



Do affluent nations value a clean environment and preserve it? Evaluating the N-shaped environmental Kuznets curve

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Abstract

Since industrialization, the world has been under great strain from rising temperatures. Economies work hard to boost economic growth by sacrificing natural surroundings that are degrading owing to increased carbon emissions from unsustainable production and consumption. The race-to-the-bottom strategy is seen in different parts of the globalized world, corroborating the pollution haven concept and energy-related emissions. The study assumed that once affluent nations reached a particular economic level, they would concentrate on environmental reforms to safeguard environmental and natural resources. The study built a model of the emissions-growth nexus by controlling inward FDI, information and communication technology, research and development expenditures, and renewable energy using aggregated data from high-income nations from 1976 to 2019. The study verified the N-shaped environmental Kuznets curve using a three-degree polynomial factor of per capita income. On the other hand, inward FDI was assessed as having the potential to support the pollution haven hypothesis (PHH) by increasing carbon emissions. The data show that the square and cubic forms of per capita income have a significant negative and positive effect on carbon emissions in the long run, corroborating the short-peak V-shaped EKC hypothesis. However, the N-shaped EKC hypothesis between income and emissions is verified in the short run. The PHH confirmed that more inward FDI is associated with higher long-term carbon emissions. For decreasing global carbon emissions and unclean production, stringent and incentive-based regulations are preferable.

Keywords Carbon emissions · Economic growth · Environmental Kuznets curve · FDI inflows · Pollution haven hypothesis · Renewable energy demand · High-income countries

Introduction

The environment is the cornerstone of human survival on this planet and the foundation of long-term human growth. Environmental sustainability has become the most prevalent and vital component of global development policy (Jianping et al. 2014). Environmental challenges that have been found globally hurt the economic prosperity of countries. It encompasses desertification, deforestation, a lack of clean drinking water, food scarcity, biodiversity loss, a high degree of fossil fuel use, soil resource depletion, ozone layer depletion, rising sea level, pollution, global warming, waste disposal, acid rain, overpopulation, and climate change (Qi et al. 2020). These issues may occur due to the mismanagement of natural resources, causing harm to our planet's ecology. One of the most severe consequences is the large-scale release of greenhouse gases and carbon dioxide generated by the combustion of fossil fuels in vehicles and

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industry (Singh and Singh 2017). Greenhouse gas emissions have a significant influence on the environment. According to the OECD and the United States Development Authority (USDA), this would result in a 2 °C increase in global temperature by 2050 and more earth changes (Arora 2018).

Human activities significantly influence the environmental system, which has a different impact on environmental flow at various sizes (Fu et al. 2021; Brueckner and Pforr 2011). Changes in farming techniques, the industrial revolution, deforestation, and environmental change all impact the composition of natural gases in the atmosphere. Humans are confronted with a reduction in freshwater, rich soil biodiversity, and a scarcity of many other natural resources (Maja and Ayano 2021, Millennium Ecosystem Assessment, 2005). Humans have wreaked havoc on the natural environment in pursuit of short-term benefits. It is difficult to measure the economic loss, and the survival rate on Earth is also decreasing (Arora 2018). According to Anand (2013), industrialized nations confronted these environmental issues due to their high living standards and economic prosperity as their economies expanded and pollution levels rose. At the same time, poverty is the primary cause of these difficulties in developing nations due to a lack of resources. These concerns have long-term consequences for the global economy and cannot be addressed unless a concerted effort is made to conserve the planet for future generations (Chen et al. 2021).

Environmental issues are a recent occurrence and a considerable threat to future generations. As a result, all of these concerns must be tackled collectively, with clear guidelines established for each nation to play its role in natural resource conservation to leave a habitable planet for future generations (Clayton 2020, Akdoğan and Hicyorulmaz 2015). Creating a sustainable environment is one of the most pressing issues confronting humanity today. It is the capacity to manage natural resources so that future generations can have a life that is at least as good as, if not better than, the present generations. Environmental sustainability is the preservation of essential goods or traits in the environment (Jenny et al. 2020; Woo and Kang 2020; Sutton 2004). It is the most effective strategy for dealing with humanity's rapidly rising population and broad exploitation of natural resources. If this is not addressed, future generations will confront a polluted environment and dwindling natural resources. Our primary obligation is to leave a secure world for future generations and other species that coexist with us (Arora 2018). Environmental sustainability may be utilized as a guide for making decisions regarding economic growth prospects that will help satisfy the demands of today's humanity (Hummels and Argyrou, 2021). The country's policies should maximize environmental advantages while minimizing environmental damage. Goals for sustainable development also include the long-term management of the planet's resources to enable

social and economic progress (Lee et al. 2020; Fulton et al. 2017).

Because the world is regarded as a global village, its real problems include air pollution, climate change, ozone layer depletion, and ocean pollution. These difficulties are unavoidable for countries (Chen et al. 2021). Nations should strive to keep the global average temperature below 2 °C. Cooperation and policy planning that reduce greenhouse gas emissions, promote socio-economic growth, and share technological knowledge and information without jeopardizing environmental sustainability are critical (UNFCCC, 2017). Countries are beginning to notice this and are taking significant measures to negotiate a wide variety of international accords to safeguard the environment and work together to preserve natural resources (Bille Larsen et al., 2021). These accords seek to preserve the planet's global integrity by conserving the environment and entertaining all world countries. Many agreements have been created to safeguard the environment; among those negotiated in the twentieth century are notable environmental protocols, treaties, and conventions, for example, the Montreal Protocol in 1987, the Kyoto Protocol in 1997, the Stockholm Convention in 2001, the Minamata Convention in 2013, and the COP24 and COP25 in 2018 and 2019, respectively (Bodansky 2020).

The Montreal Protocol is a multilateral agreement that governs the production, use, and disposal of ozone-depleting chemicals (ODSs) (Fang et al. 2018). The Kyoto Protocol is a convention that aims to reduce greenhouse gas emissions via active actions taken by member countries. Carbon dioxide, perfluorocarbons, sulfur hexafluoride, methane, nitrous oxide, and hydrofluorocarbons are examples of these gases (Rozen, 2015). The Stockholm Convention was established to safeguard human health against dangerous compounds that have been present in the air for a long time and are known as persistent organic pollutants (POPs) (Fiedler et al. 2019). The Paris Agreement's principal goal is to eliminate anthropogenic pollution to keep global temperatures below 2 °C. COP21 also attempts to create a framework to assist nations disproportionately affected by climate change. COP24 is a multilateral agreement and the 24th Conference of Parties (COP) with the UN Framework Convention on Climate Change (UNFCCC). The European Union and 196 nations took part in this accord, which established the regulations for the Katowice Rulebook, often known as the Paris Agreement (Rattani 2020). The Minamata Convention was implemented in 2013 to safeguard human health and the environment from the harmful effects of mercury and its derivatives. It focuses on the large-scale human activities that contribute to mercury contamination. The goal of COP25 was to complete the Katowice rules. COP25 was held to address all of the global climate change concerns that remained unresolved following the Paris accord of COP24.

As a result, the Katowice or Paris Agreement will be formalized at the 25th conference (Wu 2020).

The relationship between the natural environment and economic growth has been expressed in various ways. The EKC hypothesis is commonly used to study the link between these two variables. It explains why per capita income and pollution have an inverted U-shaped connection (Dinda 2004). It explains that environmental degradation increases in the early stages of economic development due to increased economic activity and massive exploitation of natural resources. However, when the economy reaches a certain level of development, pollution levels decrease due to increased public concern and awareness about environmental degradation (Stern 2004; Maneejuk et al. 2020). As public knowledge of environmental sustainability grows, industrialized nations embrace cleaner technology to safeguard the environment as their national income and living standards rise, boosting public demand for a safe environment (Grossman and Krueger 1991). As countries expand and their economic conditions improve, they will make strides toward reducing environmental deterioration (Sarkodie and Strezov 2018). Developing economies are primarily dependent on agriculture; as they progress, they shift toward industrialization, which raises pollution levels. As this trend continues, their income levels rise, their preferences shift, and they will now adopt greener technology. They are currently deploying their resources to minimize pollution levels, and environmental deterioration will begin to decrease at this point. The EKC hypothesis describes this behavior (Dermott et al., 2011). The accomplishment of increased economic development is the most challenging issue for developing countries to overcome to eradicate poverty. Nonetheless, increased utilization of natural resources is required to reach this goal. As a result, industries have grown, but the environment has deteriorated, and significant strain has been placed on the ecosystem (Li et al. 2021a, Babu and Datta, 2013).

The study offered the following research questions, which led to the research goals, based on the extensive debate on the given issue. First, do affluent nations tend to reduce carbon intensity after reaching a particular income level? This subject presents several concerns regarding meeting the United Nations' sustainable development objectives, which must be met by 2030. Complex industrialization processes and unsustainable production and consumption make this sustainability aim more perilous, resulting in higher world average temperatures. It is believed that higher-income nations would engage more in environmentally friendly manufacturing and consumption after they reach specific income thresholds in order to maintain an average temperature of fewer than 2 C. Second, does more incoming FDI raise carbon emissions due to insufficient environmental regulation? This question is critical for understanding the role of incoming FDI, which

has primarily engaged in environmental degradation policies due to the easing of environmental rules. Even though high-income nations adopt strict environmental rules that encourage filthy, polluting sectors to migrate to developing countries, the countries become net importers of pollution escalation. Finally, is there enough green energy infrastructure to cut carbon emissions? The high-income countries work hard to construct clean and green energy infrastructure. However, its contribution to overall energy use still needs more investment to replace conventional fuels with renewable fuels.

The study created the following research objectives based on the research questions:

- i) Examine the N-shaped EKC relationship between income and emissions in aggregated data of high-income nations.
- ii) Investigate the role of inward FDI and R&D expenditures on carbon emissions.
- iii) Determine the influence of renewable energy demand on carbon emissions.

These goals were designed to examine data from affluent nations' environmental sustainability agendas to go forward with green and clean environmental policies.

In many ways, this research differs from previous ones:

- I. The study incorporates three polynomials of per capita income into the carbon emissions model to test the N-shaped EKC hypothesis in the premises of technology transfer (i.e., ICT exports). Earlier research was primarily confined to a few other parameters when examining the N-shaped EKC link between income and emissions in various economic settings (see Allard et al. 2018, Gyamfi et al. 2021, Aljadani et al. 2021, Xu et al. 2020).
- II. The study assessed PHH in the context of inward FDI and carbon emissions by controlling for ICT exports, R&D expenditures, and renewable energy demand. Earlier research mainly examined the presented theory in light of many additional circumstances (see Bulus and Koc 2021; Singhania and Saini 2021; Bulut et al. 2021).
- III. The study employed aggregated data from high-income nations, which absorbed particular country shocks. At the same time, it provides a good representation of the entire high-income countries, allowing the results to be generalized properly.

The study is organized into the following sections, i.e., after the introduction in "Introduction," a detailed literature review is shown in "Literature review." "Data and methodological framework" contains the data and methodology, and

“Results and discussion” discusses the findings. The study is concluded in the final section.

Literature review

The environmental sustainability literature is mainly limited to one or two primary ecological study areas to add more causative elements to evaluate environmental policies for definitive results. The study split the previous literature into three different categories based on the need provided systematically.

Environmental Kuznets curve (EKC) literature

There has previously been a lot of debate and evidence on the degree of EKC link between different environmental toxins and development parameters. Various shapes and sizes of EKC connections were discovered in previous research across different economic contexts. For example, the EKC relationship indicates a U-shaped link between emissions and growth due to growing industrialization (see Aslam et al. 2021; Zhang and Chen 2021; Zhang et al. 2021). In certain circumstances, the EKC connection is N-shaped due to more money being invested in cleaner technology (see Kövendi and Nagy 2021; Sheng et al. 2021; Xu and Chen 2021). Furthermore, the inverted U-shaped connection arises in many cases due to strict environmental restrictions (see Ulucak et al. 2020, Jiang et al. 2020, Wolde-Rufael and Weldemeskel 2020). Exogenous shocks concerning economic uncertainty lead the connection between emissions and growth variables to flatten (see Anser et al. 2021a).

The detailed literature is presented to develop linkages to verify the EKC hypothesis across countries. For instance, Ridzuan et al. (2020) used data from 1978 to 2016 to investigate the relationship between carbon dioxide (CO₂) emissions, economic growth, urbanization, renewable energy, and agriculture subsectors in Malaysia. The research establishes an inverted U-shaped link between CO₂ emissions and economic growth. The results reveal that after a certain threshold, CO₂ emissions decrease as the economic growth expands. As per the investigation, the Malaysian economy should build a system that can minimize pollution and achieve sustainability, which is likely to be achieved by boosting renewable energy resources in agriculture. Between 1990 and 2014, Yao et al. (2019) analyzed the link between renewable energy and economic growth in a panel of 17 major developed and developing nations and six geoeconomic areas of the world to assess the existence of the EKC hypothesis. The findings confirmed the presence of the EKC hypothesis in all nations. According to the estimations, a 10% increase in renewable energy results in a 1.6% decrease in carbon emissions. As a result, expanding green

energy sources is critical to mitigating negative environmental externalities. Destek et al. (2018) used yearly data from 1980 to 2013 to examine EKC occurrence in European Union nations using ecological footprint instead of environmental deterioration factor. The findings verified the existence of a U-shaped link between environmental footprints and actual income. They also discovered a significant association between environmental deterioration and nonrenewable energy in EU nations, whereas trade openness and renewable energy are favorably connected with the environment. The green and clean energy requirement is critical to achieving the green development goal. Solaria et al. (2017) examined the relationship between CO₂ emissions, urbanization, hydroelectricity usage, and real GDP in India and China from 1965 to 2013. They discovered that EKC existed in both nations because real GDP and urbanization have a beneficial effect on CO₂ emissions. Emissions, on the other hand, are adversely associated with hydroelectricity usage. The findings underscored the need of stabilizing hydroelectricity pricing, which helped both countries.

From 2000 to 2017, Hove and Tursoy (2019) supported the U-shaped hypothesis for nitrous oxide emissions, fossil fuel energy consumption, and carbon emissions across 24 emerging economies. The necessity to enhance air quality indices across countries to minimize carbon abatement costs. From 1974 through 2016, Shahbaz et al. (2019a, b) investigated the EKC theory in Vietnam. The results reveal that EKC is only successful in the short run, not in the long run. The N-shaped EKC explains the long-run link between CO₂ emissions and economic growth. As a result, reducing CO₂ emissions is just temporary, and it will resume once the precise income level is reached. More policy measures were necessary by Vietnam’s government to reduce carbon emissions through greener technology. In the EKC hypothesis, Maneejuk et al. (2020) studied the links between environmental deterioration and economic growth. They featured 44 nations and covered the eight major international communities. The findings reveal that the EKC hypothesis exists exclusively for three communities: the OECD, the EU, and the G7. They also tested it in specific nations and discovered that, out of 44 countries, it is true in just nine of them. Financial development, urbanization, and industrial sectors, among other factors, have a detrimental influence on environmental sustainability, but renewable energy lowers CO₂ emissions. It is concluded that industrialized economies should increase green financing channels to provide clean and green energy for economic operations. Bulut (2021) investigated the EKC hypothesis in Turkey, using ecological footprints as an indicator of environmental destruction from 1970 to 2016, and discovered the validity of EKC for the country. Renewable energy negatively influences the ecological footprint, but industrialization has a positive impact on the ecological footprint. The report indicates that to achieve

energy efficiency, the government must support green and clean energy sources connected by R&D spending.

On a similar note, the most recent wave of literature is seen chiefly across many economic settings, for instance, Koonthar et al. (2021), Baloch et al. (2021), Adedoyin et al. (2021), Gyamfi et al. (2021), and Saqib and Benhmad (2021). These studies emphasized the need to improve environmental quality through various sustainable solutions, contributing to shared global wealth. The study offered the following research hypothesis, based on the given literature, i.e.:

H1: Economic growth likely follows a unique pattern with carbon emissions to validate the hump-shaped association.

Pollution haven hypothesis (PHH) reviews

The PHH evaluations mostly condemned increased inflows of foreign direct investment in unsustainable manufacturing and consumption, which has resulted in a deteriorating natural environment that must be protected from strict environmental rules. Guzel and Okumus (2020) investigated the reliability of PHH in five Asian countries between 1981 and 2014. The findings verified the presence of PHH and inverted U-shaped EKC in the nations studied. The growth in FDI inflows degrades the natural environment; hence, restricting filthy polluting companies through long-term regulatory measures is critical. To validate the PHH, Nathaniel et al. (2020) focused on the environmental difficulties encountered by ten coastal Mediterranean nations (CMCs) from 1980 to 2016. The data show that PHH does not exist in the CMCs. Furthermore, energy consumption has a detrimental influence on the ecological degradation necessary to employ green energy sources for long-term benefits. An et al. (2021) add to the existing research by studying Chinese outbound FDI-based PHH and induced income EKC data for 64 Belt and Road Initiative participating countries from 2003 to 2018. Their findings support the inverted U-shaped EKC theory and the PHH, indicating that Chinese outbound FDI raises carbon emissions from low- to middle-income nations. Furthermore, the findings revealed a positive link between people's connectedness and emissions and a negative relationship between inventions and carbon emissions. The need to develop innovative capacity can assist governments in reducing carbon emissions. Using panel data, Ahmad et al. (2020) evaluated the influence of income and FDI inflows on the natural environment in 28 Chinese provinces. The findings supported the pollution halo concept since FDI inflows and income were positively connected to better environmental quality. The stated hypothesis was confirmed in fifteen provinces, whereas PHH was proven in

seven. It has been shown that the influence of wealth and FDI inflows on the environment is unrelated to regional development. The findings showed that the government should control environmental laws for long-term development regardless of province development level.

Assamoi et al. (2020) examined the relationship between inward FDI and carbon emissions in Cote d'Ivoire from 1980 to 2014. The findings back with the PHH's conclusion that the government has to enact stricter environmental legislation in order to improve air quality indices. Hashmi and Alam (2019) studied the link between environmental policies, innovations, and carbon emissions in OECD nations from 1999 to 2014. The findings show that economic activity has a negative impact on carbon emissions. It has been demonstrated that a 1% increase in environmentally friendly legislation reduces carbon emissions by 0.017% and 0.03%, respectively. The incentive-based regulations aid in achieving the green growth objective across countries. Mert and Caglar (2020) used data from 1974 to 2018 to examine the association between inward FDI and environmental deterioration in Turkey. The findings supported the pollution halo hypothesis in both the short and long run. Cleaner technology obtained through foreign FDI may reduce dirty output in a country. Using data from 1971 to 2014, Nadeem et al. (2020) studied the existence of PHH for inflows of foreign direct investment for the four pollutants in the instance of Pakistan. The findings support the validity of PHH in Pakistan. To restrict the cost of emissions in a country, the country should adopt strict ecological rules. Marques and Caetano (2020) investigated the influence of foreign FDI on carbon emissions for 21 countries classified by income level from 2001 to 2017. According to the findings, more FDI reduces pollution in high-income nations while increasing low-income ones. These data indicate the presence of PHH in different nations. Environmental rules in middle-income nations also have an impact on trade globalization. It is advised that middle-income nations enhance their investment policies and evaluation standards to limit unsustainable production. Wang et al. (2020) investigated the influence of financial development, renewable energy consumption, human capital, and income on carbon emissions in N-11 nations between 1990 and 2017. According to the findings, financial development and income have a favorable influence on carbon emissions. Renewable energy and technical advancements, on the other hand, are adversely connected with environmental deterioration, which remains to offer a sustainable path to progress in green energy for achieving ecological sustainability. Zhuang et al. (2021) stressed the importance of attracting more foreign investment in cleaner technology innovation to help nations participating in the Belt and Road Initiative reduce carbon emissions. According to Razaq et al. (2021a), Chinese foreign investment is crucial for increasing productivity development in belt and

road initiative host countries, but its scale is limited due to technical limitations.

Recent literature has also validated several versions of financial development leading to a worsening natural environment in order to confirm PHH (see Khan and Ozturk 2021; Rehman et al. 2021; Yoon and Heshmati 2021). In other cases, the research supported the pollution halo hypothesis owing to the transfer of sustainable technology from one nation to another (see Ahmad et al. 2021a; Kisswani and Zaitouni 2021; Xu et al. 2021). The study offered the following research hypothesis, based on the relevant literature, i.e.:

H2: The pollution halo hypothesis is likely to be validated in the context of renewable energy consumption by a sustainable international collaboration of providing climate financing.

Cleaner technologies reviews

A wealth of literature on cleaner technologies and their influence on emissions control in many economic contexts, for instance, Ufua et al. (2020), examined waste management activities and their impact on a living organism's sustainable habitat. They have raised the issue of rubbish dumping in Nigeria, Ota, Idiroko Road, and Ogun State. According to the findings, the government and authorities paid less attention to effective waste management. As a result, individuals throw their trash everywhere, polluting the ecosystem. In order to safeguard the environment, there is an urgent need to create a drainage system for appropriately dumping waste. Nathaniel and Adeleye (2021) contributed to the prior research by assessing the many threats to the natural environment. The data for 44 African nations were used in the study, which spanned the years 1990 to 2016. The findings reveal that energy consumption, financial development, urban population, and per capita income are all adversely associated with lowering emissions that impede sustainable growth. On the other hand, domestic investment has aided in the transition to green development. Clean and green energy consumption and domestic investment are projected to synergize economic and environmental resources for broad-based growth. From 1995 to 2016, Hishan et al. (2019) assessed the United Nations' sustainable development objectives for carbon reduction and green development in a group of 35 sub-Saharan African (SSA) nations. The findings do not support the standard EKC concept, but they validate PHH across nations. The requirement for green knowledge transfer and long-term industrial infrastructure is critical for advancing Africa's green economic strategy. Hao et al. (2021) examined the influence of green development in enhancing environmental sustainability in the G7 nations from 1991 to 2017. The findings suggest that green growth

drivers positively influence achieving environmental sustainability. Cleaner technology and carbon-reduction initiatives aid in the transition to a healthier environment.

Danish and Ulucak et al. (2020) demonstrated the relationships between environmental technologies and green factors, allowing for the impacts of renewable and nonrenewable energy consumption in the BRICS nations from 1992 to 2014. The findings indicated that environmental technologies positively influence attaining environmental sustainability. Furthermore, renewable energy supports environmental sustainability, whereas nonrenewable energy impedes it. Reduced use of nonrenewable fuels in energy production is critical to mitigating negative environmental externalities, while cleaner technologies powered by renewable energy give a path to decent living. GuoandBai (2019) emphasized the need for public engagement in environmental preservation to achieve a green environment. The study used inter-provincial panel data from 2011 to 2015 to estimate public involvement in China. According to the findings, public engagement plays a significant role in environmental governance to promote improvements. It has been recommended that governments encourage public participation in environmental governance to better safeguard the environment. Zafar et al. (2020) explored renewable energy's function in creating a cleaner environment. They also examined the influence of education, FDI, natural resource availability, and economic growth on carbon emissions in OECD nations between 1990 and 2015. The findings suggest that renewable energy and education positively influence CO₂ emissions. On the other hand, FDI inflows and natural resource abundance degrade environmental quality. It has been concluded that governments should focus on renewable energy development and environmental education to safeguard the environment. Furthermore, it is thought essential to implement suitable policies to promote renewable energy resources to achieve carbon neutrality. Vilke et al. (2021) used empirical data from Lithuania in 2019 to investigate the effect of farmer awareness in environmental protection in cleaner production and co-efficiency. According to the survey, farmers' attitudes on environmental protection vary depending on farm size, years of experience, and other demographics. It is determined that raising farmers' awareness of environmental sustainability may significantly safeguard the ecosystem. In a panel of 11 nations, Razzaq et al. (2021b) determined that material footprints are increasing due to increased infrastructure development, continued economic expansion, population pressure, and globalization. Green innovation reduces material footprints significantly across countries, and the need to expand cleaner innovative technologies aids in mitigating negative environmental issues and achieving the global green development goal.

Additional research has prompted the need for cleaner technology to live a healthy and prosperous life (see Ullah

et al. 2021; Alola and Ozturk 2021; Awan et al. 2021a, b, c; He et al. 2021; Razzaq et al. 2021c). The study offered the following research hypothesis, based on the relevant literature, i.e.:

H3: Knowledge transfer, R&D expenditures, and renewable energy demand all probably contribute to lowering the cost of carbon emissions, which influences the achievement of the green growth agenda.

Earlier studies performed the emissions-growth nexus in the quadratic specification (see Anwar et al. 2021; Dinga et al. 2021; Filippidis et al. 2021) while ignoring the more polynomials in the stated nexus in regression apparatus across high-income countries. The N-shaped environmental Kuznets curve would provide a clearer view of the emissions-growth nexus since high-income nations begin to decrease environmental quality after beyond a specific income level. The tight environmental rules allow polluting companies to access manufacturing space in underdeveloped nations and test their ecological footprints in a pollution haven hypothesis. Furthermore, very little research included green energy demand, innovation, and technological spillovers in a regression apparatus in an aggregate data set of high-income nations, which is critical for developing sustainable policies. The offered study incorporated all of the aforementioned components in the emission-growth nexus in high-income nations data set, which aids in formulating a green and clean development plan.

Data and methodological framework

The study relied on numerous factors in carbon cost modeling to arrive at some significant conclusions. The study's outcome variable was carbon emissions, whereas the predictor factors were GDP per capita, FDI inflows, renewable energy demand, ICT exports, and R&D expenditures. Table 1 displays the variables and their descriptions.

From 1976 to 2019, annual aggregated data for high-income nations were utilized in the study. The data comes from the World Bank's World Development Indicator (WDI, 2021). Data on carbon emissions, renewable energy, and R&D expenditures are provided from 1976 to 2016, 1990 to 2015, and 1996 to 2018. The variable's previous and succeeding values are used to populate the data. Environmental degradation and climate change are increasingly becoming the most pressing issues confronting the modern world (Majeed and Ozturk 2020). The fundamental reason for this is economic and human activity. FDI, economic expansion, lifestyle, technical breakthroughs, and energy consumption patterns are factors influencing the environment and dictating the pattern of carbon emissions (Udemba 2021; Tahir et al. 2021). Environmental degradation increases as the economy expand and shifts from agricultural to industrial. However, after economic growth reaches a certain level, the degree of pollution drops because individuals with high per capita income demand more legislation to safeguard the environment. The EKC hypothesis, which depicts the inverted U-shaped link between environmental deterioration

Table 1 Description of variables

Variables	Measurement	Definition	Data source
CO2	CO2 emissions (metric tons per capita)	CO2 emissions are gases produced due to the manufacturing of cement and the burning of fossil fuels. CO2 emissions are caused by solid waste, liquid, and gas fuels. Carbon emissions, or greenhouse gases produced by releasing carbon into the atmosphere, are significant contributors to climate change	WDI (2021)
GDP	GDP per capita (annual %)	Gross domestic product per capita is a worldwide statistic used to assess an economy's growth; it is essentially the distribution of its total production to its population	WDI (2021)
FDI	Foreign direct investment inflows (% of GDP)	Foreign direct investment (FDI) is a type of cross-border investment. It is the value of any foreign investor's inbound investment in the host nation	WDI (2021)
REC	Renewable energy consumption (% of total final energy consumption)	The ratio of gross inland renewable energy consumption to total (primary) gross inland energy consumption is calculated for a calendar year. It is determined by averaging the total inland consumption of renewable energy sources	WDI (2021)
R&D expenditure	Research and development expenditure (% of GDP)	Research and development are current and capital expenditures made by the public and commercial sectors on creative work done to improve knowledge	WDI (2021)

and economic growth, is notable for this (Sarkodie and Ozturk 2020; Le and Ozturk 2020).

The validity of the N-shaped EKC for high-income economies is investigated in this study. The selection of high-income economies is based on the fact that they typically lead the world, determine the norms, and set the course for attaining sustainable development. It is accomplished via the creation and implementation of environmental rules. High-income countries' economies are mature, as seen by concentrated domestic spending. These countries transfer technologies to developing countries while emitting toxins into the environment. Pollution control technology and resources are available in high-income countries. As a result, climate change poses a modest danger (Li et al. 2021b; Ansari and Khan 2021). As a result, the study investigated the presence of N-shaped EKC in high-income nations and investigated how economic expansion harmed the environment. Furthermore, wealthy nations anticipate a temporary reduction in carbon emissions in the early phases, followed by a rise in emissions until another income turning point is reached. It is the actual rationale for the study's decision to undertake an N-shaped EKC on a panel of advanced economies.

The study used aggregated time series data from high-income countries; however, it did not use panel data. The rationale is that vast cross-country differences mislead the overall results. The World Development Indicators published by the World Bank collected the aggregated data in a time series. The study used the same data and applied techniques for parameter estimates. The earlier studies, including Nasani et al. (2019), Anser et al. (2021b), and Yu et al. (2021), used the world aggregated time series data for estimations, and, given the justification that the aggregated data absorbs the country's shocks, hence, the results can be generalized in a more sophisticated manner.

Theoretical framework

The study was inspired by Solow's (1956) growth model, which presented a continuous production function (PF) that linked output to interchangeable labor and capital inputs. This relates to output (Y), capital (K), labor (L), and technology (A). Solow discussed the fundamentals of the growth accounting concept.

$$Y(t) = F(k(t), A(t)L(t)) \quad (1)$$

The equation illustrates how the output is affected by the K , L , and "A" components. Where "t" denotes time, there is a propensity for the capital-labor ratio (K/L) to fluctuate over time, and the output will change over time if the input is altered. To begin with any K/L ratio, Solow's model is convergent to steady state. The constant returns to scale (CSR) in the efficacy of L and K is one of the model's most

crucial assumptions. If effective labor and capital were to double, production would also double. If these inputs were multiplied by any nonnegative constant c , the output would be multiplied by the same constant.

$$Y(t) = F(cK, cAL) = cF(K, AL) \text{ for all } c \geq 0 \quad (2)$$

The assumption of CRS enables us to write the above-stated function in given form.

$$F\left(\frac{K}{AL}, 1\right) = \frac{1}{AL}F(k, AL) \quad (3)$$

Here, $\frac{K}{AL}$ is the capital per unit of effective labor, and $\frac{1}{AL}F(k, AL)$ is output per unit of effective labor. This equation can be written as follows:

$$y = f(k) \quad (4)$$

showing that output is the function of the capital per unit of effective labor. This intensive form of PF assumes to satisfy the following assumptions.

$$f'(k) > 0 \quad f''(k) < 0 \quad (5)$$

The Cobb–Douglas PF with CRS takes the following form:

$$Y = K^\alpha AL^{1-\alpha} \quad 0 < \alpha < 1 \quad (6)$$

The coefficients of labor and capital are the elasticity of output.

Dividing equation (VI) by effective labor force (AL) expresses physical capital stock per worker and output. That is:

$$y = k^\alpha \quad (7)$$

where y shows real GDP per effective worker and k represents the physical capital stock per effective worker. Logarithmic form of above equation is as follows:

$$\ln y = \alpha \ln k \quad (8)$$

The purpose of this research was to take the N-shaped EKC hypothesis for high-income economies to the test. Several factors have impacted the environment, including GDP per capita, inward FDI, renewable energy, and R&D spending. These factors may have varying effects on the environment; for instance, GDP per capita increases carbon emissions, which degrade the natural environment. More emissions are required for the economy to grow (Wang et al. 2020; Nathaniel and Adeleye 2021). Inbound FDI may positively or negatively influence carbon emissions; if it is about cleaner technology, it will benefit nations; this circumstance is known as the "pollution halo theory" (Mert and Caglar, 2020). Furthermore, if inward FDI has a detrimental impact on the environment, it will support PHH. In this situation,

due to rigorous environmental rules imposed by industrialized nations, filthy, polluting sectors have migrated to developing countries. The developed world would be the sole importer of polluting commodities, jeopardizing the global healthcare agenda (Assamoi et al. 2020). Because of increasing R&D investment in energy efficiency, renewable energy is anticipated to positively influence air quality (Wang et al. 2020; Bulut 2021).

Based on this theoretical framework, this model adopts the following functional form, i.e.:

$$C = f(Y, Y^2, Y^3, FDI, RDE, REC) \tag{9}$$

where C shows CO2 emissions, Y, Y², and Y³ show the three-degree polynomials of per capita income, FDI shows inbound inflows, RDE shows R&D expenditures, and REC is renewable energy consumption.

The econometric model is represented in the natural logarithm to display the results in elasticities form. The model is given below:

$$C = \beta_1 + \beta_2 Y + \beta_3 Y^2 + \beta_4 Y^3 + \beta_5 FDI + \beta_6 RDE + \beta_7 REC + \epsilon_t \tag{10}$$

Dinda (2004) examined the various orders of polynomials used to detect the emissions-growth nexus, including quadratic and cubic versions, and found seven alternate explanations, i.e.:

- i) $\beta_2 = \beta_3 = \beta_4 = 0$: The order of polynomials of economic growth per capita up to three degrees is assumed to have a flat relationship with carbon emissions per capita.
- ii) $\beta_2 > 0, \beta_3 = \beta_4 = 0$: The coefficient of per capita income is positive with per capita carbon emissions. In contrast, the second and third-degree growth polynomials with per capita carbon emissions remain insignificant, showing the monotonic increasing relationship.
- iii) $\beta_2 < 0, \beta_3 = \beta_4 = 0$: The coefficient of per capita income is negative with per capita carbon emissions. In contrast, the second- and third-degree growth polynomials with per capita carbon emissions remain insignificant show the monotonic decreasing relationship between them.
- iv) $\beta_2 > 0, \beta_3 < 0, \text{and } \beta_4 = 0$: The positive relationship between economic growth and per capita emissions at the initial level, while at later stages, this relationship is averted at second order of polynomial verifying an inverted U-shaped relationship between them in the absence of third-degree of the polynomial.
- v) $\beta_2 < 0, \beta_3 > 0, \text{and } \beta_4 = 0$: The negative relationship between economic growth and per capita emissions at initial level, while at later stages, this relationship is averted at second order of polynomial verifying the U-shaped relationship between them in the absence of third degree of polynomial.

vi) $\beta_2 > 0, \beta_3 < 0, \text{and } \beta_4 > 0$: The positive relationship between economic growth and per capita emissions at the initial level, while this relationship is averted at the second order of the polynomial at later stages. However, at the positive presence of third order of polynomial relationship verifying the N-shaped relationship between them, and

vii) $\beta_2 < 0, \beta_3 > 0, \text{and } \beta_4 < 0$: The negative relationship between economic growth and per capita emissions at the initial level, while at later stages, this relationship is averted at second order of the polynomial. However, the negative presence of the third order of polynomial relationship verifying the opposite to the N-shaped curve.

Figure 1 shows the different shapes of EKC hypothesis for ready reference.

The quadratic version of EKC covered the country’s attempts to minimize emissions by promoting economic growth from the pre-industrial to the postindustrial eras (services sector). On the other hand, after reaching a certain threshold level, where continued economic growth significantly reduces pollution levels, pollution levels rise due to stringent environmental regulations. It provides a vacant space for dirty polluting firms to establish production plants in developing countries; emissions are required for the development. As a result, the developed world is expected to be the importer of polluting commodities. The use of higher-order polynomials for EKC testing necessitated a large data set of variables, which was limited in the study; hence, the study confined their estimate to the third order of polynomials.

Econometric framework

The autoregressive distributed lagged (ARDL) cointegration technique was used in the study to examine the connection between the outcome variable and its predictors. This approach is usually used to deal with distinct integration orders, such as I(0), I(1), or a mix of both, and a single long-run cointegration relationship between variables with a limited data set. The ARDL approach has two significant advantages: multiplier analysis and forecasting. The ARDL specification is shown in Eq. (11), i.e.:

$$\begin{aligned} \Delta C_t = & \alpha_0 + \sum_{i=1}^a \alpha_{1i} \Delta C_{t-i} + \sum_{i=1}^b \alpha_{2i} \Delta Y_t \\ & + \sum_{i=1}^c \alpha_{3i} \Delta Y_t^2 + \sum_{i=1}^d \alpha_{4i} \Delta Y_t^3 \\ & + \sum_{i=1}^e \alpha_{5i} \Delta FDI_t + \sum_{i=1}^f \alpha_{6i} \Delta REC_t \\ & + \sum_{i=1}^i \alpha_{7i} \Delta RDE_t + \beta_1 C_{t-1} + \beta_2 Y_t \\ & + \beta_3 Y_t^2 + \beta_4 Y_t^3 + \beta_5 FDI_t + \beta_6 REC_t + \beta_7 RDE_t + \epsilon_t \end{aligned} \tag{11}$$

The equation given above β represents the long run, and α shows the short-run cointegration between

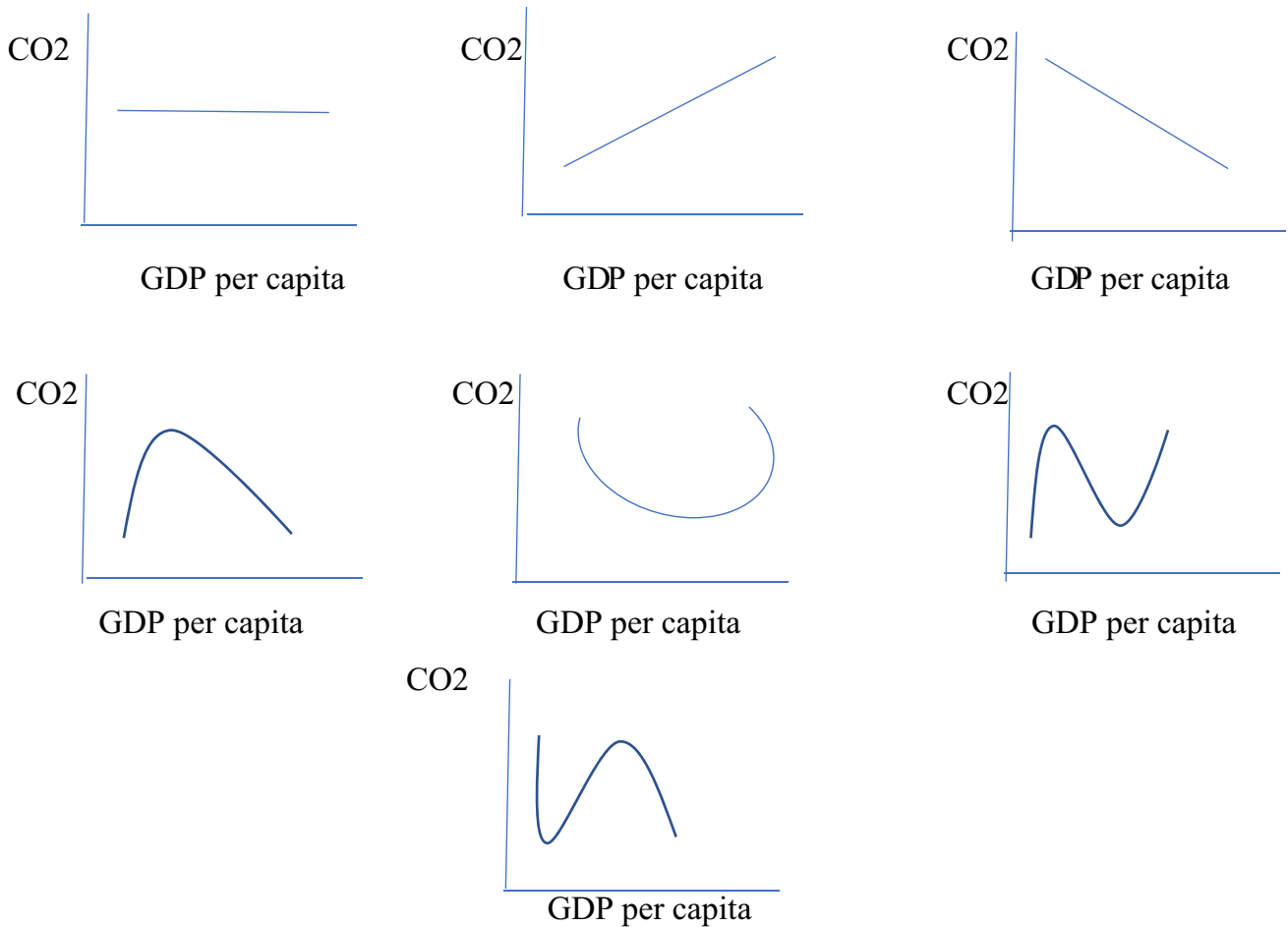


Fig. 1 Different shapes of EKC hypothesis. Source: Adapted from Dinda (2004)

variables. In this test, null hypothesis will be $H_0 : \beta_1 = \beta_2 = \beta_3 = \dots = \beta_7 = 0$ which means that there is no long-run relationship between these variables, while in H_1 , there is at least one long-run cointegration relationship between these variables. F-statistics is used to assess the significance of Wald test-derived connections. If the estimated F value is larger than the crucial value, the null hypothesis is rejected. However, if it is less than the crucial value, we do not reject the null hypothesis and conclude that there is no cointegration connection between these variables. Furthermore, within the upper and lower boundaries, it represents the ambiguity in making any choice and should be referred to as another cointegration approach.

As a prior estimation, we need to specify the lag length. Mainly the AIC and SBC are used to choose the appropriate lag length. If there exists the cointegration, we need to estimate the long-run equation, which is given below:

$$C_t = \alpha_0 + \beta_1 C_{t-1} + \beta_2 Y_t + \beta_3 Y_t^2 + \beta_4 Y_t^3 + \beta_5 FDI_t + \beta_6 REC_t + \beta_7 RDE_t + \epsilon_t \tag{12}$$

Assume that these variables have a long-run connection. We estimate the short-run equation in such an instance, expecting the error correction term (ECT) to be negative and demonstrating convergence to equilibrium. The ECT specification is shown in Eq. (13), i.e.:

$$\Delta C_t = \alpha_0 + \sum_{i=1}^a \alpha_{1i} \Delta C_{t-1} + \sum_{i=1}^b \alpha_{2i} \Delta Y_t + \sum_{i=1}^c \alpha_{3i} \Delta Y_t^2 + \sum_{i=1}^d \alpha_{4i} \Delta Y_t^3 + \sum_{i=1}^e \alpha_{5i} \Delta FDI_t + \sum_{i=1}^f \alpha_{6i} \Delta REC_t + \sum_{i=1}^i \alpha_{7i} \Delta RDE_t + \epsilon_t \tag{13}$$

Table 2 Descriptive statistics

	CO ₂	FDI	RDE	REC	Y
Mean	11.38387	1.742894	2.251224	7.642393	1.895782
Maximum	12.21222	5.890323	2.590132	11.26110	5.376971
Minimum	10.39275	0.315809	2.158549	6.392024	−4.008624
Std. dev	0.522336	1.475179	0.130982	1.760924	1.553259
Skewness	−0.293455	1.010156	1.226920	1.195299	−0.964558
Kurtosis	2.050531	3.028523	3.296722	2.804932	5.986060
Sum	569.1934	87.14472	112.5612	382.1197	94.78910
Observations	44	44	44	44	44

Table 3 Correlation estimates

	CO ₂	FDI	RDE	REC	Y
CO2	1				
FDI	0.089	1			
RDE	−0.497	0.572	1		
REC	−0.535	0.589	0.950	1	
Y	0.265	−0.152	−0.308	−0.304	1

Source: Author’s estimation

Table 4 Unit root results

Variables	Level	1st difference	Remark
CO2	−0.348 (0.551)	−5.691*** (0.000)	I (1)
FDI	−1.178 (0.214)	−6.361*** (0.000)	I (1)
RDE	−1.377 (0.855)	−4.584*** (0.000)	I (1)
REC	−1.333 (0.867)	−3.601*** (0.009)	I (1)
Y	−2.857*** (0.005)	−8.543*** (0.000)	I (0)
Y ²	−3.221*** (0.002)	−8.624*** (0.000)	I (0)
Y ³	−4.104*** (0.000)	−9.128*** (0.000)	I (0)

*, **, and ***show 10%, 5%, and 1% significance level. Small bracket shows probability values

Results and discussion

Table 2 displays the variable’s descriptive statistics. The average amount of CO2 emissions is 11.38 metric tonnes, 0.5 units more than the national average. Inbound FDI accounts for 1.74% of GDP on average, and R&D spending accounts for 2.25% of GDP. The use of renewable energy has remained stable at 7.64% of total energy consumption. Finally, GDP per capita was increasing at 1.89% per year.

Table 3 displays the correlation matrix estimates. The findings reveal that inbound FDI and per capita income increase carbon emissions, but R&D expenditures and REC significantly reduce carbon emissions over a given period. As a consequence, the PHH and technology embodied emissions were partially supported. However, in the aggregated

Table 5 F-bound test results

F-bounds test	Null hypothesis: no levels relationship			
	Test statistic	Value	Significance	I (0) I (1)
			Asymptotic: n = 1000	
F-statistic	3.989271	10%	1.92	2.89
k	7	5%	2.17	3.21
		2.5%	2.43	3.51
		1%	2.73	3.9

Source: Author’s self-calculation

Table 6 Long-run estimates of ARDL

Variables	Coefficient	Std. error	t-Statistic	Prob
Y	0.001282	0.218644	0.005864	0.9954
Y ²	−0.110785	0.049343	−2.245183	0.0342
Y ³	0.034505	0.014891	2.317141	0.0293
FDI	0.494731	0.210928	2.345495	0.0276
RDE	0.114735	3.527951	0.032522	0.9743
REC	−0.227189	0.348312	−0.652258	0.5204
C	8.624597	5.343826	1.613937	0.1196

Source: Author’s self-calculation

statistics of high-income nations, innovative elements and green energy helped the environmental sustainability goal.

The ADF unit root test was used to examine variable stationarity under the null hypothesis of a unit root. Table 4 indicates that the variables, i.e., I(1) and I(0) of integration, are intermingled. The outcome variable, CO2 emissions, is a differenced stationary variable. Furthermore, inbound FDI, REC, and RDE exhibit the first differentiated series. Three polynomials of per capita income, on the other hand, are level stationary. As a result, the volatility is most evident in the data sets of carbon emissions, inward FDI, RDE, and REC.

The ARDL test, as described by Pesaran et al. (2001), can be used to examine the relationship between variables. This approach is mainly employed when dealing with variables

integrated of distinct orders, regardless of whether they are all level stationary, all first difference stationary, or a combination of both. Before using ARDL, the model's lag length must be determined. For lag selection, we use the AIC. The chosen model is ARDL (3, 3, 2, 2, 0, 0, 2); after the lag is determined, the ARDL test may examine the long-run cointegration of CO₂ emissions and other explanatory variable factors. At a 1% significance level, the ARDL F-statistics (i.e., 3.989) exceed the upper critical constraint. As a result, the null hypothesis of no cointegration was rejected, and it was established that long-run cointegration among variables exists (see Table 5).

The study estimates ARDL short- and long-run estimates after establishing the long-run relationship between the variables. The ARDL estimations are shown in Table 6 for ready reference. The long-run results revealed a clear, V-shaped association between CO₂ emissions and economic growth. The square and cubic transformations of per capita income indicate decreasing and increasing carbon emissions levels, respectively, and increasing per capita income changes. Because the per capita income level data is not statistically significant, the V-shaped findings are generated using the square and cubic transformations of the per capita income. To validate the PHH, the coefficient of inward FDI reveals a positive impact on carbon emissions. These findings contradict Shao (2018), but they corroborate Malik et al. (2020), Shahbaz et al. (2019a, b), and GUO and Zhang (2012). Furthermore, the findings are consistent with Kheder and Zugravu (2008) and Guzel and Okumus (2020). Cleaner technology is critical for economic development and plays a critical role in long-term development. Toxic materials are being reduced, industrial waste is being lowered, and other preventative steps are being taken (Muralidharan, 2021). These technologies support environmentally friendly manufacturing methods such as recycling, biodegradable goods, carbon emission reduction, alternative energy usage, and technology to reduce air pollution, noise, soil, water, and solid waste (Ihsanullah et al. 2021; Mendes 2012). This is a systematic and inventive approach to improving the manufacturing process, services, and products while reducing their environmental effect through proactive measures (Chiappello and Engels 2021; Fresner 2004). Cleaner technology success is critical for sustainable communities since it is one of the key actions of firms aiming to improve environmental management (Benabdellah et al. 2021; Neto and Jabbour 2010). These approaches may be used to convert raw materials, improve manufacturing processes, safely dispose of trash, recycle unavoidable waste, generate atmospheric water, and make the best use of energy and water (Muthu 2020). Cleaner production is a type of environmental performance that may be accomplished by planned activities that optimize natural resources while reducing the negative

impact of technology and efficient management strategies (Al-Swidi et al. 2021).

Environmental innovation and green productivity development are critical for reducing ecological damage (Ahmad and Wu 2022). Furthermore, advancements in cleaner industrial technology will aid in the achievement of the green growth goal (Anser et al., 2021c). Incorporating green energy sources into conventional energy sources aids in achieving energy efficiency, which improves environmental quality (Iqbal et al. 2021). When encouraging inward FDI into the green development agenda to raise the percentage of green energy sources, which helps minimize carbon emissions, the pollution halo theory would be validated (Ahmad et al. 2019). Li et al. (2021c) stressed the need to improve export diversification to minimize polluting commodities exports by incorporating energy efficiency into the manufacturing process. According to Rehman et al. (2021), green energy sources and sustainable trade are critical for lowering carbon emissions and providing a path toward green development.

Table 7 displays the short-run findings for ready reference. As three-degree income polynomials followed the trend of increasing, decreasing, and increasing carbon emissions, the results proved the validity of the N-shaped EKC hypothesis. Gyamfi et al. (2021), Shahbaz et al. (2019a, b), and Özokcu and Özdemir (2017) all corroborate the findings. Furthermore, renewable energy and inward FDI are other essential factors. The initial value of inward FDI and renewable energy corroborated the negative and positive impact on carbon emissions, validating the pollution halo hypothesis and the feasibility of green energy sources in

Table 7 Short-run estimates of ARDL

Variables	Coefficient	Std. error	t-Statistic	Prob
C	2.126317	1.694290	1.254990	0.2216
CO ₂ (-1)	-0.246541	0.085333	-2.889158	0.0081
RDE	0.028287	0.871591	0.032454	0.9744
D(CO ₂ (-1))	0.403632	0.176084	2.292277	0.0310
D(CO ₂ (-2))	0.306371	0.164906	1.857850	0.0755
D(Y)	0.085366	0.031235	2.733042	0.0116
D(Y(-1))	0.077559	0.032372	2.395884	0.0247
D(Y(-2))	0.073523	0.027348	2.688397	0.0128
D(Y ²)	-0.018462	0.005788	-3.189605	0.0039
D(Y ² (-1))	0.011649	0.005204	2.238721	0.0347
D(Y ³)	0.005033	0.001595	3.155159	0.0043
D(Y ³ (-1))	-0.004924	0.001990	-2.474090	0.0208
D(Y ³ (-2))	-0.005664	0.001424	-3.978370	0.0006
D(FDI)	0.012775	0.030350	0.420922	0.6776
D(FDI(-1))	-0.150499	0.045866	-3.281276	0.0032
D(REC)	0.176458	0.154208	1.144285	0.2638
D(REC(-1))	0.563900	0.175608	3.211131	0.0037

industrialized nations. The findings are consistent with An et al. (2021) and Assamoi et al. (2020). The notion of sustainable development has heightened societal awareness of the significance of environmental variables’ services and functions (Nazar et al. 2020; Dogaru 2013). Environmental sustainability prioritizes ecosystem and biodiversity integrity, and it necessitates the preservation of natural resources as economic inputs. These resources must not be depleted faster than they can be replenished (Jhariya et al. 2021, Bithas 2020, Basiago 1998). The four criteria for environmental sustainability have been developed in the first decade of the twenty-first century’s environmental plan. Assimilation, substitutability, regeneration, and avoidance of irreversibility are the four criteria. Because environmental, economic, and social sustainability are intertwined and interwoven, they must be coordinated (Larsson and Larsson 2020).

According to Ahmad et al. (2021b), urbanization and continued economic growth are critical elements that increase the emissions index at the beginning while decreasing the intensity of emissions later on. As a result, it is preferable to regulate these elements through sustainable urban development and the development of green infrastructure. According to Işık et al. (2021), government expenditure on armed defense has a positive spillover impact on economic growth, resulting in adverse environmental externalities due to increased carbon emissions. Government investment should be tied to incentive-based environmental legislation to reduce carbon emissions. Işık et al. (2021) stressed the importance of promoting the eco-tourism agenda, which is critical for achieving the global ecological sustainability goal. Ahmad et al. (2021c) discovered that economic prosperity is essential for enhancing environmental sustainability through improved command-and-control mechanisms.

Ahmad et al. (2021d) advocated for increased healthcare spending and land changes to promote global healthcare sustainability.

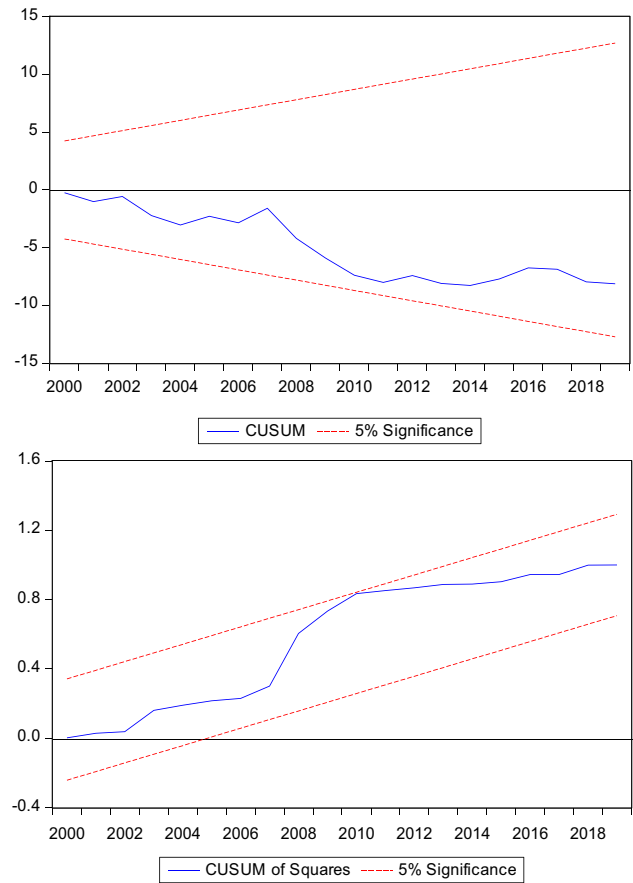


Fig. 2 CUSUM and CUSUMS square test estimates. Source: Author’s estimation

Table 8 Diagnostic test estimates

Test	Coefficient	Probability value	Remarks
Error correct term	-0.335	0.000	Model is converged toward equilibrium
Jarque–Bera test	0.797	0.671	Residual is normally distributed
Autocorrelation-LM (1) test	0.624	0.439	No serial correlation issue
Heteroskedasticity test	1.028	0.475	Variance is homoscedastic
Ramsey RESET test	1.461	0.160	Model is functionally stable
CUSUM test		$p < 0.05$	Model is stable
Square CUSUM test		$p < 0.05$	Model is stable
Variance inflation factor (VIF)			
Variables	VIF value		
FDI	1.462		
REC	1.646		
RDE	1.584		
Y	5.943		
SQY	1.534		
CUBEY	7.123		

Table 8 displays the model diagnostic tests, which supported the feasibility of the regression coefficient estimates since the estimates converged in the short run with an adjustment coefficient of -0.335% toward equilibrium. Furthermore, the model has no autocorrelation and heteroskedastic issues. The VIF value is used to investigate the possibility of multicollinearity in the given model. The estimates first regressed all factors except R&D spending and reported the VIF values of the candidate variables, confirming that the VIF value is less than 10. In the second round, R&D expenditures were added. At the same time, renewable energy consumption was removed, and the VIF value for R&D expenditures was reported as 1.584, confirming that there is no multicollinearity in the model.

Figure 2 depicts the CUSUM and square CUSUM tests, which proved the model's stability over time.

Conclusions

Environmental sustainability is a hot topic in today's world, and it is seen as a critical component of development programs. As economies go toward industrialization, their primary goal is to expand and boost economic growth. They harness natural resources to increase material output and achieve a high degree of development. Most economies overlook environmental sustainability for short-term advantages in this competition, and estimating the economic cost is difficult. The survival rate on Earth is likewise decreasing (Arora 2018). Economic growth and the environment have been linked in a variety of ways. The EKC hypothesis has been widely utilized to predict the relationship between these two variables scientifically. This explains the inverted U-shaped association between income per capita and pollution. This study was carried out to put the N-shaped EKC to the test for high-income nations from 1976 to 2019. The ARDL bound test was used to examine the relationship between variables. Long-run estimations reveal a strong, V-shaped link between CO₂ emissions and per capita income with square and cubic transformation. The findings support the N-shaped EKC hypothesis for high-income nations in the short run. Inbound FDI and carbon emissions, on the other hand, were positively connected with supporting the pollution haven hypothesis.

As a result of the findings, the following policy implications for environmental protection have been proposed:

- High-income countries may prioritize long-term environmental and economic strategies to achieve a sustainable environment.
- Policymakers should devote greater attention to promoting energy sector innovations for a more sustainable environment.

- The government should limit its use of filthy energy sources and promote renewable energy.
- CO₂ emissions should be reduced by implementing infrastructural advancements.
- Countries must enhance their foreign direct investment policies and their FDI evaluation standards and encourage the investment of clean technology that assists in cleaning up the environment. Governments should encourage green growth for a cleaner environment.
- Countries should encourage public participation in environmental governance to safeguard the environment better.

The command-and-control program should be incentive-based that help to reduce negative environmental externalities. Cleaner technology and accompanying environmental certifications aid in manufacturing environmentally friendly items. Carbon prices and emission caps would make it more difficult for polluting companies to deploy ecologically beneficial technologies. Green energy sources should be investigated and enhanced to achieve energy efficiency, and these measures would aid in creating a clean, green environment.

The analysis is confined to the quadratic and cubic versions of economic growth per capita. However, it might include more growth polynomials about carbon emissions per capita to test alternative variants of the EKC hypothesis. For more strong inferences, the study may include other socio-economic and environmental factors in the emissions-growth nexus, such as eco-innovation factors, industrialization, combustible waste, and urbanization. Finally, the analysis is confined to estimating the GDP of a particular nation, namely, Pakistan. As a result, the South Asian panel of nations may be utilized to estimate the results' generalizability. Future researchers might include these ideas in their studies to better understand the interactions between the variables in the EKC framework.

Author contribution FS: conceptualization, methodology, and writing—reviewing and editing. KZ: software and formal analysis. MSL: methodology and formal analysis. AAN: supervision, resources, and software. MH: formal analysis, resources, and validation. MMQA: resources, visualization, and formal analysis.

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Declarations

Ethics approval Not applicable.

Consent to participate The study was conducted with equal participation by all authors.

Consent for publication The paper's publication is permitted by all of the authors.

Conflict of interest The authors declare no competing interests.

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