-fuel power, forestry, and GDP on the Economic Growth Chain (EF) in Pakistan from 1990 to 2018. The findings corroborated the EKC hypothesis and demonstrated the decreasing influence of green power, forestry, and agriculture on EF. Haq et al. [43] employed ARDL to examine the consequences of agricultural exports and financial transparency on the environment in Pakistan, concluding that agricultural products enhance the surroundings.

The empirical work predominantly addresses CO_2 emissions and presents inconclusive conclusions. Furthermore, research concerning the adverse effects of AGR on EF lacks a theoretical foundation, as it typically presumes a linear correlation between the two. Consequently, given the scarcity of research on the influence of agriculture on ecological footprints (EF), our study aims to address this deficiency and enhance comprehension of the relationship among agriculture, GDP, energy, and EF in Bangladesh.

Methodology

Data and model

The literature allows for the analysis of a long-term link among EF, GDP, energy consumption, and agriculture in a quadratic functional manner. In order to assess the accuracy of the EKC hypothesis, we have established the following formula.

$$EF = f(Y, Y^2, E, A) \tag{1}$$

The endogenous variable EF shows the ecological footprint in global hectares per capita. The variables "Y" shows GDP per capita (in current USD) as a measure of economic growth, "Y^2" shows the square of Y, "E" shows energy consumption in kilograms of oil equivalent per capita, and "A" shows the agricultural value added as a percentage of GDP. We sourced the EF information from the Global Footprint Network (GFN) [20] and acquired the agriculture, GDP, and power usage statistics for Bangladesh from the World Development Indicators (WDI) [21] for the period from 1971 to 2022. The author converted the parameters into their natural logarithms to determine the growth rates of the factors of concern and the coefficients of elasticity. Equation (1) reformulated and transformed the model into the linear-logarithmic format.

$$LEF_t = \tau_0 + \tau_1 LY_t + \tau_2 LY_t^2 + \tau_3 LE_t + \tau_4 LA_t + \varepsilon_t \tag{2}$$

According to the EKC framework, the coefficients of τ_1 and τ_2 are anticipated to have positive and negative signs, respectively. It indicates that ecological damage increases as income levels rise, but as earnings rise above a certain threshold, this decline gradually decreases. The projected signals of τ_3 and τ_4 are positive, as larger power adoption and other earth assets, including land and water, exert a strain on the state of the planet.

Econometric methods

Employing a unit root examination is essential for avoiding flawed regression analysis. This method isolates the parameters in a regression to assure their stationarity, utilizing only stationary procedures to calculate the formula of concern. To fully comprehend cointegration across factors, empirical research emphasizes the necessity of first articulating the order of integration. Studies show that because unit root tests work differently depending on the size of the sample, it is important to use more than one when looking at the integration sequence of the series [44]. The Augmented Dickey-Fuller (ADF) [45], the Dickey-Fuller generalized least squares (DF-GLS) [46], and the Phillips-Perron (P-P) [47] tests were applied to detect the autoregressive unit root. Unit root tests have been carried out to make sure that no variables deviated from the amalgamation pattern and to support the DOLS system above traditional cointegration frameworks.

The dynamic ordinary least squares (DOLS) technique [48] was employed to assess the time series statistics. The DOLS cointegration process combines descriptive parameters and the leads and lags of the initial variance phase into the error covariance matrix, which then aligns endogeneity with the standard deviation calculations. The incorporation of the initial and final terms from the various parts demonstrates the orthogonalization of the error term. The DOLS estimator's standard deviations have a typical asymptotic distribution, making it an accurate proxy for testing statistical validity. Moreover, it can accurately approximate the dependent variable on illustrative factors at different levels, leads, and lags when there is a combined integration arrangement. This makes it easier to include certain factors in the cointegrated framework. Several additional factors in the regression were I(1) parameters, representing the leads (p) and lags (-p) of the initial variance, while other variables remained I(0) parameters with a constant term. The evaluation eliminates issues of small-sample bias, endogeneity, and autocorrelation by aggregating both leads and lags across representative variables [49]. Subsequently, the researcher deployed Equation (3) to estimate the long-run coefficient using the DOLS procedure.

$$\Delta LEF_t = \tau_0 + \tau_1 LEF_{t-1} + \tau_2 LY_{t-1} + \tau_3 LY^2_{t-1} + \tau_4 LE_{t-1} + \tau_5 LA_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LEF_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta LY_{t-i} + \sum_{i=1}^{q} \gamma_3 LY^2_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LE_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LA_{t-i} + \varepsilon_t \quad (3)$$

Results and discussion

Table 1 highlights the statistical description of the parameters for the time span 1971–2022. Skewness projections near 0 demonstrate that the parameters have a normal distribution. Additionally, the kurtosis data indicates that each dataset is platykurtic, with values below 3. Also, the Jarque-Bera probability evaluations suggest that each factor exhibits a normal distribution.

We conducted unit root assessments to demonstrate the superiority of the DOLS approximation model over mere cointegration, ensuring that no component exceeds the assimilation process. Unit root analyses are incorporated on parameters at logarithmic levels and logarithmic first differences. The null hypothesis for these tests posits that the series has a unit root. Table 2 showcases the outcome of unit root analysis with the ADF, DF-GLS, and P-P examinations. It demonstrates that all factors are non-stationary at levels (I(0)) but attains stationarity at the first difference (I(1)).

The DOLS assessment outcomes are shown in Table 3. The DOLS test findings indicate a substantial correlation between EF and other variables. It indicates that a 1% upsurge in GDP results in a 0.86% rise in EF at the 1% significance level, while a 1% surge in the square of GDP leads to a 0.29% drop in EF in Bangladesh. Notably, there is a strong negative coefficient in the square of GDP and EF, even though EF and GDP have a positive relationship. This shows that economic growth and EF are connected in a nonlinear, inverted U-shaped way. Consequently, those findings corroborate the accuracy of the EKC for Bangladesh [50-55]. Our outcomes align with previous studies that confirmed the agriculture-induced

EKC for different countries [8,9,22,26,27,32,35,42]. This hypothesis suggests that countries prioritize economic growth over environmental concerns during the transition from an agricultural to an industrial economy. However, at high-income levels, the demand for environmental protection increases.

Table 1. Descriptive statistics

Variables	LEF	LY	LE	LA
Mean	-0.76	6.04	4.96	3.21
Median	-0.85	5.97	4.91	3.15
Maximum	-0.31	7.89	5.62	4.13
Minimum	-1.04	4.51	4.42	2.42
Std. dev.	0.23	0.87	0.37	0.49
Skewness	0.66	0.56	0.33	0.28
Kurtosis	1.98	2.49	1.80	2.12
Jarque-Bera	5.14	3.27	4.07	2.15
Probability	0.15	0.21	0.13	0.34
Observations	52	52	52	52

Note: LEF = ecological footprint, LY = economic growth, LE = energy USE, LA = agricultural value added, *** indicates significance at a 1% level.

Table 2. Results of unit root test

Variables	ADF		DF-GLS		P-P	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LEF	-0.96	-7.42***	-0.92	-6.38***	-0.96	-7.23***
LY	-0.34	-6.84***	-0.30	-6.48***	-0.38	-6.61***
LE	-0.38	-4.68***	-0.36	-3.85***	-0.39	-4.32***
LA	-0.99	-6.64***	-0.75	-5.70***	-0.95	-7.73***

Note: ADF = Augmented Dickey-Fuller test, DF-GLS = Dickey-Fuller generalized least squares test, P-P = Phillips-Perron test, LEF = ecological footprint, LY = economic growth, LE = energy use, LA = agricultural value added, *** indicates significance at a 1% level.

Table 3. DOLS test results.

Variables	Coefficient	Standard error	t-statistic	p-value
LY	0.86***	0.20	4.23	0.00
LY^2	-0.29***	0.07	-3.87	0.00
LE	0.61***	0.11	5.61	0.00
LA	0.69***	0.10	6.83	0.00
C	9.82	7.27	1.35	0.00
R^2	0.97			
Adjusted R^2	0.96			
F-statistic	72.41			0.00
RMSE	0.02			
MAE	0.02			

Note: LY = economic growth, LY^2 = square of economic growth, LE = energy USE, LA = agricultural value added, RMSE = root mean square error, MAE = mean absolute error, *** indicates significance at a 1% level.

The LE factor is statistically significant at 1%, indicating that an additional 1% in energy consumption results in about a 0.61% spike in EF. The finding is supported by previous studies [56-61]. The ecological issues associated with the generation and use of power encompass air quality, global warming, water contamination, thermal emissions, and garbage disposal. The utilization of energy amplifies the ecological footprint as it exacerbates different environmental problems. The release of greenhouse gases from burning fossil fuels is the primary contributor to residential air contaminants. The demand for energy resources such as coal and oil increases Bangladesh's ecological footprint.

At the 1% threshold, agricultural value production has a favorable and statistically significant implication on the ecological footprint. A 1% boost in agricultural value-added leads to a 0.69% spike in EF. The estimated conclusions reveal that agricultural output in Bangladesh degrades its ecological integrity. Previous studies elucidate that farming methods necessitate the utilization of fossil fuels (such as diesel or oil) and amplified usage of nitrogen-rich fertilizers to safeguard crop harvests. Furthermore, methane and nitrogen oxide released through animal and farm operations are major contributors to air pollution. Consequently, crop cultivation may culminate in loss of resources (water, soil) and deforestation at a rate that exceeds the regrowth rate, particularly in emerging economies such as Bangladesh. These results prove that agriculture and energy usage harm the surroundings [18,19,37,38,39,41,62], aligning with some studies while contradicting a select few [42,43].

Moreover, the patterns of the projected coefficients are coherent from both a conceptual and a practical perspective. Additionally, multiple diagnostic methods were utilized to evaluate the adequacy of the calculated simulation. The regression model that was created fits the data well, with $R^2 = 0.97$ and modified $R^2 = 0.96$. This means that the explanatory parameters explain 96% of the variation in the predictor factors. Both the endogenous and exogenous parameters confirm the DOLS paradigm, as demonstrated by the F-value. The regression model is statistically significant, with an F-test p-value of 0.00. The RMSE and MAE were effectively utilized to determine the precision of the model's predictions. The DOLS procedure delivered outcomes that closely align with the statistics, as evidenced by the RMSE and MAE values being almost zero and non-negative.

To assess the adequacy of the DOLS model, we conducted the Breusch–Godfrey LM test for serial correlation, the Breusch–Pagan–Godfrey evaluation for heteroscedasticity, the Jarque–Bera test for the normality of residuals, and the Ramsey RESET test for model specification, outlined in Table 4. The marginal probability values for the Breusch–Godfrey LM test, Breusch–Pagan–Godfrey heteroscedasticity test, Jarque–Bera test, and Ramsey RESET analyses exceed 0.10. Diagnostic tests indicate a thorough distribution of residuals and the absence of problems such as serial correlation and heteroskedasticity in our estimation.

Table 4. Results of diagnostic test.

Diagnostic tests	Coefficient	p-value	Decision
Breusch-Godfrey LM test	0.75	0.41	No serial correlation
Breusch-Pagan-Godfrey test	1.03	0.35	No heteroscedasticity
Jarque-Bera test	1.58	0.89	Normal residual distribution
Ramsey RESET test	1.49	0.76	The model is properly specified

Note: LM = lagrange multiplier, RESET = regression equation specification error test.

Conclusions and policy recommendations

Prior agriculture-induced EKC investigations have a significant drawback in that they predominantly rely on CO_2 emissions to validate the EKC concept. However, pollutants alone cannot fully capture the entirety of ecological damage. This research, in addition to previous work, empirically analyzes the implications of agricultural output on EF, leveraging data from 1971 to 2022 and the DOLS technique. It also evaluates the agriculture-induced EKC for Bangladesh, considering energy as a control factor. It seeks to formulate strategies for long-term growth in this nation.

We can describe the principal conclusions of this inquiry as such. At first, the DOLS simulation results back up the idea that agriculture causes an inverted U-shaped connection between Bangladesh's GDP and EF. This underscores that expansion in GDP allows Bangladesh to mitigate loss of biodiversity and enhance environmental sustainability. The EF illustrates that ecosystem damage initially escalates with financial growth and subsequently develops as the economy expands. Secondly, energy consumption appears to degrade the natural world within the country. A 1% rise in energy usage elevates Bangladesh's EF threshold by 0.61%. Third, our statistics suggest that agricultural output in Bangladesh intensifies the nation's EF. A 1% boost in agricultural value added lifts Bangladesh's EF level by 0.69%. This outcome aligns with data reflecting a major increase in power and/or usage of electricity within Bangladesh's farming industry. The comparative analysis reveals that agriculture's adverse consequences for ecological health in Bangladesh surpass those of energy use. This is not surprising, considering that agriculture contributes to air pollution and depletes the earth's resources through the constant use of chemicals and herbicides. Our findings have several legislative consequences. Given that electricity utilization degrades the surroundings, Bangladesh must expedite the shift from fossil fuels to sustainable energy technology. Despite significant advancements in the adoption of clean power in Bangladesh, it is unable to maximize its green energy possibilities. So, more innovations in renewable energy, more incentives for incorporating alternative energy sources, and stricter environmental laws will all help Bangladesh cut down on pollution and grow its economy. Given that agriculture significantly impacts the state of the planet, the government should develop laws that encourage the use of greener alternatives such as solar, wind, biomass, biogas, and geothermal in crop cultivation while simultaneously reducing the exploitation of agricultural land. Furthermore, it is crucial to capitalize on the latest innovations in the agricultural sector to boost production while avoiding the application of fertilizers, power sources, and pesticides, thus averting further environmental damage. Moreover, ICT and modern technology may lessen emissions and resource utilization in the agricultural sector. Therefore, we must implement the green farming industry and smart crop cultivation solutions (Agriculture 4.0) to promote long-term prosperity. In this regard, as blockchain solutions promote the attainment of all SDGs, not only farming companies but all businesses ought to harness the benefits of this innovation to create strategies based on the blockchain platform.

This inquiry has certain drawbacks. Our research did not adjust for all the elements driving the EF in the country. Future studies might cover additional variables such as ICT, R&D, human capital, green energy, trade, and FDI that impact EF. Furthermore, future investigations could apply sophisticated econometric methods to explore the link between EF and its factors. Subsequently, future studies can discuss the connection within the context of various nations or groups of states, allowing us to compare the results with those of the present inquiry.

Funding: Not applicable.
Acknowledgment: Not applicable.
Conflict of Interest: The authors declare no conflict of interest.
Authors' contributions: Asif Raihan assisted in the study's conception and design. Material preparation, data collection, and analysis were done by Asif Raihan, Mohammad Ridwan, Md. Shoaibur Rahman, Tipon Tanchangya, Junaid Rahman, Khayruzzaman, Md. Zia Uddin Foisal, Babla Mohajan, and Samanta Islam. All authors read and approved of the final manuscript.
Data availability statement: Data supporting this manuscript will be provided upon reasonable request from the corresponding author.

References

1. Nazir, M. S., Ali, Z. M., Bilal, M., Sohail, H. M., & Iqbal, H. M. (2020). Environmental impacts and risk factors of renewable energy paradigm—a review. Environmental Science and Pollution Research, 27, 33516-33526.
2. Zhang, L., Xu, M., Chen, H., Li, Y., & Chen, S. (2022). Globalization, green economy and environmental challenges: state of the art review for practical implications. Frontiers in Environmental Science, 10, 870271.
3. Brugger, H., Eichhammer, W., Mikova, N., & Dönitz, E. (2021). Energy Efficiency Vision 2050: How will new societal trends influence future energy demand in the European countries?. Energy Policy, 152, 112216.

4. Klein, T., & Anderegg, W. R. (2021). A vast increase in heat exposure in the 21st century is driven by global warming and urban population growth. Sustainable cities and society, 73, 103098.
5. Tian, X., Engel, B. A., Qian, H., Hua, E., Sun, S., & Wang, Y. (2021). Will reaching the maximum achievable yield potential meet future global food demand?. Journal of Cleaner Production, 294, 126285.
6. Raihan, A., Muhtasim, D. A., Farhana, S., Hasan, M. A. U., Pavel, M. I., Faruk, O., ... & Mahmood, A. (2022). Nexus between economic growth, energy use, urbanization, agricultural productivity, and carbon dioxide emissions: New insights from Bangladesh. Energy Nexus, 8, 100144.
7. Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability, 12(22), 9375.
8. Cetin, M. A., Bakirtas, I., & Yildiz, N. (2022). Does agriculture-induced environmental Kuznets curve exist in developing countries?. Environmental Science and Pollution Research, 29(23), 34019-34037.
9. Muoneke, O. B., Okere, K. I., & Nwaeze, C. N. (2022). Agriculture, globalization, and ecological footprint: the role of agriculture beyond the tipping point in the Philippines. Environmental Science and Pollution Research, 29(36), 54652-54676.
10. Shayan, N. F., Mohabbati-Kalejahi, N., Alavi, S., & Zahed, M. A. (2022). Sustainable development goals (SDGs) as a framework for corporate social responsibility (CSR). Sustainability, 14(3), 1222.
11. Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. International Journal of Production Economics, 219, 179-194.
12. Tang, C. S. (2022). Innovative technology and operations for alleviating poverty through women's economic empowerment. Production and Operations Management, 31(1), 32-45.
13. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. The Quarterly Journal of Economics, 110(2), 353-377.
14. Pata, U. K. (2021). Renewable and non-renewable energy consumption, economic complexity, CO_2 emissions, and ecological footprint in the USA: testing the EKC hypothesis with a structural break. Environmental science and pollution research, 28, 846-861.
15. Pata, U. K., & Caglar, A. E. (2021). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: evidence from augmented ARDL approach with a structural break. Energy, 216, 119220.
16. Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080.
17. Ansari, M. A. (2022). Re-visiting the Environmental Kuznets curve for ASEAN: A comparison between ecological footprint and carbon dioxide emissions. Renewable and Sustainable Energy Reviews, 168, 112867.
18. Usman, A., Ozturk, I., Naqvi, S. M. M. A., Ullah, S., & Javed, M. I. (2022). Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: Fresh evidence from novel CS-ARDL model. Progress in Nuclear Energy, 148, 104220.
19. Pata, U. K. (2021). Linking renewable energy, globalization, agriculture, CO_2 emissions and ecological footprint in BRIC countries: A sustainability perspective. Renewable Energy, 173, 197-208.
20. GFN. (2022). Global Footprint Network. Available at: https://data.footprintnetwork.org/#/analyzeTrends?type=EFCpc&cn=16 (accessed 10 October 2022).
21. WDI. (2022). World Development Indicators. Available at: https://databank.worldbank.org/source/world-development-indicators# (accessed 10 October 2022).

22. Agboola, M. O., & Bekun, F. V. (2019). Does agricultural value added induce environmental degradation? Empirical evidence from an agrarian country. Environmental Science and Pollution Research, 26(27), 27660-27676.
23. Doğan, N. (2019). The impact of agriculture on CO_2 emissions in China. Panoeconomicus, 66(2), 257-271.
24. Volkan, Ö., Gözde, B., & Hasan, T. (2020). Review of Environmental Kuznets Curve Hypothesis Sectoral Basis: Case of Turkey. EKOIST Journal of Econometrics and Statistics, (32), 49-68.
25. Vlontzos, G., Niavis, S., & Pardalos, P. (2017). Testing for Environmental Kuznets curve in the EU Agricultural Sector through an eco-(in) efficiency index. Energies, 10(12), 1992.
26. Gokmenoglu, K. K., Taspinar, N., & Kaakeh, M. (2019). Agriculture-induced environmental Kuznets curve: the case of China. Environmental Science and Pollution Research, 26, 37137-37151.
27. Selcuk, M., Gormus, S., & Guven, M. (2021). Do agriculture activities matter for environmental Kuznets curve in the Next Eleven countries?. Environmental Science and Pollution Research, 28(39), 55623-55633.
28. Parajuli, R., Joshi, O., & Maraseni, T. (2019). Incorporating forests, agriculture, and energy consumption in the framework of the Environmental Kuznets Curve: A dynamic panel data approach. Sustainability, 11(9), 2688.
29. Kara, F., Bas, T., TIrmandioğlu Talu, N. H., & Alola, A. A. (2022). Investigating the carbon emission aspects of agricultural land utilization in Turkey. Integrated Environmental Assessment and Management, 18(4), 988-996.
30. Ehigiamusoe, K. U., Lean, H. H., & Smyth, R. (2020). The moderating role of energy consumption in the carbon emissions-income nexus in middle-income countries. Applied Energy, 261, 114215.
31. Khan, N., Ray, R. L., Sargani, G. R., Ihtisham, M., Khayyam, M., & Ismail, S. (2021). Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture. Sustainability, 13(9), 4883.
32. Gurbuz, I. B., Nesirov, E., & Ozkan, G. (2021). Does agricultural value-added induce environmental degradation? Evidence from Azerbaijan. Environmental Science and Pollution Research, 28, 23099-23112.
33. Ridzuan, N. H. A. M., Marwan, N. F., Khalid, N., Ali, M. H., & Tseng, M. L. (2020). Effects of agriculture, renewable energy, and economic growth on carbon dioxide emissions: Evidence of the environmental Kuznets curve. Resources, Conservation and Recycling, 160, 104879.
34. Liu, X., Zhang, S., & Bae, J. (2017). The impact of renewable energy and agriculture on carbon dioxide emissions: investigating the environmental Kuznets curve in four selected ASEAN countries. Journal of cleaner production, 164, 1239-1247.
35. Bas, T., Kara, F., & Alola, A. A. (2021). The environmental aspects of agriculture, merchandize, share, and export value-added calibrations in Turkey. Environmental Science and Pollution Research, 28(44), 62677-62689.
36. Usman, M., & Makhdum, M. S. A. (2021). What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. Renewable Energy, 179, 12-28.
37. Alvarado, R., Ortiz, C., Jiménez, N., Ochoa-Jiménez, D., & Tillaguango, B. (2021). Ecological footprint, air quality and research and development: The role of agriculture and international trade. Journal of Cleaner Production, 288, 125589.
38. Udemba, E. N. (2020). Mediation of foreign direct investment and agriculture towards ecological footprint: a shift from single perspective to a more inclusive perspective for India. Environmental Science and Pollution Research, 27(21), 26817-26834.
39. Olanipekun, I. O., Olasehinde-Williams, G. O., & Alao, R. O. (2019). Agriculture and environmental degradation in Africa: The role of income. Science of the Total Environment, 692, 60-67.

40. Soltani, E., Soltani, A., Alimagham, M., & Zand, E. (2021). Ecological footprints of environmental resources for agricultural production in Iran: a model-based study. Environmental Science and Pollution Research, 28(48), 68972-68981.
41. Salari, T. E., Roumiani, A., & Kazemzadeh, E. (2021). Globalization, renewable energy consumption, and agricultural production impacts on ecological footprint in emerging countries: using quantile regression approach. Environmental Science and Pollution Research, 28(36), 49627-49641.
42. Aziz, N., Sharif, A., Raza, A., & Rong, K. (2020). Revisiting the role of forestry, agriculture, and renewable energy in testing environment Kuznets curve in Pakistan: evidence from Quantile ARDL approach. Environmental Science and Pollution Research, 27, 10115-10128.
43. Haq, I. U., Khan, D. A., Taj, H., Allayarov, P., Abbas, A., Khalid, M., & Awais, M. (2021). Agricultural exports, financial openness and ecological footprints: An empirical analysis for Pakistan. International journal of energy economics and policy, 11(6), 256-261.
44. Raihan, A., & Tuspekova, A. (2022). The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: New insights from Peru. Energy Nexus, 6, 100067.
45. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 74(366a), 427-431.
46. Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). Efficient Tests for an Autoregressive Unit Root. Econometrica, 64(4), 813-836.
47. Phillips, P. C., & Perron, P. (1988). Testing for a Unit Root in Time Series Regression. Biometrika, 75(2), 335-346.
48. Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica: Journal of the Econometric Society, 61(4), 783-820.
49. Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096.
50. Sultana, N., Rahman, M. M., & Khanam, R. (2022). Environmental kuznets curve and causal links between environmental degradation and selected socioeconomic indicators in Bangladesh. Environment, Development and Sustainability. 24, 5426-5450.
51. Miah, M. D., Masum, M. F. H., & Koike, M. (2010). Global observation of EKC hypothesis for CO_2, SOx and NOx emission: a policy understanding for climate change mitigation in Bangladesh. Energy Policy, 38(8), 4643-4651.
52. Rahman, M. M., Karim, A. A. M. E., Ahmed, Z., & Acet, H. (2021). Environmental Kuznets Curve (EKC) for Bangladesh: Evidence from fully modified OLS approach. JOEEP: Journal of Emerging Economies and Policy, 6(2), 5-14.
53. Voumik, L. C., Rahman, M. H., & Hossain, M. S. (2022). Investigating the subsistence of Environmental Kuznets Curve in the midst of economic development, population, and energy consumption in Bangladesh: Imminent of ARDL model. Heliyon, 8(8), e10357.
54. Hasan, M. A., Nahiduzzaman, K. M., Aldosary, A. S., Hewage, K., & Sadiq, R. (2022). Nexus of economic growth, energy consumption, FDI and emissions: A tale of Bangladesh. Environment, Development and Sustainability, 24, 6327-6348.
55. Rahaman, M. A., Hossain, M. A., & Chen, S. (2022). The impact of foreign direct investment, tourism, electricity consumption, and economic development on CO_2 emissions in Bangladesh. Environmental Science and Pollution Research, 29(25), 37344-37358.
56. Nathaniel, S. P. (2021). Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. GeoJournal, 86(5), 2057-2070.
57. Rehman, A., Radulescu, M., Ma, H., Dagar, V., Hussain, I., & Khan, M. K. (2021). The impact of globalization, energy use, and trade on ecological footprint in Pakistan: does environmental sustainability exist?. Energies, 14(17), 5234.

58. Khan, I., & Hou, F. (2021). The dynamic links among energy consumption, tourism growth, and the ecological footprint: the role of environmental quality in 38 IEA countries. Environmental Science and Pollution Research, 28(5), 5049-5062.
59. Nathaniel, S., Nwodo, O., Adediran, A., Sharma, G., Shah, M., & Adeleye, N. (2019). Ecological footprint, urbanization, and energy consumption in South Africa: including the excluded. Environmental Science and Pollution Research, 26, 27168-27179.
60. Majeed, M. T., Tauqir, A., Mazhar, M., & Samreen, I. (2021). Asymmetric effects of energy consumption and economic growth on ecological footprint: new evidence from Pakistan. Environmental Science and Pollution Research, 28, 32945-32961.
61. Shahzad, U., Fareed, Z., Shahzad, F., & Shahzad, K. (2021). Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: New insights from quantile methods. Journal of Cleaner Production, 279, 123806.
62. Wang, L., Mehmood, U., Agyekum, E. B., Uhunamure, S. E., & Shale, K. (2022). Associating renewable energy, globalization, agriculture, and ecological footprints: implications for sustainable environment in South Asian countries. International Journal of Environmental Research and Public Health, 19(16), 10162.