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Analyzing the Nexus of Globalization, Green Technological Innovation,Tourism and Environment in High-Emitting Economies

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Abstract

In the era of advancement, our globe grapples with formidable challenges, with a particular emphasis on the escalating issue of environmental degradation. Recent years have witnessed a heightened scrutiny of the interplay between globalization and ecological sustainability. In this regard, different studies have investigated different elements that affect environmental sustainability. However, the impact of Green Technological Innovations (GTIs) on the environment has been overlooked. This study fills the gap by investigating the impact of GTI on environmental sustainability. Therefore, this study endeavors to explore the repercussions of globalization, GTI, Gross Domestic Product (GDP), and tourism on the environment across five nations—China, Japan, India, Russia, and the United States—spanning the period from 1992 to 2021. Employing an Autoregressive Distributed Lag (ARDL) model, the investigation seeks to unveil the enduring relationships among the variables under consideration. The empirical results divulge a positive correlation between globalization and Carbon Dioxide (CO_2) levels in China, Russia, Japan, and India, contrasting with a negative association in the United States. Notably, a beneficial connection between GTI and the environment is observed in all studied countries. The study further reveals an inverse link between GDP and environmental indicators across all examined countries. Additionally, tourism is identified as a contributor to pollution in India and Russia, while serving as a mitigating factor in China, Japan, and the United States. The policymakers and governments of these countries should emphasize the implementation of GTIs for environmental sustainability.

Keywords: Environment, Globalization, Green technological innovation, Gross domestic product, Tourism, Autoregressive distributed lag.

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1|Introduction

Rising temperature and environmental degradation are hot debates nowadays; the world is anxious to find solutions to these issues.

Growing economic and human activities are the main factors behind environmental degradation and hurdles in achieving sustainable development goals. Increased industrial activities and economic expansion are threatening humanity worldwide [1]. Incredible intensification of economic activities has been considered a catalyst for the expeditious rise in greenhouse gas emissions. It has been observed that the complicated collaboration of economic growth, energy, and the environment is the key factor behind the unexpected rise of temperature and climate change [2]. It is crucial to detect the determinants of carbon emissions to cut the Carbon Dioxide (CO_2) emissions for sustainability in the economy and environment worldwide [2]. Global policies supporting sustainable development have been imposed in response to severe environmental issues. Over the last 150 years, we have seen the effects of changing global temperatures on ecosystems. In particular, CO_2 emissions have increased by 80%, from 19 million tons in 1980 to 36 million tons now [3]. Environmental sustainability has become the most focused research area over the last few decades. The researchers have worked mainly on climate change and global warming in the present era [4–6]. Governments and organizations worldwide are searching for a safe and sustainable environment for current and future generations. These efforts lead to the establishment of frameworks and strategies to cut Greenhouse Gase (GHG) emissions and lower them [7–9]. Earth is in danger of climate change and environmental degradation, and GHGs are largely to blame. CO_2 is the most important GHG, making up 76% of all GHGs. Damage to biodiversity, waste production, and rising water and air pollution are only a few of the many environmental dangers linked to the possibility of climate crises. Previous studies have shown that reducing CO_2 emissions is critically important for human health [10].

The Paris Agreement aims to combat global warming, climate change, and its harmful effects. 195 countries signed the Paris Agreement in 2015 and agreed to decrease GHG emissions. However, progress towards the Sustainable Development Goals remains slow, and environmental degradation continues to be a grave problem for the whole world. Different researchers investigated different aspects affecting the environment, such as Renewable Energy (RNE) consumption [11], Economic policy uncertainty [12], and globalization [3]. However, the impact of Green Technological Innovations (GTIs) on the environment has been ignored, particularly for the top five CO_2 emitter countries, including China, the USA, Japan, India, and Russia.

A country's carbon footprint grows in proportion to its level of international trade and industrial activity. On the other hand, sustainable technologies and ideas may be more easily exchanged due to globalization. For successful climate change mitigation, it is crucial to have a nuanced view of the environmental consequences of global integration, as this intricate interaction shows. One of the main goals of globalization is to help countries become more economically prosperous. But it can also have bad consequences by lowering environmental standards. An increase in economic activity, urbanization, and industrialization, all of which contribute to higher CO_2 emissions, is a common side effect of globalization. Theoretically, globalization has the potential to improve environmental quality by reducing CO_2 emissions, especially with the spread of green technologies. Analysis of the dynamic interaction between globalization and CO_2 emissions is crucial, particularly in the quest for economic and environmental progress at the same time, because globalization's environmental impacts are not always clear [13]. Globalization is a complex phenomenon which much apart from the concept of economic globalization. Globalization is actually a congestion of diverse activities, skills, norms, and products [14]. Globalization, whether political, social, or economic, has been observed to have mixed effects on the environment during the current decades among various countries. To improve the quality of the environment and minimize energy utilization, foreign investors should bring the latest and new technologies to host countries [15]. Furthermore, the utilization of the latest and advanced technologies will lessen the cost of production as well as energy demand, which will motivate domestic investors to utilize the latest technology to improve environmental sustainability. However, the environmental quality will degrade if foreign investors still practice outdated technologies and ways of production [15].

The World Tourism Organization (UNWTO) report shows a significant growth in tourism in those countries that have adopted tourism promotion policies. In 2018, the number of international tourists increased by 5%, which ultimately grew the export revenue by 1.7 trillion US dollars. The tourism industry generates new job opportunities and works as a catalyst for innovations and economic expansion, according to the UNWTO [16]. Although tourism development enhances Gross Domestic Product (GDP), significantly, it may have adverse impacts on the environment. As many tourism activities depend mainly on electricity produced from fossil fuels, logistics used in tourism activities are the main culprit behind pollution. It's all because of poor logistic infrastructure, which is poisoning the environmental quality. UNWTO and the International Transport Forum reported that global transport and freight were responsible for 7.23 billion tons of CO_2 emissions, of which passenger transport generated 64% of CO_2 [17]. Plenty of work has examined the relationship between tourism and economic expansion; to some extent, there is a consensus among researchers that tourism is a catalyst for economic development. However, this expansion is not cost-free; rather, it deteriorates social, economic, and environmental sustainability. Rapid increases in tourism stimulate energy demand and transportation, which eventually aggravate environmental degradation [2].

GTI is considered a new technology breakthrough for lowering energy usage, improving environmental sustainability, minimizing pollutants, and enhancing the green future. Green and clean energy alternative resources of energy instead of conventional energy, and new technological procedures can be seen in GTIs [18]. Developing nations can enjoy a reduction in environmental pollution and sustainable development by using advanced Technological Innovation (TI) and renewable sources [18]. Government policy incentives, hikes in electricity prices, and the reduced expenses of RNE generation technology have all contributed to a surge in investment in green energy generation in recent years, despite the green scheme system being a relatively new technique [19]. The reduction in pollutant emissions is directly proportional to the amount of green technologies [20]. Adopting environmentally friendly practices can help restore a polluted ecosystem. Using renewable resources related to nature is central to green practices in achieving sustainable development goals; moreover, technology development procedures and the components of green technology are less harmful to the environment than other methods [21]. Environmentally responsible industrial methods that reduce emissions are at the heart of the concept of "green growth," which has recently attracted a lot of intellectual attention. The goal of this change is to promote cleaner production by converting current supply networks into more environmentally friendly models. The concept of green development is also gaining traction as a potential response to the widespread environmental degradation that is caused by carbon emissions [22].

Economic development, along with energy, is the key factor in skyrocketing environmental pollution and degradation. Economic expansion means large economic activities in industries and manufacturing, which consequently boost pollution in many countries. Huge capital is required to meet the increasing needs of people, which causes resource depletion, which is an eminent source of environmental degradation [23]. Economic progress is hampered by the ongoing depletion of natural resources, which also intensifies environmental contamination. The benefits of progress and competitiveness are obvious, but we must not forget that the environment frequently pays the price. Consistently increasing average GDP per person has been a major contributor to environmental degradation, but it has also been an essential driver of economic growth [23]. Economic growth amplifies human well-being, high standards of living, and urbanization, which ultimately degrade the environment through high energy usage. In 2008, urbanization exceeded the rural equivalent for the first time in history. The desire for economic development stimulates industrialization at the cost of environmental damage [4]. The empirical investigation of actual catalysts of economic growth is essential to formulate effective and implementable [24–26]. Economists believe in the significant and inevitable role of Financial Development (FD) in economic progress [26–28]. Carbon neutrality refers to a set of policies and agenda to promote a free ecosystem free of harmful effects of CO2 emissions [24], [25], [29]. Concerning effects on environmental sustainability, especially pollution, frequently correspond to economic expansion. Pollutants are released at a higher rate by many economic activities that are compatible with and motivated by the goal of growth. This position is supported by the fact that there is a clear correlation between rising fossil fuel usage and economic growth, which means that as GDP grows, energy consumption and CO_2 emissions both rise. Agriculture, petroleum, energy mining, and manufacturing are just a few of the many businesses that contribute to pollution and CO_2 emissions as a result of economic development's vast span [30]. For many nations, promoting long-term economic growth is the top priority when formulating their national economic policies. However, there are consequences to pursuing such expansion, especially in light of critical global concerns such as climate change and global warming. Emissions of CO_2 and other GHGs into the atmosphere have increased as a result of human-caused economic expansion and societal advancement [31]. Sustaining a balance between environmental preservation and sustainable growth is the most pressing issue of our day. Increasing energy consumption is a key component of a growing economy, which in turn causes emissions of CO_2 [32]. When discussing theories of economic growth, economists frequently overlook other important aspects in favour of labour and capital, the two main inputs into production [33–35].

This study significantly contributes to the existing literature by investigating the impact of GTI and globalization on CO_2 emissions in the top five CO2 emitter countries. Previous studies focus on a global or regional approach, but this study provides deeper insights into country dynamics by focusing on five high-CO_2-emitting countries. Secondly, this study uniquely investigates the impact of GTIs on environmental sustainability. While previous literature typically focuses on general technological advancements. Thirdly, this study examines globalization's dual role. While globalization enhances CO_2 emissions due to increased industrial activities, it also works for environmental sustainability through the transfer of green technologies. Lastly, as far as our knowledge extends, this research stands as a pioneering effort in investigating the impact of globalization, GTI, GDP, and tourism on a panel of the five most polluted economies spanning from 1992 to 2021. The uniqueness of this approach, both in terms of the time frame and the variables considered, enhances our understanding of the dynamics at play in these economies, making a noteworthy contribution to the field.

This study provides some future guidelines for research opportunities. It concentrates solely on the five most polluted countries globally. There is potential for future studies to expand and include more countries, using both time series and panel data setups. Additionally, upcoming research could contribute to existing knowledge by examining the model using different pollution indicators and diverse econometric techniques.

The next section of this article is about the literature review, while Section 3 explains the methodology utilized in this study. Section 4 explains the concluding remarks and future recommendations.

2 | Literature Review

2.1 | Globalization and Environmental Quality

Here, we'll take a look at the five nations with the biggest environmental impacts and analyze various theoretical and empirical studies that have explored the complex relationship between globalization, tourism, economic growth, GTI, and CO_2 emissions. A sizable corpus of academic research has examined the complex interactions between environmental deterioration and globalization during the past ten years. However, the results have produced some uncertainty, exposing a complex relationship. Studies have found both positive and negative correlations between CO_2 emissions and globalization. Jahanger et al. [13] identified the influence of human capital, social globalization, political globalization, GDP, industry labor force, urbanization, and population growth, on CO_2 for 78 developing economies using time series data from 1990 to 2016. The estimated assessment of the research uncovered that human capital, economic globalization, political globalization, and FD diminish CO_2, while social globalization and GDP harm environmental quality. The fellowship between population growth, Alternative and nuclear energy, GDP, globalization, and environment, Rehman et al. [36] utilized the Nonlinear Autoregressive Distributed Lag (NARDL) model over the years 1985 to 2020 for a global perspective. The empirical findings of the study uncovered that positive shocks of globalization and GDP impede the environmental quality; in addition, negative shocks of these variables ameliorate the environment. Conversely, alternative nuclear energy improves the environmental quality in both shocks. But population growth enhanced pollution. For 180 countries from 1980 to 2016, employing the POLS, Farooq et al. [14] evaluated that economic globalization and GDP per capita square lessened CO_2; conversely, GDP and urban population enhanced environmental pollution. Gaies et al. [37] explored that GDP and urbanization have positive ramifications on CO_2, while positive shocks of financial globalization damage the environmental quality, but negative shocks have no effect on the environment for 17 Middle East and North Africa (MENA) countries employing the NARDL model over the years 1980 to 2018. For One Belt One Road (OBOR) countries, utilizing the Dynamic Seemingly Unrelated Regression (DSUR) model, Bilal et al. [38] conducted the connection between technology innovation, globalization, Information and Communication Technology (ICT), GDP, and the environment over the years 1991 to 2019. The estimated assessment of the experiment reported that globalization, ICT, and GDP harm the environmental quality; meanwhile, TI reduces CO_2. Adopting the Fully Modified Ordinary Least Squares (FMOLS) model, Yang et al. [39], [40] found a favorable attachment of economic globalization and population ageing with the environment, while energy usage harms environmental quality for Organisation for Economic Co-operation and Development (OECD) countries over the period 1971 to 2016. For Pakistan, through the NARDL model, Farooq et al. [15] reported the correspondence between globalization, Institutional Quality (INSQ), Foreign Direct Investment (FDI), GDP and CO_2 covering the years 1985 to 2017. The estimated assessment of the research displayed that globalization, FDI and GDP worsen the environmental quality. From 1990 to 2016, Nguyen and Le [41] reported the attachment between globalization, FDI, export, coal and the environment adopting the Autoregressive Distributed Lag (ARDL) model. The findings of the study in the case of Vietnam exhibited that globalization and coal accelerated environmental pollution, yet export and FDI lessen CO_2. By adopting the ARDL approach, Khan et al. [42] described that globalization, energy usage, GDP, FDI, and trade damaged the environmental quality in Pakistan for the period of 1971 to 2016, while FDI innovation ameliorated the environmental quality.

H1. Globalization influences environmental stability.

2.2 | Economic Growth and Environment

A wide range of macroeconomic variables, acting via direct and indirect channels, are known to affect the overall condition of the environment. The importance of understanding the environmental impacts of economic growth is highlighted by the fact that the Environmental Kuznets Curve (EKC) hypothesis provides a theoretical framework for doing so. This theory lays forth the complex connection between expanding economies and better environmental conditions.

Covering the years 1971 to 2016, Agboola et al. [43] established the union between total natural resources rent, oil rent, GDP, and CO_2 employing the ARDL model for Saudi Arabia. The verifiable result of the research proposed that GDP and total natural resources damage the environment; conversely, oil rent purifies the environment. From 50 African countries, Namahoro et al. [44] probed the bond between GDP, energy intensity, and CO_2, covering the years 1980 to 2018. The observed outcomes of the research unveiled that energy intensity demolished the environmental quality, yet RNE supported the clean environment; meanwhile, GDP holds the EKC hypothesis. The association between nuclear energy, GDP, and CO_2 was documented by Nathaniel et al. [45] for G-7 countries from 1990 to 2017. The observed calculation of the dissemination that nuclear energy improves environmental quality; meanwhile, GDP amplifies CO_2. Adopting the ARDL model for 24 Silk Road Economic Belt (SREB) countries from 1995 to 2014, Yang et al. [39], [40] conducted the correlation between GDP, trade, and CO_2; the assessment of the research unveiled that trade mitigates CO_2 emissions, yet GDP accelerates CO_2. Utilizing the FMOLS approach covering the years 1996 to 2017, Liu et al. [46] probed the correlation between GDP, institutional governance, and CO_2. However, outcomes of the research in the case of 5 high-emissions economies show that GDP increased pollution, while institutional governance, economic governance, and political stability aggravated the environmental quality. The population growth, GDP, and CO_2 over the years 1990 to 2017 was asserted by Shaari et al. [47] for selected countries. The main outcomes of the research proposed that GDP and population growth enhanced environmental pollution while RNE decreased environmental pollution. From 1970 to 2018, for Spain, Pilatowska et al. [48] tested the correlation between decoupling GDP, nuclear energy, and CO_2, adopting the Threshold Vector Autoregression (TVAR) approach. The empirical findings of the research disclosed that nuclear energy accelerated the environmental quality, while GDP deteriorated the environment. For China, covering the years 2000 to 2016, Ahmad et al. [49] explored the affiliation between urbanization GDP, energy usage, and CO_2 employing the Augmented Mean Group (AMG) approach. The observed outcomes of the research exhibited that GDP, urbanization, and energy use amplified environmental pollution. Yan et al. [50] found that GDP degrades environmental quality in MENA countries. Ibrahim et al. [51] confirmed that ICT enhances CO2 in G-7 countries. Khan et al. [52] in lower-middle-income countries confirmed that RNE cleans environmental quality. Employing the 3Stage Least Squares (3SLS) approach covering the period 1980 to 2014, Mahmood et al. [53] identified the interconnection between GDP, energy usage, and CO_2 in Pakistan. The final outcomes of the inquiry disseminated that GDP and trade pollute the environment. The alliance between FD, trade, GDP, energy use, and CO_2 for MENA countries during the period 2001 to 2017 was analyzed by Muhammad et al. [54]. The verifiable outcomes of the research uncovered that FD and trade reduce environmental pollution, In addition, GDP and energy usage environmental pollution.

H2. GDP affects environmental sustainability.

2.3 | Tourism and Environment

Lorente et al. [1], for 36 OECD countries covering the years 2000 to 2018, reported the tie between ICT, urbanization, income per capita, tourism, and environment. They found that tourism, urbanization, and per capita income pollute the environment, while ICT controls CO_2. Employing the ARDL model, Bandyopadhyay et al. [55] found a correlation between GDP, energy intensity, tourist arrival, and CO_2 emission, covering the years 1980 to 2019. However, the observed assessment of the research in the case of India uncovered that GDP and energy intensity degrade the environmental quality, while tourist arrival declines CO_2. Oad et al. [56] identified the favorable reverberation between GDP, energy use, and CO_2; in contrast, tourism accelerated the environmental quality in Pakistan, covering the years 1995 to 2014, adopting the Vector Error Correction Model (VECM) approach. The attachment between GDP, tourism, and CO_2 over the years 1995 to 2018 was inspected by Wang and Wu [17] for major tourist arrival countries. The observed assessment of the research uncovered that tourism controls CO_2 in France and the USA; meanwhile, tourism deteriorates the environmental quality in China.

Adopting the FMOLS model, Wei and Ullah [2] indicated the union between tourism, digital infrastructure, GDP, and CO_2 emissions for Asian economies. The empirical observation disseminated that digital infrastructure and tourism reduce CO_2. Meanwhile, GDP exacerbates CO_2. For 70 countries, Liu et al. [3] demonstrated the linkage between tourism FD, GDP, trade, and CO_2 from 2000 to 2017. The assessment of the calculation showed that tourism, FD, trade, and GDP harm the environmental quality. For 12 post-communist countries from 1995 to 2014, Isaeva et al. [57] tested the connection between FD, tourism, and CO_2. The empirical outcomes of the research disclosed that FD enhanced CO_2, while tourism lessened CO_2. From 1995 to 2016, for the Association of Southeast Asian Nations (ASEAN) countries, Kongbuamai et al. [58] discovered the correlation between natural resources, tourism, and ecological footprint. The verifiable outcomes of the research indicate that natural resources and tourism have inverse reverberation on Environmental Footprint (EF). Anser et al. [59] observed the bond between international tourism, GDP, FDI, inflow, and CO_2 emissions over the years 1995 to 2015 for G-7 economies. The verifiable calculation confessed that international tourism and FDI worsen the environmental quality.

H3. Tourism affects environmental sustainability.

2.4 | Green Technological Innovation and Environment

Time series data from 1995 to 2020, for South Asian countries, Amin et al. [18] evaluated the linkage between GTI, INSQ, trade, population, GDP, and CO_2. The verifiable outcomes of the research disclosed that GTI and RNE mitigate CO_2, yet INSQ, population, trade, and GDP damage the environmental quality. The alliance between FDI, GTI, INSQ, FD, and CO_2 during the years from 2003 to 2019, adopting the Generalized Method of Moments (GMM) approach, was investigated by Ali et al. [60]. The observed calculation of the paper suggests that FD, GDP, and trade reduce environmental quality; meanwhile, GTI and INSQ reduce CO_2. For Australia and 23 top green scheme economies covering the period 2008 to 2019, Zakari et al. [19] examined the connection between TI, GDP, population, green energy credit, and CO_2. The observed calculation unfolds that GTI, green energy credit, and GDP augmented pollution; meanwhile, Gross Domestic Product2 (GDP2) and population damage the environmental quality. For the top 10 world's green economies, time series data from 1980 to 2019, the connection between GTI, GDP, ICT, and CO_2 were explored by Ramzan et al. [20] employing the Method of Moments Quantile Regression (MMQR) method. However, GTI and financial depth reduce CO_2 emissions; conversely, GDP and ICT deteriorate the environmental quality. Adopting the Vector Autoregression (VAR) system, Su et al. [61] indicated the correlation between TI and environment covering the years 2010 to 2021. However, the outcomes of the research disclosed that in the case of the USA TI has mixed results on CO_2. For Nordic economies covering the period 1995 to 2020, Sharif et al. [21] estimated the alliance between green energy, environmental taxes, GTI, and CO_2. The results of CS-ARDL showed that green technology, environmental taxes, and green energy improved environmental quality; meanwhile, population decreases environmental quality. Adopting the Dynamic Autoregressive Distributed Lag (DYARDL) model, Javed et al. [62] established the tie between RNE, GTI, environmental taxes, GDP, and EF over the period from 1994 to 2019. However, the outcomes of the research in the case of Italy spilled over to GTI, environmental taxes, and RNE reduce EF. In addition, trade and GDP exerted favorable reverberations on EF. The attachment between GTI, GDP, population, and environment was discovered by Kuang et al. [63] over the period 1990 to 2018, employing the AMG approach for China. They found that GTI and RNE stimulated the environmental quality. For 6 Asian countries, Suki et al. [22] discovered the connection between GTI, RNE, and CO_2 emissions over the period 1992 to 2018. GTI and RNE reduce CO_2. For the top 10 countries, by employing CS-ARDL, Ibrahim et al. [64] followed up on the association between GTI, green finance, and CO_2 emissions. The practical findings of the paper confirmed that GTI and green finance augmented the environmental quality.

H4. GTI affects environmental stability.

Literature gap

Although numerous studies have explored the impact of GTIs and globalization on environmental sustainability, several research gaps exist, particularly in the context of the top five CO_2-emitting countries.

Previous research studies conducted by Du et al. [65] and Li & Ma [66] observed the impact of TIs on CO_2 emissions. Previous studies mainly explored the impact of general TIs on CO_2 emissions, yet few examined the impact of GTIs on CO_2 emissions.

Previous literature sheds light on the individual impact of GTI, globalization, and tourism on the environment; however, the interaction effect among these variables is very significant. In existing literature, this intersection needs to be addressed.

Theoretical framework

Reducing CO_2 emissions has become a hot debate to attain Sustainable Development Goal 13 (SDG-13) and improve life on this planet. Over the past few years, factors affecting CO_2, such as GTI, GDP, and globalization, have received greater attention than ever before. Globalization is the primary source of the transfer of modern technology from developed to developing countries. It plays a crucial role in enhancing the total factor productivity of the economy. Different researchers have investigated the impact of globalization in many different ways. One of the most famous ways is "Ecological modernization theory," presented in the early 1980's. This theory argues that technological advancement, economic growth, capitalism, and the increased rate of multinational organizations not only enhance environmental sustainability but also could bring ecological reforms [67].

Moreover, Acemoglu's theory of environmentally-biased technology provides the basis for the theoretical framework of GTI. This theory argues that new green technologies play a crucial role in the more efficient utilization of resources, balancing economic growth, and achieving a sustainable environment. Due to these critical features, GTI is considered a new and improved version of innovation, reducing environmental damage by improving environmental sustainability [68]. The EKC theory claims that at the initial stages of economic growth, economies face high levels of environmental pollution and adversely influence the environmental welfare indicators, but after reaching a certain point of growth, the pollution level decreases to restore environmental well-being [69]. The existence of the EKC hypothesis is mainly based on three different factors, including: 1) the scale of production, 2) the compositional arrangements of the factors of production, and 3) technology utilization in the production process [70]. *Figs 1* and *2* also explain the theoretical framework.

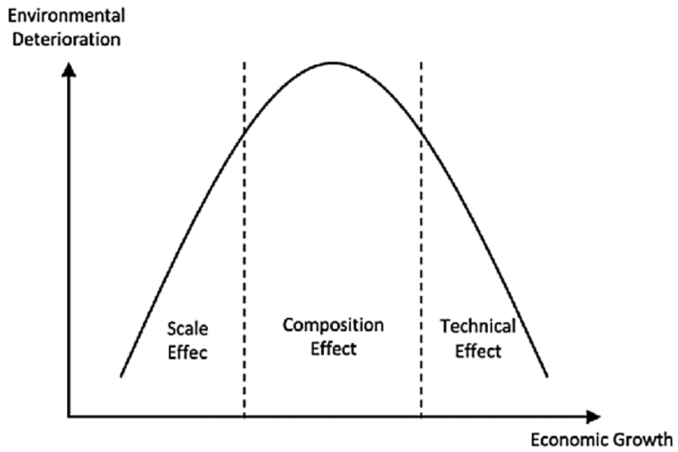

Fig. 1. Theoretical framework of GTI based on environmentally-biased technological change theory.

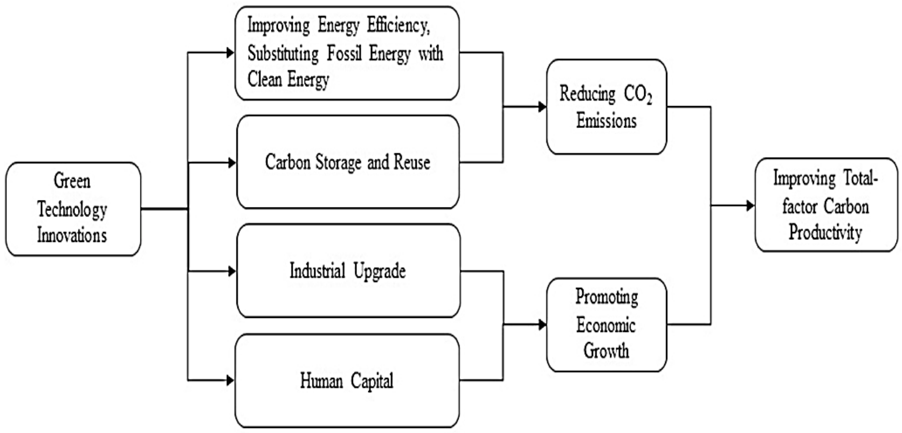

Fig. 2. EKC hypothesis illustrating the relationship between economic growth and environmental pollution.

3 | Methodology

4 | Research Design

The present study has investigated the impact of GTIs, globalization, tourism, and GDP on CO_2 emissions for the top five CO_2-emitting countries. This study covers the time span from 1992 to 2021 due to easy and availability of data. For evaluating the association between study variables, different proxies were utilized and were taken from different sources. CO_2 is taken from World Development Indicators (WDI) as "CO_2 emissions (kt)", GTI stands for "Patent applications, residents", TOU describes "International tourism, number of arrivals (TOU)", GDP as "GDP growth(annual %)", GI demonstrates "KOF index" extracted from KOF Globalisation Index (KOFGI), EF stands for "EF (gha per person)" taken from the Global Footprint Network. This study covered the data of the USA, Japan, China, Russia, and India.

The first and foremost step is to select the best technique to determine the variable's relationship in the long term. The best and most effective way to look at the relationship is to use co-integration. The empirical technique used in this paper consists of three fundamental stages. Firstly, unit root tests are applied. Secondly, we applied the co-integration test. Within the ARDL technique, there are some other alternatives; however, the current study applied ARDL. This paper applied the ARDL methodology proposed by Psaran and Shin [71] to determine the long-run relationship of study variables. This methodology has many advantages over other time series data models: 1) it can be used for small data sets, 2) it can be utilized when data is stationary at I(0) or I(I), or both, and 3) it can be used to handle the problem of endogeneity.

Rationale of the study

The present study has investigated the impact of GTIs and globalization on environmental sustainability, particularly in the presence of tourism and GDP.

The long-run relationship between predictors and dependent variables is described in the equation.

$$CO2 = f\,(GI, GTI, TOU, GDP, GDPS), \tag{1}$$

$$EF = f(GI, GTI, TOU, GDP, GDPS). \quad (2)$$

The research paper's econometric equation will look like this:

$$CO_{2t} = ƛ_{03} + ƛ_{04}GI_t + ƛ_{05}GTI_t + ƛ_{06}TOU_t + ƛ_{07}GDP_t + ƛ_{08}GDPS + \mu_t. \quad (3)$$

$$EF_t = ƛ_{03} + ƛ_{04}GI_t + ƛ_{05}GTI_t + ƛ_{06}TOU_t + ƛ_{07}GDP_t + ƛ_{08}GDPS + \mu_t. \quad (4)$$

The word "t" shows the time span from 1992 to 2021. Here, $ƛ_{03}$ is the intercept $ƛ_{04}$ is the elasticity of globalization towards CO_2, $ƛ_{05}$ shows the flexibility of GTI, $ƛ_{06}$ expresses TOU elasticity towards CO_2, $ƛ_{07}$ shows GDP elasticity towards CO_2, $ƛ_{08}$ denotes GDPS elasticity towards CO_2. μ_t denotes the error term.

Despite the fact that globalization is helpful in mitigating poverty, unemployment, and inequality, it also brings harmful effects on environmental quality as it is the key factor in the persistent rise of CO_2 and GHG. Globalization brings nations close to each other in terms of sharing their knowledge, public policies, skills, and culture. It also helps individuals, economies, and firms in the outsourcing and trading of goods and services worldwide [13]. The tourism industry has been estimated to grow rapidly in the twenty-first century; this rapid tourism will lead to excessive energy consumption and depletion of natural resources, which eventually affect the environmental quality in terms of resource use and waste generation globally [58].

Empirical methodology

In this section, firstly, we have applied the descriptive analysis followed by evaluating mean, median, and range estimates. The standard deviation tells about the dispersion of the data in relation to the mean. We have utilized skewness and kurtosis to evaluate the normality of data. In this paper, we have used time series data to determine the long-run relationship. It is compulsory to check the stationarity of all study variables. After applying the unit root test, we have found that all variables are stationary at I(0) or I(I). For determining the stationarity, we applied the Augmented Dickey-Fuller test (ADF) and the Phillips-Perron test (PP). Therefore, the ARDL technique is appropriate for this study. The final findings of descriptive statistics and stationarity are summarized in "Appendix A" and *Table 1* respectively.

The following are the formulations of the equations used for ARDL estimation:

$$\Delta CO_{2t} = ƛ_{03} + \sum_{m=1}^{n1}\sigma_{04i}\Delta CO_{2t-1} + \sum_{m=0}^{n2}\sigma_{05i}\Delta GI_{t-i} + \sum_{m=0}^{n3}\sigma_{06i}\Delta GTI_{t-i} + \sum_{m=0}^{n4}\sigma_{07i}\Delta TOU_{t-i} + \sum_{m=0}^{n5}\sigma_{08i}\Delta GDP_{t-i} + \sum_{m=0}^{n6}\sigma_{09i}\Delta GDPS_{t-i} + \alpha_3 CO_{2t-1} + \alpha_4 GI_{t-1} + \alpha_5 GTI_{t-1} + \alpha_5 TOU_{t-1} + \alpha_6 GDP_{t-1} + \alpha_7 GDPS_{t-1} + \mu_t. \quad (5)$$

$$\Delta EF_t = ƛ_{03} + \sum_{m=1}^{n1}\sigma_{04i}\Delta EF_{t-1} + \sum_{m=0}^{n2}\sigma_{05i}\Delta GI_{t-i} + \sum_{m=0}^{n3}\sigma_{06i}\Delta GTI_{t-i} + \sum_{m=0}^{n4}\sigma_{07i}\Delta TOU_{t-i} + \sum_{m=0}^{n5}\sigma_{08i}\Delta GDP_{t-i} + \sum_{m=0}^{n6}\sigma_{09i}\Delta GDPS_{t-i} + \alpha_3 EF_{t-1} + \alpha_4 GI_{t-1} + \alpha_5 GTI_{t-1} + \alpha_5 TOU_{t-1} + \alpha_6 GDP_{t-1} + \alpha_7 GDPS_{t-1} + \mu_t. \quad (6)$$

To estimate the Error Correction Model (ECM) model, we can use:

$$\Delta CO_{2t} = ƛ_{02} + \sum_{m=1}^{n3}ƛ_{04i}\Delta CO_{2t-1} + \sum_{m=0}^{n4}ƛ_{05i}\Delta GI_{t-i} + \sum_{m=0}^{n5}ƛ_{06i}\Delta GTI_{t-i} + \sum_{m=0}^{n6}ƛ_{07i}\Delta TOU_{t-i} + \sum_{m=0}^{n7}ƛ_{08i}\Delta GDP_{t-i} + \sum_{m=0}^{n8}ƛ_{09i}\Delta GDPS_{t-i} + \lambda ECT - 1 + vt_t \quad (7)$$

$$\Delta EF_t = \lambda_{02} + \sum_{m=1}^{n3} \lambda_{04i} \Delta EF_{t-1} + \sum_{m=0}^{n4} \lambda_{05i} \Delta GI_{t-i} + \sum_{m=0}^{n5} \lambda_{06i} \Delta GTI_{t-i} + \sum_{m=0}^{n6} \lambda_{07i} \Delta TOU_{t-i} + \sum_{m=0}^{n7} \lambda_{08i} \Delta GDP_{t-i} + \sum_{m=0}^{n8} \lambda_{09i} \Delta GDPS_{t-i} + \lambda ECT - 1 + vt_t \quad (8)$$

The results and discussions

This section describes the results of research. Firstly, Appendix A describes the descriptive statistics, which is a concise description of the main features of the data. Descriptive statistics indicate the mean, maximum, and minimum values. Moving to *Table 1*, the results of the unit root test indicate that all variables are found stationary at I(0) or I(i). None of the variables is stationary at I(ii).

Table 1. Descriptive statistics and unit root test results of the variables.

China				
Variable	**ADF**		**PP**	
	Level	**First Difference**	**Level**	**First Difference**
CO_2	-1.920	-3.163**	-1.899	-3.163**
EF	-1.673	-3.921**	-1.679	-3.940***
GI	-2.843*	-3.890**	-7.173***	-3.886**
GTI	-2.880*	-2.070	-2.850*	-1.952
GDP	-2.083	-1.752**	-2.061	-1.642**
GDPS	-1.660	-3.592**	-1.663	-1.926**
TOU	-1.819	-2.277**	-0.390	-2.109**
Japan				
Variable	**ADF**		**PP**	
	Level	**First Difference**	**Level**	**First Difference**
CO_2	-1.858	-2.789**	-0.810	-3.777**
EF	-2.185	-3.008**	-2.185	-3.008**
GI	-3.725**	-2.458	-3.725**	-2.458
GTI	-3.239**	-2.184	-0.427	-14.905***
GDP	-2.279	-3.680**	2.961	-3.680**
GDPS	5.128	-3.484**	1.088	-3.465**
TOU	-1.844	-3.379**	-1.919	-3.337**
India				
Variable	**ADF**		**PP**	
	Level	**First Difference**	**Level**	**First Difference**
CO_2	-1.765	-3.010**	-1.778	-2.982**
EF	-1.943	-3.586**	-2.63	-3.562**
GI	-3.992***	-3.372**	-8.394***	-3.366**
GTI	-2.097	-1.175**	-0.394	2.178**
GDP	-0.151	-5.005***	1.211	-19.45***
GDPS	1.057	-4.985***	5.563	-5.017***
TOU	0.464	-4.653**	0.850	-4.422***
Russia				
Variable	**ADF**		**PP**	
	Level	**First Difference**	**Level**	**First Difference**
CO_2	-0.891	-5.724***	-0.926	-5.262***
EF	-2.422	-2.958**	-2.481	-2.845**
GI	-3.092**	-5.357***	-3.092**	-5.357***
GTI	-2.381	-4.389**	1.022	-6.688***
GDP	-1.571	-3.045**	-1.020	-3.014**
GDPS	-0.229	-2.909**	-0.298	-2.837**
TOU	-2.432	-4.822***	-2.464	-4.877***
USA				
Variable	**ADF**		**PP**	
	Level	**First Difference**	**Level**	**First Difference**
CO_2	-1.368	-2.814**	-1.374	-2.814**
EF	-2.498	-3.382**	-2.498	-3.345**
GI	-5.322***	-2.921*	-5.246***	-3.046**
GTI	-1.127	-4.067**	-0.631	-2.177**

GDP	0.259	-3.274**	-0.613	-1.814**
GDPS	1.907	-4.576***	0.060	-1.869**
TOU	0.128	-6.451***	-0.373	-12.617***

The present study has applied the ARDL bound test to determine the co-integration among variables. *Table 2* shows the results of the bond test. The result shows co-integration and a long-run association between study variables. The F statistic is higher than the upper bound.

Table. 2. F-bound test (ARDL).

CO_2 Model					Ecological Foot Print Model				
China	**Japan**	**India**	**Russia**	**USA**	**China**	**Japan**	**India**	**Russia**	**USA**
3.82	6.69	13.64	5.20	4.566	5.93	4.75	16.47	6.14	4.635
I(0)					I(1)				
2.45					3.52				
2.86					4.01				
3.74					5.06				

After fulfilling all requirements, the ARDL is applied. Since four predictors estimate the CO_2 levels in the studied countries.

Assessing the connection between globalization and CO_2, the nature of the connection was found to be useful in four countries, namely China, Japan, India, and Russia, but was found to be adversely connected with CO_2 in the USA. Positive association between the KOF Globalisation Index (GI) and CO_2 leads to generating more CO_2. The variance in the significance level could be because of the implication of CO_2, which becomes more terrifying with the expansion of globalization and vice versa in the USA. These findings are described in *Table 3*.

Evaluating the association between GTI and CO_2, the kind of relationship was ascertained to be negative in all studied countries. There is a difference in the significance level in all studied countries. These findings declared the balancing role of GTI with CO_2, which plays a pivotal role in abating CO_2. GTI was found significant at 1% level in China and India, at 5% in Russia and the USA; conversely, the relationship was found insignificant in Japan. The contrariety of significance may possibly be due to the response of economies towards GTI as a feasible solution for minimizing CO_2 for a sustainable environment. The negative association of GTI and CO_2 recorded the adverse role in polluting the environment. The results of the relationship are mentioned in *Table 3*.

Examining the correspondence between GDP and CO_2, the essence of the connection was observed to be beneficial in all studied countries. The difference is found only in terms of significance; precisely, GDP was found significant at level 5% in China, Russia, and the USA, at 1% in Japan, but found insignificant in India. From the observed relationship between GDP and CO_2, it is recorded that GDP showed conflictive affect on environmental sustainability as it enhances the CO_2 level, that's why the nature of the connection is positive.

Estimating the linkage between tourism and environment, the sort of linkage was recorded to be beneficial for environmental sustainability in China, Japan, and the USA, conversely the association was found to be detrimental in the case of India and Russia. The level of significance was found to be different due to the implications of CO_2. Specifically, TOU was found significant at 5% in China, Japan, and the USA, at 10% in India, and insignificant in the case of Russia. From observed results, it was confirmed that tourism had both effects positive as well as negative effects in different countries.

Table 3. ARDL long-run estimates.

	CO_2 Model					Ecological Foot Print Model				
	China	Japan	India	Russia	USA	China	Japan	India	Russia	USA
GI	2.36** [0.05]	0.91** [0.28]	2.48*** [0.38]	5.18** [1.99]	-2.28** [2.46]	18.71*** [1.57]	2.39*** [0.22]	1.34** [0.71]	6.92*** [0.87]	-3.75*** [0.16]
GTI	-0.43*** [0.005]	-0.35 [0.23]	-0.11*** [0.01]	-0.97** [0.65]	-0.36** [0.30]	-0.30** [0.08]	-1.20 [0.59]	-0.60*** [0.16]	-0.54** [0.22]	-0.49*** [0.01]
GDP	0.64** [0.01]	0.59*** [0.02]	0.02 [0.04]	0.14** [0.21]	0.26** [0.45]	4.43*** [0.55]	0.37** [0.08]	0.10 [0.10]	0.92*** [0.15]	0.19*** [0.00]
GDPS	-0.24** [0.03]	-0.32*** [0.02]	-0.05 [0.11]	-0.09** [0.19]	-0.13** [0.23]	-2.96*** [0.10]	-0.21** [0.03]	-0.03 [0.07]	-0.22*** [0.12]	-0.14*** [0.03]
TOU	-0.09** [0.002]	-0.04** [0.02]	0.19*** [0.01]	0.09 [0.10]	-0.29** [0.40]	-0.44*** [0.06]	-0.06** [0.02]	-0.03 [0.05]	1.24*** [0.08]	0.17** [0.01]
C	-12.98** [0.22]	-8.72*** [1.73]	8.18** [0.94]	-11.92** [5.08]	17.55*** [1.10]	-43.51*** [8.83]	-16.90*** [1.27]	-10.09*** [1.48]	-25.19*** [2.00]	16.88*** [0.60]

Note: *,**,*** represents 10%, 5%, & 1% significance level.

Table 4. Short-run results.

	CO_2 Model					Ecological Foot Print Model				
	China	Japan	India	Russia	USA	China	Japan	India	Russia	USA
D(CO_2(-1))	1.44** [0.03]	-0.73** [0.31]	0.51 [0.37]	-	-	-	-	-	-	-
D(CO_2(-2))	0.15** [0.01]	-	-0.62 [0.52]	-	-	-	-	-	-	-
D(CO_2(-3))	0.53** [0.01]	-	-	-	-	-	-	-	-	-
D(EF(-1))	-	-	-	-	-	0.76** [0.26]	0.65** [0.16]	1.11** [0.37]	1.41*** [0.31]	0.97*** [0.02]
D(EF(-2))	-	-	-	-	-	-	-	-	-	1.07*** [0.03]
D(GI)	1.08** [0.02]	0.75** [0.25]	4.58** [1.58]	1.93** [0.78]	-0.83 [0.86]	15.75*** [0.83]	0.75 [0.67]	2.33* [1.18]	-0.59*** [0.15]	-0.14 [0.12]
D(GI(-1))	-	-	-	-	-	-	-	0.25 [0.32]		
D(GTI)	-0.03** [0.01]	-0.28 [0.17]	0.47** [0.12]	-0.36** [0.16]	0.56** [0.23]	-1.25 [0.10]	4.28* [1.86]	0.47** [0.16]	-0.08* [0.04]	-0.31*** [0.01]
D(GDP)	1.61** [0.04]	0.48*** [0.10]	0.09 [0.15]	0.05 [0.03]	0.09 [0.17]	-0.82 [0.15]	-0.05 [0.10]	0.38** [0.15]	-0.38** [0.08]	-0.26*** [0.00]
D(GDP(-1)	-	-	-	-	-	-	-	-	0.45*** [0.07]	-

Table 4. Continued.

	CO₂ Model					Ecological Foot Print Model				
	China	Japan	India	Russia	USA	China	Japan	India	Russia	USA
D(GDPS)	-1.22** [0.07]	-0.28*** [0.11]	-0.03 [0.10]	-0.03 [0.01]	-0.05 [0.08]	0.98 [0.13]	0.05 [0.30]	-0.19** [0.07]	0.14** [0.05]	0.15*** [0.09]
D(TOU)	-0.23** [0.01]	-0.04** [0.01]	0.35** [0.11]	0.03 [0.02]	-0.10 [0.13]	-0.24*** [0.02]	-0.10* [0.04]	-0.05 [0.09]	0.12** [0.02]	0.36*** [0.02]
D(TOU(-1))	-	-	-	-	-	-	-	-	-1.79*** [0.18]	
CointEq(-1)	-2.49** [0.04]	-0.81*** [0.16]	-4.00** [1.25]	-0.79*** [0.16]	-0.36** [0.18]	-0.84*** [0.06]	-1.6*** [0.21]	-1.73*** [0.48]	-1.51*** [0.13]	-1.34*** [0.02]

Note: *,**,*** represents 10%, 5%, & 1% significance level.

Table 5. Diagnostic test (ARDL).

	CO_2 Model					Ecological Foot Print Model				
	China	Japan	India	Russia	USA	China	Japan	India	Russia	USA
R^2	0.999	0.998	0.995	0.982	0.985	0.999	0.996	0.999	0.995	0999
Adj R^2	0.999	0.996	0.984	0.983	0.981	0.998	0.989	0.996	0.987	0.998
D.W	2.381	2.112	2.450	2.029	2.407	2.372	2.293	1.932	2.432	2.561
LM test	0.459 (0.177)	2.334 (0.212)	1.348 (0.425)	5.841 (0.192)	1.879 (0.214)	0.414 (0.707)	1.151 (0.464)	0.556 (0.687)	0.874 (0.464)	4.689 (0.0.310)
Hetero	3.151 (0.264)	0.455 (0.833)	1.076 (0.511)	0.428 (0.849)	0.966 (0.493)	0.263 (0.948)	0.891 (0.595)	1.400 (0.587)	0.394 (0.949)	1.650 (0.376)
J.B	0.548 (0.760)	0.678 (0.712)	0.648 (0.723)	3.998 (0.135)	1.116 (0.572)	2.213 (0.330)	1.057 (0.589)	0.408 (0.815)	1.8375 (0.1198)	1.382 (0.501)
Ramsey reset	1.618 (0.331)	1.796 (0.237)	1.453 (0.314)	0.027 (0.875)	0.014 (0.907)	0.008 (0.934)	0.102 (0.769)	0.063 (0.824)	0.928 (0.367)	0.021 (0.0.907)
CUSUM	S	S	S	S	S	S	S	S	S	S
CUSUMQ	S	S	S	S	S	S	S	S	S	S

4 | Conclusion and Recommendations

Despite recent pledges from nations to attain carbon neutrality, the environment is currently in a vulnerable position, requiring more extensive efforts. Deaths caused by floods as a result of droughts in other parts of the world highlight the critical need for immediate international action to address problems like air pollution, food insecurity, and insufficient water supply. Both wealthy and poor nations are vulnerable to the effects of climate change, and although international agreements have seen withdrawals and produced little environmental progress, it is critical to acknowledge this. Protecting our planet from these threats calls for swift and concerted actions [72]. As a result of our increasing reliance on fossil fuels, the rate of environmental degradation is becoming an increasingly pressing issue on a worldwide scale. One of the leading causes of climate change that poses a threat to human life is CO_2, which accounts for 76% of all greenhouse gas emissions. This is a major roadblock on the path to accomplishing the SDGs. Desertification, pollution, and soil erosion are made worse by rapid development, which in turn exacerbates the already-existent problems of climate change, increasing temperatures, and excessive CO_2 emissions. If we want to ensure a sustainable future, we must solve these problems [12].

The primary goal of this research was to identify the most significant sources of pollution on a global scale and to identify ways to improve environmental standards in the five countries with the largest emissions. This study discovered the role of GI, GTI, GDP, and TOU on the environment, focusing on the top 5 emitting economies, China, Japan, Russia, India, and the USA, using the ARDL technique. GI was found to have a positive impact on CO_2 in China, Japan, India, and Russia. The environmental impacts of economic globalization, especially in relation to carbon emissions, are becoming an increasingly pressing issue in light of the worldwide push for greater connectivity and the many threats presented by climate change. The question of whether globalization makes decarbonization harder or easier remains unanswered because the literature on the subject has no clear evidence of a link between the two. There is an abundance of research on the complex relationship between globalization and CO_2 emissions, but some studies have found a positive correlation [39], [40]. Around the world, people are still very interested in the ongoing discussion on whether globalization helps or hurts ecological balance. Concerning the consequences of globalization on the environment, theoretical debates provide competing predictions, outlining both positive and negative outcomes. The empirical literature adds to the conversation by illuminating multiple and frequently contradictory environmental effects of globalization. The inclusive character of globalization allows it to bypass national boundaries, facilitating the movement of investments and changing social and political dynamics. But when societies develop in the midst of globalization, it also affects the state of the environment. Numerous works investigate the complex interplay between globalization and ecological harmony in light of the fact that climate change poses a grave danger to humankind's continued existence. Worldwide, climate policies are being shaped by the urgent need to transition to a low-carbon global economy in order to ensure human survival, ecological balance, and sustainable economic growth. Much discussion has been roused in recent decades over the interconnected problems of climate change and globalization, with a focus on the so-called "pollution haven hypothesis," which proposes that polluting businesses should move from industrialized to underdeveloped countries. A holistic, multi-dimensional view is necessary for a complete analysis of globalization because of its complex and multi-faceted character [15]. These findings are similar to previous studies. Farooq et al. [15] for Pakistan reported the correspondence between globalization. The estimated assessment of the research displayed that globalization worsens the environmental quality. Bilal et al. [38] conducted a study on the connection between globalization and the environment. The estimated assessment of the experiment reported that globalization harms environmental quality. Yang et al. [39], [40] investigated the correlation between globalization and CO_2. They found a favorable attachment of the economic globalization environment for OECD countries.

GTI was found to be adversely associated with CO_2 in all studied countries. Environmental pollution can be alleviated through the implementation of green strategies, which aim to accomplish SDGs through the utilization of renewable resources derived from nature. In light of growing worries about environmental deterioration, ecologists are calling on governments to replace harmful traditional corporate practices with more sustainable alternatives. This change protects the planet from harmful environmental contamination and reduces its negative effects because green technology uses less harmful ingredients and processes than traditional technology development methods [21]. The connection between TI and CO_2 emissions is becoming more and more discussed as the world's environment confronts more and more problems. If we want to make environmental policies that actually work, we need to look at how TI can reduce CO_2 emissions. According to a plethora of research, TI is an essential tool for reducing CO_2 emissions and protecting the environment. In addition, TI helps with economic restructuring by paving the way for new models that emphasize sustainability, rather than the old ones that were based on output [61]. By encouraging the use of sustainable energy sources and regulating pollutants, TI stands out as the best policy to tackle carbon emissions. Businesses can benefit from TI's ability to increase the efficiency of RNE production, which contributes to the ongoing worldwide effort to move to a more economical and sustainable energy source. Utilizing TI extensively in power generation has dual benefits: lowering energy consumption and drastically reducing the negative effects of carbon pollution on the environment. As a formidable challenge to international peace and safety, reaching carbon neutrality is within reach with the revolutionary potential of new technologies [61].

New research highlights the critical importance of environmentally friendly technology advancements as an important tactic for reducing carbon emissions worldwide. In order to achieve low-carbon and sustainable development, the emphasis has changed to green energy and technical innovation, which greatly aids economic growth and ecological vitality. A consensus-based definition of "green innovation" has yet to be reached, but the idea of green technology, which includes pollution management, ecological treatment, purification, recycling, monitoring, and various evaluation technologies, was presented. The term "green innovation" has recently been used to describe any technique or product that is innovative, unique, valuable, eco-friendly, and conserves resources [73]. The findings of the present study are similar to those of many previous studies. Amin et al. [18] conducted the linkage between GTI and CO_2. The verifiable outcomes of the research disclosed that GTI mitigates CO_2 for South Asian countries. The alliance between GTI, and CO_2 was investigated by Ali et al. [60]. The observed calculation of the paper suggests that GTI reduces CO_2 emissions. The advent of environmentally friendly technical innovation heralds a fresh perspective on technology that could reduce energy usage, lessen pollution, improve environmental quality, and encourage the growth of a sustainable and environmentally conscious economy. This new way of thinking involves making eco-friendly products using technical procedures, to reduce pollution and energy consumption [74]. Technological advancements that are environmentally friendly also help industrialized countries make better use of renewable resources and speed up the development of RNE. More and more, the argument has been made that developing nations may greatly benefit from reducing their environmental emissions and promoting long-term sustainable development through investing in RNE and green technology. For this reason, developing countries might find a practical way to lower their carbon emissions by investing in green technology innovation, which in turn reduces CO_2 emissions and improves environmental quality, and need not only the development of green technologies but also the support of reputable institutions [74].

As per the findings of this study, GDP was found to be detrimental with regard to environmental sustainability. GDP was found to be responsible for environmental damage in all studied countries. Researchers have spent decades studying the EKC hypothesis—the link between economic growth and environmental degradation—from a variety of theoretical and empirical perspectives. A major worry in the modern world is the ubiquitous threat that climate change poses. Rapid shifts in regional and global climate patterns are hallmarks of climate change, which threatens human health and prosperity. Due to the interrelated nature of these issues, it is critical that we comprehend the dynamic relationship between environmental sustainability and economic development in light of the pressing need to address climate change [46]. Worldwide, people are working together to find solutions that will reduce emissions of CO_2 and help the environment. The major causes of emissions, which include economic expansion and the use of non-RNE sources, have recently received a lot of focus. Research by Kuznets [75], for instance, shows that CO_2 levels and economic growth have an inverted U-shaped relationship [44]. With climate change highlighting the connection between economic activities and environmental deterioration, rising economies are understandably concerned about how sustainable development and economic growth interact. Air and water pollution, soil erosion, deforestation, and population increase are some of the causes. The problems caused by emissions of GHGs, especially CO_2, are a result of some countries' prioritization of production over environmental preservation. For a future that is both balanced and sustainable, it is essential to address these concerns [34], [35]. The findings of this study are in line with many previous studies.

Mahmood et al. [53] identified the interconnection between GDP and CO_2 in Pakistan. The final outcomes of the inquiry revealed that GDP pollutes the environment. Agboola et al. [43] established the union between total natural resources rent, oil rent, GDP, and CO_2 employing the ARDL model for Saudi Arabia. The verifiable result of the research proposed that GDP demolish the environmental quality. Liu et al. [46] probed the correlation between GDP, and CO_2. However, outcomes of the research in the case of 5 high-emissions economies show that GDP increased pollution.

Tourism was found to be responsible for improvement in environmental quality in China , Japan, and the USA, but showed a detrimental impact on environmental sustainability. Internationally, tourism thrives on the appeal of natural and cultural assets such as landscapes, climate, wildlife, historical monuments, traditional crafts, festivals, and local traditions. This surge in tourism has substantially bolstered national economies. Despite the positive economic impact, the rapid expansion of the tourism sector has concurrently led to notable adverse environmental effects on the country [56]. The tourism industry is a significant contributor to economic strength. However, existing studies on sustainability mainly focus on descriptive analyses of the tourism-sustainability association, leaving the long-term relationship between tourism and the environment unclear and overlooked. These studies also lack appropriate implications for achieving sustainable tourism. This study aims to fill this gap by providing empirical estimations of the role of tourism in environmental deterioration. In recent years, a few studies have utilized various models, including computable general equilibrium models and decomposition approaches, to highlight the critical role of the tourism industry in environmental degradation [1]. The findings of the current study are consistent with previous studies. Lorente et al. [1] reported the link between tourism and the environment. They found that tourism damages the environmental quality in 36 OECD countries. For 70 countries, Liu et al. [3] demonstrated the linkage between tourism and CO_2 from 2000 to 2017. The assessment of the calculation showed that tourism harms the environmental quality. Bandyopadhyay et al. [55] found a correlation between tourist arrivals and CO_2 emissions. However, the observed assessment of the research in the case of India uncovered that tourist arrivals decline CO_2.

Based on the findings of the study, the governments of these studied countries should focus on R & D programs to enhance the adoption of green technologies. Moreover, governments should implement carbon taxes along with strict environmental regulations. Global collaboration might be a great solution for carbon emissions reduction. These countries should strengthen international agreements for environmental betterment through GTIs. Globalization-related activities like trade and transport should be monitored by an international system for tracking and reporting emissions. The policymakers and governments should raise awareness about the harmful impact of globalization on the environment. Countries should develop strong global institutions to address transboundary environmental challenges. These countries should switch to renewable sources and utilize new and standard technologies in economic activities. Furthermore, the government should offer monetary incentives to the carbon industries. All stakeholders should work together on formulating policies and strategies to motivate tourism. Sustainable tourism investments can boost tourism revenue while cutting down on CO_2 emissions from the industry's transportation sector.

Limitations and future research

NARDL, threshold regression, or any other advanced methodology could be employed in future studies to better capture the non-linear relationship between the variables. Future studies could provide a comprehensive global understanding of emission trends by adding more countries, including mid-level and developing countries. The time period for analysis could be expanded to incorporate the effects of advanced technologies and recent international agreements.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

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All data are included in the text.

Conflict of Interest

The author declares that he does not have any conflict of interest.

Consent for Publication

The author has given consent for the publication of this manuscript.

Ethics Approval and Consent to Participate

This study does not involve any research conducted on human participants or animals.

Reference

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Appendix A

Table A1. The final findings of descriptive statistics and stationarity of China.

	CO_2	EF	GI	GTI	GDP	GDPS	TOU
Mean	6945603	1.803908	58.59259	468593.9	8.762772	81.9055	1.06E+08
Median	7199605	1.890191	62	194579	8.490093	72.08169	1.25E+08
Maximum	10089273	2.54496	65	1426644	14.23086	202.5174	1.63E+08
Minimum	3070505	0.891662	44	10011	2.238638	5.011502	30402000
Standard deviation (Std. Dev.)	2899557	0.653553	6.680968	525457.3	2.305694	40.50921	38975707
Skewness	-0.19584	-0.24699	-0.98269	0.764118	-0.20464	1.003981	-0.53856
Kurtosis	1.354684	1.391711	2.589575	1.936566	4.469534	4.565237	2.071643
Jarque-Bera	3.218039	3.184433	4.53508	3.899693	2.617921	7.292111	2.274772
Probability	0.200084	0.203474	0.103567	0.142296	0.270101	0.026094	0.320656
Sum	1.88E+08	48.70551	1582	12652036	236.5948	2211.448	2.87E+09
Sum Sq. Dev.	2.19E+14	11.10541	1160.519	7.18E+12	138.2218	42665.9	3.95E+16

Table A2. The final findings of descriptive statistics and stationarity of Japan.

	CO_2	EF	GI	GTI	GDPS	GDP	TOU
Mean	1166234	3.466209	70.59259	311842.7	4.729153	0.729302	10489572
Median	1172604	3.516809	72	330110	2.202165	1.37235	6790000
Maximum	1267376	3.831316	78	387364	32.41294	4.097918	31881000
Minimum	975469.9	2.741456	58	222452	0.000567	-5.69324	3345000
Std. Dev.	65996.11	0.25429	5.645006	51642.61	7.272185	2.087751	8698239
Skewness	-1.24715	-0.89997	-0.4141	-0.16039	2.514528	-1.42058	1.510584
Kurtosis	4.569256	3.651352	2.262995	1.636333	9.245216	5.406622	3.904745
Jarque-Bera	9.769552	4.122076	1.382729	2.207797	72.33089	15.59706	1.12E+01
Probability	0.007561	0.127322	0.500892	0.331576	0	0.00041	3.72E-03
Sum	31488310	93.58764	1906	8419754	127.6871	19.69116	2.83E+08
Sum Sq. Dev.	1.13E+11	1.681247	828.5185	6.93E+10	1375.002	113.3263	1.97E+15

Table A3. The final findings of descriptive statistics and stationarity of India.

	CO_2	EF	GI	GTI	GDP	GDPS	TOU
Mean	1520880	0.455409	55.22222	8538.444	6.171626	46.59543	6989667
Median	1424383	0.454962	59	6425	7.410228	54.91147	5168000
Maximum	2308804	0.63828	63	26267	9.050278	81.90753	14570000
Minimum	737856.4	0.280867	39	1545	-5.83105	9.527705	2124000
Std. Dev.	587889.3	0.124487	7.767453	6839.777	2.972144	21.7013	4996403
Skewness	0.150756	0.014808	-0.76944	1.036641	-2.53947	-0.26303	0.668851
Kurtosis	1.422057	1.407147	2.116657	3.285469	10.85131	1.811157	1.73085
Jarque-Bera	2.903416	2.855316	3.542033	4.927489	98.36859	1.901353	3.83E+00
Probability	0.23417	0.23987	0.17016	0.085116	0	0.38648	1.48E-01
Sum	41063749	12.29603	1491	230538	166.6339	1258.077	1.89E+08
Sum Sq. Dev.	8.99E+12	0.402925	1568.667	1.22E+09	229.6746	12244.61	6.49E+14

Table A4. The final findings of descriptive statistics and stationarity of Russia.

	CO_2	EF	GI	GTI	GDP	GDPS	TOU
Mean	1593740	3.429013	67.37037	23939.81	2.693696	27.44192	21807389
Median	1592559	3.428141	69	24072	4.024086	20.25	22486000
Maximum	1699083	3.842357	72	29269	10.00007	100.0013	33729000
Minimum	1487965	2.947867	57	15106	-7.79999	0.037516	6359000
Std. Dev.	51478.66	0.233821	4.47341	3963.508	4.578461	25.83514	6283106
Skewness	-0.08236	-0.02705	-0.76685	-0.65562	-0.57854	1.084846	-0.53016
Kurtosis	2.817261	2.369831	2.454965	2.569112	2.526996	3.543804	3.54125
Jarque-Bera	0.068092	0.450045	2.980464	2.143137	1.757903	5.628698	1.59E+00
Probability	0.966527	0.798498	0.22532	0.342471	0.415218	0.059944	4.51E-01
Sum	4.30E+07	92.58335	1819	646375	72.72979	740.9319	5.89E+08
Sum Sq. Dev.	6.89E+10	1.42148	520.2963	4.08E+08	545.02	17353.82	1.03E+15

Table A5. The final findings of descriptive statistics and stationarity of the United States.

	CO_2	EF	GI	GTI	GDP	GDPS	TOU
Mean	5262756	6.646208	79.25926	221393.3	2.409528	9.39621	1.32E+08
Median	5273486	6.959992	80	231588	2.684217	7.324436	1.62E+08
Maximum	5775807	7.60275	82	295327	5.945485	35.34879	1.83E+08
Minimum	4049747	5.643916	74	106892	-2.7678	0.01493	62082000
Std. Dev.	449481.2	0.784935	2.39539	60186.78	1.930927	7.97358	50019840
Skewness	-0.89218	-0.16773	-0.56891	-0.43654	-1.05788	1.540614	-0.35222
Kurtosis	3.382483	1.238824	2.035177	1.92702	4.662082	5.327884	1.21E+00
Jarque-Bera	3.75E+00	3.616053	2.503709	2.152735	8.143801	16.77714	4.17E+00
Probability	1.54E-01	0.163977	0.285974	3.41E-01	0.017045	0.000227	1.24E-01
Sum	1.42E+08	179.4476	2140	5977620	65.05725	253.6977	3.57E+09
Sum Sq. Dev.	5.25E+12	16.0192	149.1852	9.42E+10	96.94041	1653.027	6.51E+16

Appendix B

Table B1. Correlation Matrix of China.

	CO_2	GI	GTI	GDPS	GDP	TOU
CO_2	1					
GI	0.909336	1				
GTI	0.855947	0.700266	1			
GDPS	-0.36701	-0.18328	-0.6116	1		
GDP	-0.42175	-0.2537	-0.66936	0.971161	1.00E+00	
TOU	0.557725	0.634112	0.274938	0.049037	8.12E-02	1

	EF	GI	GTI	GDPS	GDP	TOU
EF	1					
GI	0.919599	1				
GTI	0.834982	0.700266	1			
GDPS	-0.34578	-0.18328	-0.6116	1		
GDP	-0.40108	-0.2537	-0.66936	0.971161	1	
TOU	0.561942	0.634112	0.274938	0.049037	0.081232	1

Table B2. Correlation Matrix of Japan.

	CO_2	GI	GTI	GDPS	GDP	TOU
CO_2	1					
GI	-0.28403	1				
GTI	0.495553	-0.81626	1			
GDPS	-0.35342	0.010529	-0.15993	1		
GDP	0.40975	-0.2501	0.189757	-0.41679	1	
TOU	-0.26585	0.737761	-0.64757	-0.24531	0.04275	1
	EF	**GI**	**GTI**	**GDPS**	**GDP**	**TOU**
EF	1					
GI	-0.70297	1				
GTI	0.822122	-0.81626	1			
GDPS	-0.17953	0.010529	-0.15993	1		
GDP	0.059768	-0.2501	0.189757	-0.41679	1	
TOU	-0.51996	0.737761	-0.64757	-0.24531	0.04275	1

Table B3. Correlation Matrix of India.

	CO_2	GI	GTI	GDP	GDPS	TOU
CO_2	1					
GI	0.890112	1				
GTI	0.917242	0.767816	1			
GDP	-0.14767	-0.07134	-0.25452	1		
GDPS	0.075234	0.094869	0.112284	0.67611	1	
TOU	0.948856	0.748522	0.922599	-0.15435	0.114464	1.00E+00
	EF	**GI**	**GTI**	**GDP**	**GDPS**	**TOU**
EF	1					
GI	0.908987	1				
GTI	0.846746	0.767816	1			
GDP	-0.05906	-0.07134	-0.25452	1		
GDPS	0.057898	0.094869	0.112284	0.67611	1	
TOU	0.89678	0.748522	0.922599	-0.15435	0.114464	1

Table B4. Correlation Matrix of Russia.

	CO_2	GI	GTI	GDP	GDPS	TOU
CO_2	1					
GI	0.293693	1				
GTI	0.627427	0.727332	1			
GDP	0.322151	0.064583	0.299602	1	0.494097	
GDPS	0.077897	-0.24588	0.079623	0.494097	1	
TOU	0.326692	0.501193	0.65162	0.194027	-0.13659	1
	EF	**GI**	**GTI**	**GDP**	**GDPS**	**TOU**
EF	1					
GI	0.556382	1				
GTI	0.559658	0.727332	1			
GDP	0.276052	0.064583	0.299602	1		
GDPS	-0.13245	-0.24588	0.079623	0.494097	1	
TOU	0.286821	0.501193	0.65162	0.194027	-0.13659	1

Table B5. Correlation Matrix of the United States.

	CO_2	GI	GTI	GDP	GDPS	TOU
CO_2	1					
GI	-0.53226	1				
GTI	-0.58119	0.955324	1			
GDP	0.184703	-0.34393	-0.35145	1		
GDPS	-0.13934	-0.3208	-0.38795	0.681589	1	
TOU	-0.60907	0.902738	0.856153	-0.3713	-0.30925	1
	EF	**GI**	**GTI**	**GDP**	**GDPS**	**TOU**
EF	1					
GI	-0.79838	1				
GTI	-0.86625	0.955324	1			
GDP	0.330202	-0.34393	-0.35145	1		
GDPS	0.216884	-0.3208	-0.38795	0.681589	1	
TOU	-0.78251	0.902738	0.856153	-0.3713	-0.30925	1