The Impact of Green Growth, Technological Change and Renewable Energy on CO_2 Emission: Evidence from Selected Asian Countries

BY

Samreen Rafique

NATIONAL UNIVERSITY OF MODERN LANGUAGES

ISLAMABAD

FEBRUARY, 2024

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Samreen Rafique

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF PHILOSOPHY

IN ECONOMICS

To

Department of Economics

FACULTY OF MANAGEMENT SCIENCES

NATIONAL UNIVERSITY OF MODERN LANGUAGES, ISLAMABAD

NATIONAL UNIVERSITY OF MODERN LANGUAGESFACULTY OF MANAGEMENT SCIENCS

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Thesis Title: The Impact of Green Growth, Technological Change and Renewable Energy on CO_2 Emission: Evidence from Selected Asian Countries

Submitted by: Samreen Rafique **Registration** #: 17-Mphil/Eco/F20

Master of Philosophy
Degree Name

Economics
Name of Discipline

Dr. Hmaira Saleem ________________________
Name of Supervisor Signature of Supervisor

Dr. Hadayat Ullah Khan ________________________
Name of HOD Signature of HOD

Prof. Dr. Muhammad Zahid Iqbal ________________________
Name of Dean (FMS) Signature of Dean (FMS)

____
Date

AUTHOR'S DECLARATION

I, Samreen Rafique Daughter of Muhammad Rafique

Registration # 17-Mphil/Eco/F20

Discipline Economics

Candidate of **Master of Philosophy** at the National University of Modern Languages do hereby declare that the thesis **The Impact of Green Growth, Technological Change and Renewable Energy on CO_2 Emission: Evidence from Selected Asian Countries** submitted by me in partial fulfillment of MPhil degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in future, be submitted by me for obtaining any other degree from this or any other university or institution.

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Abstract

The debate on green growth has been increasing among researchers as an approach to address environmental conservation and provide a sustainable solution to the climate change dilemma. Numerous nations are working on their emission neutrality goals. The present research examines the role of green growth, technological change, GDP growth, renewable energy, and trade openness on environmental degradation in the context of selected Asian economies from 1990–2018. This investigation applied second-generation panel data techniques. Within the framework of Environmental Kuznets (EK) curve theory, the present study employed the cross-section augmented autoregressive distributed lag (CS-ARDL) strategy to investigate the effects of green growth and economic expansion (GDP) along with other macroeconomic indicators on the environmental quality. The findings of this study concluded technological innovation, green growth, clean energy and expansion of GDP all have an important impact (positive/negative) on CO_2. There is an inverting U-shaped EK curve exists in the selected Asian countries. This analysis indicates that the green growth significantly minimizing the level of CO_2. Additionally, it has been revealed that using renewable energy and technological change reduces the production of CO_2 emissions. The Dumitrescu–Hurlin panel estimation technique was employed to determine whether all factors were causally interrelated. Thus, results concluded that bi-directional relationship found between CO_2-trade openness, CO_2-green growth, GDP-renewable energy, GDP-green growth, GDP-technological change, GDP-trade, technological change-renewable energy, renewable energy-green growth, technological innovation-green growth, trade-green growth and technological innovation-trade openness. And unidirectional causality is running from GDP, GDP^2, technological change, renewable energy to CO2, GDP^2 to renewable energy and renewable energy to trade openness. Policy makers should concentrate on adopting clean energy policies, leading to a more rapid reduction in energy-associated CO_2 pollution.

Key words: GDP growth per capita, Green growth, Technological change, Carbon dioxide emissions, Renewable energy consumption.

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List of Abbreviations

GHG	Greenhouse Gas
EKC	Environmental Kuznets Curve
MMQR	Method of Moments Quantile Regression
FMOLS	Fully Modified Ordinary Least Square
DOLS	Dynamic Ordinary Least Square
E7	Emerging 7 is the seven countries Brazil, China, India, Indonesia, Mexico, Russia and Turkey
V.A.R	Vector autoregression
V.E.C.M	Vector Error Correction Model
BRI	Belt and Road Initiative
GMM	generalized method of moments
ARDL	autoregressive distributed lag
LM	Lagrange Multiplier
CADF	Covariate Augmented Dickey-Fuller
SYS-GMM	The system GMM estimator
OECD	The Organization for Economic Cooperation and Development
AMG	augmented mean group
PMG-ARDL	pooled mean group ARDL
CIP unit root	cross-sectionally augmented panel unit root test
CCEMG	common correlated effects mean group
MERCOSUR	an economic and political bloc originally comprising Argentina, Brazil, Paraguay, and Uruguay
STIRPAT	Stochastic Impacts by Regression on Population, Affluence and Technology
D-H	Dumitrescu–Hurlin
DF	Dickey-Fuller
PP	Phillips–Perron
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
BRICS	Brazil, Russia, India, China, and South Africa
GCC	Gulf Cooperation Council

Acknowledgment

I express my deepest gratitude to Allah Almighty for His blessings and guidance throughout this journey. My heartfelt thanks go to my parents and family for their unwavering support and belief in me. I am truly indebted to my dedicated supervisor, **Dr. Humaira Saleem**, whose expertise and encouragement have been instrumental in shaping this thesis. I also thank my class fellow for the collaborative learning experience and my friends for their constant encouragement. This accomplishment reflects the collective support and inspiration I have received from these special individuals. Their contributions have been invaluable in making this thesis possible**.**

DEDICATION

This thesis is dedicated to my late Dad for his love, endless support and encouragement. Dad you are not away but in my every breath.

Also Dedicated to

My Teachers

CHAPTER 1

INTRODUCTION

1.1Introduction

The Industrial Revolution took place in the 18th century (1700s) in Britain and subsequently expanded globally. This revolution has a positive impact on the development of the industrial sector and, at the same time, has a negative impact on the climate (Singh Ahuti, 2015). Adopting machinery and establishing factories enabled extensive mass production, contributing to severe environmental challenges. The negative outcomes of the revolution included the depletion of natural resources, increased GHG emissions, especially carbon dioxide emissions (CO_2), escalated pollution, global warming, and climatic change. Climate change has emerged as a formidable global challenge in recent years, posing severe consequences for human lives and property. The buildup of greenhouse gases mostly causes climate change in terms of tropical Storms, floods, droughts, and heat waves are among the extreme weather events that result in increased frequency and intensity. Such occurrences greatly impact populations, biodiversity, and the agricultural sector. The existing literature has emphasized CO_2 emissions as a crucial indicator of environmental pollution (Shahbaz et al. 2019; Saleem et al. 2022; Tiba and Omri 2017). Numerous prior studies (Baskaya et al. 2022; Long et al. 2017 & Ahmad et al. 2021) have observed this association and found strong evidence of a relationship between CO_2 emissions and their main drivers. Thus, trade openness, technological change, green growth, the consumption of renewable energy, and economic growth have been identified as potential factors influencing CO_2 emissions. The environmental risks associated with economic development and growth has gained international attention and is a hotly debated topic in the fields of sustainable development and environmental economics.

Economic growth has played a significant role in driving CO_2 emissions for several decades. The Environmental- growth relationship is explained under the umbrella of the environmental Kuznets curve (EKC) theory. It is a concept that highlights the relationship between economic development and environmental issues (Grossman & Krueger, 1991). According to the EKC, countries, particularly developing economies, tend to encounter environmental challenges during the early stages of their development(Liang and Yang 2019), attributed to the initial utilization of resources that may adversely affect the environment. However, as countries progress and reach higher income levels, there is a shift in their development structure towards incorporating environmentally friendly resources like renewable energies and innovative production processes.

From a global perspective, many advanced and emerging economies are responsible for environmental depletion. According to the findings of the Joint Research Centre (2019), fifteen countries are responsible for 72.2% of the worldwide environmental decline. Specifically, China's CO_2 emissions in 2017 contributed 27.2% to this deterioration, amounting to 9.84 billion tons. The United States followed with the second-highest CO_2 emission level at 5.27 billion tons, contributing to 14.6% of the global environmental decline. In the same year, other notable contributors included India at 6.8%, Russia at 4.7%, Japan at 3.3%, Germany at 2.2%, Iran at 1.9%, Saudi Arabia at 1.8%, South Korea at 1.7%, Canada at 1.6%, Mexico at 1.4%, Indonesia at 1.3%, Brazil at 1.3%, South Africa at 1.3%, and Turkey at 1.2%. The remaining nations collectively constituted 27.7% of the factors contributing to global environmental destruction in that year.

In the same direction, the World Health Organization (WHO 2017) reported that due the air pollution annually, over 2.1 million people die globally. On a global scale, the Asian region is considered the most populated area, experiencing a drastic increase in particulate matter (PM) 2.5. This surge in PM 2.5 is particularly seen in emerging countries such as China, Bangladesh, Pakistan, and India. Moreover, the report emphasized that specific Asian metropolitan areas, including Beijing, Xi'an, Delhi, Bombay, Dhaka, Karachi, Lahore, and Islamabad, face substantial air pollution, resulting in smog and a notable decrease in visibility. India and China continue facing the persistent issues of heavy smog, PM 2.5, and carbon emissions, adversely affecting their global reputation and causing serious health issues (Khan et al. 2019). These health concerns encompass pollution-related diseases such as lung cancer, asthma, and cardiovascular ailments within their respective populations. These challenges highlight the urgent need for environmental measures and health interventions in these regions. Also, internationally, the drastic environmental change is considered a big challenge for environmentalists and policymakers as they seek an effective solution to safeguard the world's environment. Therefore, in 2005, the United Nations (UN) introduced green growth as an efficient solution for attaining sustainable development and resolving environment-related concerns. The Organization for Economic Co-operation Development (OECD) is also on the same page as the UN in promoting green growth because it decreases environmental pollution and improves environmental quality.

The achievement of net-zero carbon dioxide emissions, or carbon neutrality, is a goal of significant significance to researchers and policymakers. Global efforts to advance environmentally friendly solutions are reflected in the active promotion of technological change and green growth by nations around the world. Green growth means enhancing economic growth and development while ensuring the continuous provision of resources and environmental services from natural assets that contribute to our well-being. It stimulates investment and innovation, serving as the foundation for sustained growth and creates new economic opportunities in inclusive ways for everyone. Green growth is a vital strategy for achieving sustainable development. The international community is focusing on pro-environmental economic growth, which promotes a sustainable environment. The United Nations Development Programme (UNDP) and other international institutions encourage such growth strategies that enhance the sustainability of the environment. Several international reports and agreements set the agenda points for developing and developed nations to meet sustainable goals (e.g., MDGs (2000), SDGs (2015), Kyoto Protocol (1997)) and Paris Agreement (2015)). The addition of clean energy sources into the energy mix is also a potential source to curb environmental degradation. Additionally, green growth, as defined by the OECD (2011), green growth encourages low-carbon, resource-efficient and, socially inclusive development in an effort to balance environmental sustainability with economic growth. The concept of "green growth" is limited because it provides a particular framework for sustainable improvements at the nexus of environmental sustainability and economic growth. Green growth encourages an economical and resource-conscious approach to making sustainable decisions in the manufacturing and consumption process.

Many developed countries are implementing green growth strategies to protect the environment. Germany, as a developed nation, is continuously reducing coal consumption for producing electricity and at the same time, Germany promotes renewable energy sources to generate electricity. The other developed nation is the United Kingdom (UK) is also following the path of Germany .The third developed nation in Asia is Singapore, which established a Sustainable Development Commission (Blue Plan for Sustainable Singapore) in 2009. The core objective of this Commission was to increase energy efficiency in public transportation, enhance life quality, decrease environmental damage, and reduce water consumption. On the other hand, Norway encourages using green technology as a viable policy to achieve environmentally friendly growth. Through targeted research techniques, Norway uses this environmentally persistent technology in its energy, health, tourism, petroleum, maritime, and agriculture sectors. The Netherlands also stands out as a pivotal example of public-private collaboration during the shift to a green economy. A project company named DBFMO (Design, Build, Finance, Maintenance, and Operation) was established between the government and the private sector. A consortium, which includes other private companies, is dedicated to making investments with the goal of realizing a minimum 21% reduction in carbon emissions, ultimately contributing to a cleaner environment.

Many developing countries also consider green growth as an eco-friendly growth method to achieve sustainability. Green growth plays a vital role in enhancing and advancing various sectors, such as renewable energy, green technology and, organic agriculture production, etc. On a global scale, solar photovoltaic (PV) power is projected to emerge as a key player in the international energy supply by 2030 and is expected to become a predominant energy source by 2050. China's policy aim is to develop a photovoltaic (PV) industry with a total capacity of 1050 GW by 2030, given its position as a leading producer and the largest exporter (over 98% of production) of PV for solar energy.

Malaysia is effectively improving energy accessibility in rural regions, serving as a notable case study for the application of renewable energy. In the same direction, the Egyptian government aims to produce approximately 42% of its electricity from renewable sources, particularly solar energy, by the year 2034/35. Morocco is also on the same line as China and Egypt, as it's implemented the Morocco Solar Energy Agenda (MASEN) to facilitate the financing of solar energy investments, enhancing the efficiency and accessibility of the process. South Korea is trying to develop the latest structure of its economy with the help of green technology to lessen its dependence on ecological change and energy conservation to upgrade its standards of living (Gültekin and Erenoğlu 2018). Korea also installed the latest and environmentally friendly engines, better water quality in Jeju Island, and seed quality upgrading production practices for producers, gigantic eco-friendly investments in public transportation. For the low emissions production practices in energy and other sectors of the economy, public support for research and development applications is at the front line; imposing environmental pollution taxes and the firm's law for environmental protection can be explained in other measures taken (Mathews 2012). These initiatives represent a commitment to attaining sustainable economic development in this particular context. Thus, green growth, clean energy and technological innovation are prerequisites that incorporate pollution control, ecological treatment, and other methods. Therefore, it is clear that green policies are important for both developed and developing economies.

1.2 Environmental Degradation Outlook for Selected Asian Economies

The Asian region severely faces numerous challenges of climatic change, biodiversity loss and ecosystem destruction. Asia is the largest and most populated region around the globe. The continent of Asia alone produced 16.75 billion Metric tons of CO_2 emissions in 2020. All other content emissions from the Asian region were more than the total emission (Wei et al., 2023). Around the globe, the Asian region comprises the fastest growing and fastest emerging economies and is the world's greatest donor of CO_2 emissions. 31% of the world's CO_2 emissions in 2020 alone were produced by China, which is also considered the most significant contributor to CO_2 emissions globally.

It is observed that the Asian region comprises the world's biggest economies because the total population size of this region is more than half of the world. This region accounts for 53% of the global coal consumption and 28% of the world's total primary energy demand; these sources are the major sources of carbon emissions (Nasreen and Anwar 2014; Bloch et al. 2012). According to Asian Energy Outlook (2018), a sustainable global environment for future generations could be achieved if vigorous efforts are taken to account for energy conservation and cut down pollution, as most of the pollution emissions and the utilization of energy consumption belong to the Asian region. By 2040, China and India will account for 32% of global energy consumption. Therefore, the nexus between green advancement, consumption of environmentally safe energy sources, technological innovation, trade liberalization, and releases of CO_2 in a most populated and swiftly growing Asian region is the focus of our study.

1.3 Significance of the Study

This research examined the impact of green growth and other factors such as GDP growth, renewable energy consumption, trade openness and technological change on environmental damage for 12 Asian economies. The environmental quality could be impacted in these economies characterized by extensive fossil fuel consumption, unwise financial sector investments, industrial contamination, and the trading of environmentally unprotected goods (manufactured without adhering to environmental standards). Asian economies are now simultaneously considering a heart of economic growth and development. Because of expanding urbanization, industrialization, government programs to reduce poverty and population pressure, the need for energy sources is rising quickly throughout the Asian region. This research will endeavor to fill the gap in the existing literature and find an appropriate way to sort out the growth-energy-emission interconnection in more detail and with the application of modern estimation techniques. The environmental Kuznets curve (EKC) framework and other controlling variables are included in the present research to extend the theoretical examination of previous literature. Green output, clean energy consumption, trade openness, and technological change are the essential components for substantial policy reforms in this part of the world.

1.4 Contribution of the Study and Potential Research Gap

The novel contribution of this study is to identify the green growth- clean energy-environment nexus and contribution in the existing literature in three-fold. Firstly, according to the author's knowledge, only a few studies (Wei et al., 2023; Saleem et al., 2022) investigate the impact of green growth on the discharge of CO_2 pollution with some control variables in the context of Asian economies, even though several studies examine the association among GDP expansion, green energy, CO_2 pollutants in Asian economies. This study utilized the latest available data (1990-2018) for selected Asian economies and investigated whether green growth has any role in minimizing CO_2 emissions. Secondly, this study also analyzed the effects of traditional economic growth, renewable energy consumption, technological innovation, openness of trade and the outcomes it produces concerning the release of CO_2. Finally, this analysis identifies the GDP growth per capita with its plausible control variables under the premises of EKC in Model 1. It analyzes the impact of green change with the same control variables under the scheme of green EKC in Model 2.

1.5 Research Questions

The significance of incorporating sustainable development into the nation's economic plans is easily noticeable. This research indicates the following relevant research questions.

1. Do the selected Asian economies demonstrate green growth-CO_2 emission hypothesis?
2. Does technological change significantly mitigate the level of CO_2 in selected Asian economies?
3. Does renewable energy decrease CO_2 emissions in Asian economies?

1.6 Objectives of the Study

The study evaluates the following objectives within a panel of Asian economies.

1. To investigate the impact of GDP growth on CO_2 emissions within the premises of EKC for selected Asian countries.

2. To explore the influence of green growth on CO_2 under the framework of green EKC for selected Asian economies.

1.7 Organization of the Study

This chapter aims to introduce the study, environmental degradation-growth nexus condition in the context of Asian countries, the study's significance, the study's contribution and potential research gap, research questions and the study's objectives. Chapter 2 comprises the review of prior studies, and Chapter 3 explains the model and methodology, theoretical framework, reduced form equation and econometric modeling, data description and estimation techniques. Chapter 4 based on the results and discussion of the study, conclusion and policy recommendation is postulated in Chapter 5. Towards the end of the research, the references are mentioned.

CHAPTER 2

LITERATURE REVIEW

2.1Introduction

The literature review should aim to synthesize and summarize the theories and findings of the previous studies related to the topic of the current studies. It does not generate any novel contribution to the present study. However, reviewing existing research is a helping hand because it's evolving the wheel of new research. This chapter comprises the literature on the prior knowledge of the fundamental analysis. The introduction of this chapter is described in section 2.1. The second segment, 2.2, depicts the literature on Economic growth and CO_2 emissions. The existing work on Green growth and CO_2 emissions is presented in section 2.3. Section 2.4 examines the previous literature on renewable energy consumption and CO_2 emissions. The literature review regarding technological innovation and CO_2 is represented in section 2.5. Section 2.6 explains the assessment of prior analysis on CO_2 release and free trade.

2.2 Relationship between Economic Growth and CO_2 emissions

The interconnection between economic advancement and environmental quality is extensively investigated by numerous researchers under the scheme of the environmental Kuznets curve (EKC) theory. Simons Kuznets (1955) assumed that income inequality rises during the initial state of economic progress; after that, it begins to fall as economic development begins. According to the study by (Boamah et al. 2017), researchers found the different shapes of the environment-growth nexus using various indicators of environmental pollutants. Ecological deterioration has gone alongside economic advancement in developing and advanced economies. Though many analyses affirmed the existence of the EKC hypothesis, many other studies found the varying shapes of the EKC, and several studies showed ambiguous results (Ahmad et al. 2021). Several researchers state that enhancing economic growth increases the level of pollution emissions the contrary and others support vice versa. However, the findings of the studies mainly focus on the traditional Environmental Curve theory.

Baskaya et al. (2022) studied the interconnection among financial development, clean and conventional energy use and the generation of CO_2 by using the scheme of EKC. For this purpose, annual time series data regarding the BRICS economies is taken from 2002 to 2019. Different econometrics methods are utilized for empirical analysis, i-e, MMQR and Dumitrescu- Hurlin cause and effect technique. Findings confirmed the EKC theory's functioning in all five sample states, i.e., Brazil, Russia, India, China, and South Africa. Outcomes also demonstrated a negative coefficient of financial inclusion and renewable energy in all quantiles for carbon emissions. Thus, financial inclusion and pure use of energy may aid in controlling pollution released from the natural atmosphere.

You et al. (2022) investigated the link between ICERTD (international collaboration in environmental-related technology development) and CO_2 emissions by incorporating the role of gross domestic product per capita, domestic environmental innovation, renewable energy consumption, and freedom of trade as determining factors. Quarterly data is used from 1990-2018 in the case of the US. The study employed the latest approaches i.e., FMOLS, correlated component regression and DOLS, for testing the long-term association between predictors. The study confirmed the long-term cointegration amid gross domestic product per capita, ICERTD, trade openness, usage of green energy, domestic green technology and environmental depletion. GDP per capita and trade openness are positively related to CO_2 emissions. Domestic ecological creation, use of sustainable energy and ICERTD reduced the pollution emission across the U.S. economy for a long time.

Gyamfi et al. (2021) highlighted the collaboration in the nation's output and ecological depletion in the case of E7 countries. Authors postulated that global climate change and ecological crises could be detected by the worldwide surge in the emissions from the economies' activities related to producing and consuming goods. It is a current requirement to discover the influence of economic progress on CO_2 gases. The authors asserted that this study is essential in understanding the relationship between output level and environmental destruction in the E7 countries. The empirical outcomes of the study indicated traditional growth escalates the rates of pollutant discharge throughout the sample countries. The authors also argued that to decrease CO_2 emission and achieve sustainable development goals simultaneously, they should explore sustainable natural resources.

Sun et al. (2021) utilized the V.A.R., Granger causality test, and V.E.C.M. techniques and investigated the relationship between economic development, green technologies, and carbon emissions from 1990 to 2017 in China. The findings revealed that renewable energy technologies are the best solution to curtail carbon emissions. The outcomes affirmed the validity of the EK concept in the longer time for china. The estimation revealed that, economic development, renewable energy technology, and carbon pollution are integrated at second order in the long-term cointegration relationship. The results also showed that the enhancement in solar technology innovation helps reduce carbon emissions.

Zeraibi et al. (2021) Examined the impacts of economic enlargement, financial development, and environment-friendly electricity generation capacity on the ecological footprints over the period 1985–2016 in the case of five Southeast Asian economies, namely Indonesia, Thailand, Malaysia, the Philippines, and Vietnam. To anticipate the short-long term influence on ecological footprints, study employed the CS-ARDL (Cross-sectional Augmented Autoregressive Distributed Lag) estimation method. The study used robust econometric methods to deal with the problem of CSD and slope variability in full panel. Results suggested that technological advancement and renewable energy reduce the effects of ecological footprints in the context of Southeast Asian economies, i.e., Indonesia, Thailand, Malaysia, Vietnam, and the Philippines. However, financial development and economic growth increase carbon ecological footprints in this region.

Khan et al. (2020) investigated the affiliation amongst GDP enlargement, tourism, energy demand, natural resources, and emissions in the case of 51 BRI nations from 1990 -2016. This analysis utilized the system of the equation under the scheme of dynamic GMM. For the BRI countries, the outcomes suggested an inversed U-form linkage in the middle of economic prosperity and the environment and validated the EKC hypothesis. Also, the outcomes explored the bidirectional causal link between economic advancement and tourism. The BRI economies' tourism push emission hypothesis is also confirmed. Natural resources give rise to energy use, tourism development, and pollution release across the BRI region. According to the natural resource curse theory, resources derived from nature considerably and adversely affect gross domestic product. Therefore, allocating capital investments towards an environmentally friendly framework is essential to improve the ecological condition.

Ike et al. (2020) analyzed the evolving influence between crude oil generation and emission levels by considering growth in the economy, democracy, electricity production, and trade for the 15 oil-producing nations from 1980 to 2010. This research employed MMQR test with fixed effects. The findings confirmed the existence of the EK curve in median and higher emission nations. Electricity production surge in CO_2 emissions and trade openness compresses the carbon emission among all quantiles and the existence of pollution halo hypothesis in this region. Oil production significantly expands carbon emissions in all six quantiles with a greater impact in the first and the weaker impact in the sixth quantile. Democracy had a favorable impact throughout every quantile, although the impact was mainly noticeable among nations having average carbon footprints.

Murshed (2020) examined the nexus between income and the environment and also explored the non-linear effects of ICT trade to enhance energy use efficiencies, increase access to cleaner cooking fuels, undergo renewable energy transition, and alleviate the degradation of the environment. In six SA (South Asian) economies, for the annual period 1980–2016, controlling the role of liquefied petroleum gas (LPG) consumption using the ARDL regression model. The results revealed only the inverted U-type scheme of EK curve in India, Bhutan, Bangladesh, and Sri Lanka. Outcomes from the empirical analysis showed that ICT trade directly enhances renewable energy consumption, diminishes energy use intensity, increases renewable energy shares, promotes the adoption of cleaner cooking fuels, and lowers carbon dioxide emissions. Additionally, ICT trade significantly reduces gases such as CO_2 discharge by raising the amount of green energy, promoting the availability of cleaner cooking fuels, and strengthening the effectiveness of energy use.

Murshed and Dao (2020) examined the credibility concerning the EKC concept generated by greenhouse gases (CO_2) while incorporating the effects of export-related quality upon the connection between the release of emissions and economic enhancement. This study used the panel of 5 SA (South Asian) nations, i.e. India, Bangladesh, Pakistan, Nepal, and Sri Lanka from 1972-2014. Findings suggested the existence of the growth-environment nexus. Also, they confirmed the EKC assumption for the entire group of economies, whereas the heterogeneous results were found in the context of the country-specific investigation. The environmental Kuznets theory is proved for India and Bangladesh, while according to Pakistan, there appears to be a U-formed connection between GDP growth and air pollution. Conversely, economic growth mitigates the environmental destruction in Nepal and Sri Lanka. Furthermore, the time series and panel analysis results also suggested that improvement in export quality can reduce carbon emissions in sample countries.

Osobajo et al. (2020) used data of seventy economies during 1994-2013, and studied the impact of GDP and energy use on carbon pollution. The study applied the novel econometric test i.e., the fixed effects, pooled ordinary least square, panel cointegration and traditional case and effect procedures to estimate the correlation among GDP, energy consumption, and carbon emission. Following the findings of OLS models and fixed effects, energy consumption and economic growth give rise to emissions. Outcomes also showed a unidirectional causal link between energy and carbon emission and a bidirectional causal association between population, capital stock, and advancement of the economy with environmental degradation. Moreover, it has been revealed that the utilization of energy and the advancement of GDP have a noteworthy and advantageous impact on the state of the environment. On the other hand, cointegration test results indicated a long-term correlation between energy use and economic expansion with CO_2 emissions.

Zhou et al. (2018) analyzed the influence of economic development, population, FDI, and others on ecological destruction in Chinese urban areas. This research applied dynamic panel data modeling to anticipate the reactions of fiscal drivers on toxic discharge. According to the standard ecological Kuznets curve (EKC) theory, the investigation's results fail to demonstrate a reversed U-type link between GDP output and climate.

However, the research supported an inverse N-form association between the expansion of the economy and ecological pollution. Furthermore, current foreign direct investment escalates the carbon emissions of Chinese urban areas.

Haseeb et al. (2018) evaluated the reliability of the EKC and the relationship between monetary expansion, CO_2 outflows, globalization, growing urbanization, and utilization of energy within the context of the emerging economies of the BRICS. The latest estimation approaches, mainly the LM test, CADF unit root test, Dynamic Seemingly Unrelated Regression (D.S.U.R.), Westerlund Cointegration test, the FMOLS test, and the D-H causal process, are implemented for conducting the analysis. The results confirmed an inverted U-formed connection of economic growth with pollution emissions for BRICS economies. This estimation also postulated that the bidirectional relationship exists among economic growth, GDP^2 growth, energy consumption, and Advances in finance with emissions. One-way cause and effect moves from globalization to the release of CO_2. Financial development and energy consumption increase carbon pollution, whereas urbanization and globalization have insignificant and negative associations with carbon emissions.

Pata (2018) explored the dynamic interconnection between per capita GDP economic growth, financial development, per capita CO_2 production, urbanization, clean energy use per capita, alternative energy usage, and hydropower consumption of energy. The ARDL bounds testing approach, FMOLS, Gregory-Hansen and Hatemi-J cointegration and Canonical cointegrating regression methods are utilized for empirical analysis. Furthermore data is taken in the context of Turkey during the annual periods of 1974–2014. The outcomes confirmed the validity of the EK curve, which formulates an inversed U-type connection between economic enlargement and pollutant release in Turkey. On the other side, total renewable, alternative energy consumption, and hydropower consumption has no impact on the destruction of CO_2. According to the results, economic progress, urbanization, and FD increase carbon emissions.

Zhou et al. (2018) examined how energy use and GDP development may affect the generation of carbon pollution and also tested the validity of the EKC in the top ten CO_2 emitters countries in the world, including four developed nations, namely the European

Union, the United States of America, Canada and Japan and five developing economies namely China, India, Brazil, Mexico, and South Africa. Unobserved heterogeneity among individuals and distributional heterogeneity is taken into account by the group quantile regression framework used in the present research. Results showed the heterogeneous impact of economic indicators on environmental depletion in different quantiles. Energy consumption expands carbon dioxide emissions with a strong effect at different quantiles. However, the outcomes also revealed energy consumption has a greater influence on pollution in advanced countries than in growing economies. The findings validated the theory of the Environmental Kuznets Curve across sample nations.

Al-Mulali et al. (2016) investigated how renewable energy consumption influences environmental pollution and whether the nexus of economic enlargement and destruction of the environment developed an inverted U-form interconnection, which leads to the confirmation of EK curve scheme. Non-stationary panel data econometrics procedures were employed to estimate the seven selected regions. According to Pedroni and Fisher's cointegration tests, the variables were cointegrated. However, the vector error correction model and DOLS approaches exhibited that green energy utilization negatively impacts environmental pollution in Western Europe, East Asia and the Pacific, Central and Eastern Europe, America, and South Asia. Moreover, the empirical analysis indicated that sustainable energy use does not significantly influence environmental pollution in North Africa, Sub-Saharan Africa, and the Middle East. The results also suggested that EKC exists in different regions and a high correlation exists between renewable energy and environmental pollution. These studies included energy consumption (total or disaggregated), such as renewable energy consumption under the scheme of the EKC framework.

Abid (2016) evaluated the consequences of economic development, financial stability, and institutional reforms upon CO_2 outflow in the case of 25 Sub-Saharan African economies (SSA) during the time 1996–2010. In this study, the reduced form modeling and GMM dynamic panel method are used to take into account the country-specific unobserved heterogeneity and also to deal with the endogeneity issue. The study's findings between SSA economies did not support the EKC model, while an increasing monotonic impact of economic development on carbon emission is found. The study also concludes a stable political environment, democracy, the efficiency of government, and anti-corruption measures harm the environment, while the rule of law and regulatory quality positively influence CO_2 emissions. Institutional quality, directly and indirectly, affects carbon dioxide emissions through trade openness and economic enlargement.

Al-Mulali et al. (2015) examined the traditional theory of environment-growth nexus by dividing the Ninety-three nations according to their income level. This analysis used a nation's natural footsteps to measure ecological destruction. The fixed effects and the GMM were utilized for further anticipation. In upper-middle- and high-income regions, environmental impacts and economic growth have an unambiguous inverse U-formed interaction that supports the idea that EKC exists. Whereas the rejection of the EKC hypothesis in low and lower-middle Countries. Furthermore, energy consumption and trade openness surge in environmental pollution through their positive impact on the ecological footprint of most nations across all groups. Conversely, financial progress slows down by all income classifications, causing pollution.

Tamazian and Rao (2010) tested the idea of an environmental curve and analyzed the consequence of institutional quality and financial growth over ecological destruction. The study utilized the time series data from 1993 to 2004 from the perspective of 24 transition economies. This research paper used GMM estimates for endogenous variation and the usual reduced-form simulations strategy for adjusting country-by-country undetected variability. The findings showed the acceptance of the EKC hypothesis and advocated that institutional quality and financial stability prove beneficial in environmental gradation. This examination also concluded that if financial freedom is not carried out within a solid system of institutions, it could be detrimental to ecological health.

Selden and Song, (1994) investigated the association between economic advancement and environmental pollution. The study used a cross-national group of statistics on greenhouse gases that include 4 significant atmospheric toxic wastes: carbon monoxide (CO), sulfur dioxide, nitrogen-based oxides, and particles in suspension. The study's findings showed that the four contaminants' per person pollution and gross domestic product per person show an inverted-U connection, confirming the EKC-related research theory. Econometric techniques confirm the evidence of the EKC. The estimated turning points of this study are relatively more remarkable than those of the earlier studies. The truing points estimated in terms of per capita income for a single pollutant are oxides of nitrogen ($11,200) and carbon monoxide ($6000). Sulfur oxides ($8700) and suspended particulate matter ($10,300).

2.3 Relationship between Green Growth and CO_2 emissions

Green growth has gained greater attention over the last few years, and identifying the concrete and actual green growth is the main focus of many scholars(Wu et al. 2020; Zhu et al. 2020). Some studies have investigated green growth regarding production efficiency (Lin et al. 2013; Xie et al. 2018). Mostly, the analysis stated that green growth increases preferable production and reduces unexpected yield. Some scholars identify the green GDP regarding green economy (Li and Fang 2014; Talberth and Bohara 2006) because the environmental cost is deducted in the green economy compared to conventional GDP.

(S. Wei et al., 2023) looked into the effects of the use of clean energy, sustainable development, environmentally friendly innovation, ecological trade openness, and inbound FDI on the health of the environment across the most advanced green emerging countries worldwide during 1990 - 2018. This study used the CS-ARDL strategy, AMG, and CCMG techniques to determine the association among economic factors in the long-term assessment to test overall reliability. The outcomes demonstrate that FDI and sustainable international trade considerably raise environmental standards. According to the findings, trade liberalization has short-term and long-term positive effects on the atmosphere. The usage of clean energy promotes sustainable development. This investigation concluded that the advancement of green technologies is greatly enhancing the well-being of the environment. The two-way relationship between environmentally friendly innovations and sustainable output suggests that both support a natural and healthy climate. According to environmentally conscious trade statistics, a decrease in CO2 emissions promotes the expansion of the sustainable economy.

Li et al. (2022) analyzed the dynamic association among green growth, green energy, and green trade in 30 provinces in the republic of China from 2007-2016. The SYS-GMM method explores the influence of clean energy consumption and environment-friendly trade on sustainable growth. The article concludes that green energy and trading ecological products positively influence green growth. The result also suggested that the impact of green trade is heterogeneous in different regions because of different trade levels and asymmetric in different quantiles according to the entire panel. The technical, positive investment and labor effects are considered effective mediators in the association between green growth and green trade. Green trade enhanced domestic green growth by increasing high and medium technology.

Dogan et al. (2022) estimated the reaction of green output, cleaner energy usage, environmental taxes, and energy efficiency over pollutants of CO_2 for the context of 25 environmentally friendly economies from 1994–2018. For empirical analysis, the study applied the quantile regression approach to gather economic indicators' effects. The quantile regression results also suggested that renewable energy, energy efficiency, and environmental taxes are vital in mitigating CO_2 emissions. The outcomes showed the negative coefficient of green growth, cleaner energy consumption, environmental taxes, and energy efficiency in higher, medium, and lower quantiles.

Hao et al. (2021) analyzed the influences of green advancement, human capital, pure use of energy, and environmental taxes upon carbon pollution concerning G7 economies from 1991 to 2017. The research used the environmentally adjusted multifactor productivity growth as a proxy to measure green growth. For empirical findings, the study utilized the 2^{nd}-gen econometric techniques, namely Cross section ARDL method. The results showed that green growth, square term of green growth, human capital, eco-friendly energy usage, and environmental taxes decrease environmental depletion in G7 economies. Furthermore, the results also suggested that the prospect of green growth will encourage the industry and firms to use renewable energy sources. Therefore on the pathway to sustainable development, green growth ponders a salient technique to achieve sustainable development and a sustainable environment. Short-term and long-term environmental degradation are effects of Economic expansion.

Chien et al. (2021) estimated the linkage between carbon neutrality targets and green development from the USA's perspective. The findings confirmed the negative and significant association between green growth and environment abasement and environmental taxes and CO_2 discharge in the USA, as higher carbon emissions lower the environmental quality. The study suggested more attention to green growth, renewable energy consumption, and environmental-related taxes. Moreover, the study also suggested that efficient policies should be developed for climate change and to implement these policies efficiently and effectively improve environmental quality.

(Feng et al., 2017) estimated worldwide variations in green growth and it's affecting elements using an environmentally friendly growth index (GDPI) utilizing a data-envelopment analysis. This study used data from 165 nations. The findings indicate that: (1) Global ecological growth trends are unbalanced. 2) An EK pattern of a U-formation is found between GDPI and the income level, with the turning point being 2424 $; (3 GDPI has a positive correlation with living altitude, power framework, and overall fuel prices, whereas it is inversely linked to ecological carrying capacity.

2.4 Relationship between Renewable Energy and CO_2 emissions

In the environmental economics literature, finding the contribution of conventional energy and eco-friendly energy demand is considered a primary objective. Several research analysts have investigated the correlation between environment-friendly energy consumption and environmental performance because clean energy sources are environmentally friendly and can execute energy demands.

Mehmood (2022) analyzed the reactions of sustainable energy, globalization, financial involvement, and traditional growth at the emission rate of CO_2 under the theoretical notion of EK curve regarding selected south Asian countries. Second-generation panel data estimation techniques, namely, cross-sectional dependence, Westerlund cointegration test, and Cross-sectional autoregressive distributive lag approach, were applied from 1990 to 2017. Results affirmed the long-lasting relationship in the entire panel set. The outcomes of the study demonstrated that renewable energy supports mitigating pollution. Conversely, financial inclusion, GDP enhancement, and globalization increase environmental contamination. It is advised that Pakistan, India, Bangladesh, and Sri Lanka change their foreign trade laws to reduce fossil fuel releases in light of the research's results.

Shahnazi and Dehghan Shabani (2021) Study the interconnection of renewable energy and economic liberty by introducing the role of the nonlinear impact of economic freedom and CO_2 emissions. Additionally, the traditional nexus between economic freedom and pollution emission is also tested under the shelter of the EKC framework related to European countries over the period 2000–2017. The European nations are taking more efficient steps to shrink CO_2 emissions than the other regions. The analysis results affirmed that the usage of green sources of energy reduces the depletion of the environment. At the same time, the U-shaped connection is present amid economic freedom and CO_2 emissions in selected EU nations. To achieve SDGs (sustainable development goals), analysis encouraged the construction of such environmentally friendly policies and boosted the environmentally friendly energy source.

Le et al. (2020) analyzed the association amid the expansion of the economy, usage of power (renewable energy consumption and conventional utilization of energy), and ecological destruction in the context of 102 nations over the period of 1996 to 2012. The latest panel data estimation methods are employed for further empirical analysis. This study individually measures the response of clean and nonrenewable use of energy. In Support of the growth hypothesis, the analysis findings showed that both kinds of energy consumption accelerate the economic output across countries. The findings also suggest that non-renewable energy consumption surges carbon emissions. It is identified that environment-friendly energy consumption proves to help reduce pollution outflows in developed economies but not in the developing world.

Erdogan et al. (2020) investigated the role of free trade, economic development, oil prices, and energy usage (clean and traditional) in determining environmental quality. An analysis is conducted on 25 OECD economies from 1990–2014. The study used first-generation and the 2nd generation panel data techniques simultaneously, namely FMOLS, AMG and DOLS approach for further empirical findings. According to the empirical results of FMOLS and DOLS, the validity of the EKC theory is proved in 25

OECD states. On the other hand, the outcomes of the (AMG) estimator showed the invalidity of the EK curve hypothesis in the selected OECD nations. Empirical findings also revealed that increasing oil prices and using renewable energy lowers CO_2 emissions, and nonrenewable energy consumption increases emissions. The findings showed the nonexistence of any significant association between trade openness and CO_2 outflows.

Ummalla and Goyari (2021) employed the Dumitrescu–Hurlin causal technique and FMOLS in the case of BRICS economies for the time series 1992-2014. They investigated the response of ecologically friendly energy use on GDP advancement and the release of carbon. The theoretical structure of the environmental Kuznets hypothesis is also examined in this research work. The findings suggested that using clean sources of energy decreases environmental depletion significantly, while energy consumption and economic development increase CO_2 emissions. The study's outcomes also affirmed the acceptance of the inverted U-shaped hypothesis in the context of BRICS nations. The empirical results also indicated that one-directional causation running from energy demand to GDP expansion is proved by the Dumitrescu–Hurlin panel causality test. The study did not demonstrate any causal nexus between green energy consumed and economic progress.

Saidi and Omri (2020) utilized the VECM and FMOLS methods from 1990 to 2018 in 15 OECD economies and examined the influence of purifying and nuclear use of energy over environmental quality. The outcomes of the FMOLS suggested that utilization of clean energy (i-e, renewable energy) mitigates pollution emissions in the UK, Canada, Switzerland, France, Belgium, Germany, the US, Sweden, Japan, Finland, Czech Republic; however, it escalates the CO_2 emissions in South Korea and the Netherlands. The analysis also explored that promoting nuclear usage of energy reduces environmental abasement across UK, Canada, Japan, Netherlands, Switzerland, and the Czech Republic. As for the concern of panel estimation findings, renewable energy consumption and nuclear energy consumption improve the environmental performance. Likewise, the findings of the VECM indicated that green energy and nuclear power sources cut down CO_2 emissions in the long time period among most of the selected OECD economies.

Alola et al. (2019) for 16 European nations investigated the connection between economic growth, eco-friendly energy usage, conventional use of energy, trade liberalization, fertility rate, and CO_2 emissions. PMG-ARDL model, Kao, and Pedroni cointegration estimation techniques were applied from 1996 to 2014. The results of the cointegration technique found an association between GDP output, clean and non-clean energy utilization, trade freedom, fertility rate and emissions discharge. The results of the Panel Pool Mean Group ARDL model showed that traditional energy use increases release of pollutants and purifying sources of energy reduce ecological degradation in selected European Union (EU) nations.

Bekun et al. (2019) investigated the interaction regarding GDP development, sustainable application of energy, non-purify utilization of energy and carbon outflows under the observation of 16 European Union economies over a balanced panel from 1996–2014. The study considers the effect of price for natural assets in the model as an additional variable. PMG-ARDL, Kao cointegration test, and panel cause and effect method are applied to estimate the long-term relationship and the casual association in economic drivers. The analysis results affirmed a cointegration exists among both types of energy consumption, economic progress, natural resource rents, and carbon emissions. The findings further postulated that in the long period, natural resource prices have positively and significantly interconnected with CO_2 emissions. Finally, the analysis concluded that environmentally friendly energy use mitigates the depletion of the natural environment and the economic advancement and nonrenewable energy consumption swell carbon emission.

Sasana and Aminata (2019) explored the impact of energy-related economic development and carbon outflow for the time series annual data set from 1990-2014 from the perspective of Indonesia. The analysis used the multiple linear regression models and the ordinary least square method to measure the relation between dependent and independent variables. Out-turn of the estimation techniques asserts that economic enhancement, primary power consumption, and population expansion directly link air pollution. Moreover, the validity of the EK curve could not be found in Indonesia's perspective. The outcomes of the study also suggested that globalization has not been noticeable in reducing pollution emissions. This investigation also indicated that clean usage of energy has an inverse connection with the release of CO_2, which means renewable energy may be beneficial in reducing the CO_2 emissions from the environment.

Zandi and Haseeb (2019) applied the advance panel data estimation inferences i-e, bootstrap cointegration, Kao and Pedroni cointegration method, CIP unit root test, DOLS, FMOL, and heterogeneous causality tests over the periods 1995-2017 in the context of 35 Sub- Saharan African economies. They estimated the role of clean energy in the reduction of environmental destruction. According to the empirical findings, globalization asserts a significant and positive effect on environmental destruction. In the same direction, globalization and agricultural production also have a positive and significant impact on environmental destruction. Green or clean energy refers to an environmentally friendly energy source as it reduces emissions and improves the environmental quality. The causality test confirmed the bidirectional causality between clean energy consumption and environmental depletion in all 35 sub-Saharan African (SSA) economies.

In the same direction, Hu et al. (2018) explored the participation of clean energy consumption and trading in commercial goods and services in determining environmental deterioration from the perspective of 25 developing economies from 1996–2012. This paper used FMOL, Granger causality tests, DOLS and Panel co-integration tests for empirical analysis. The analysis findings demonstrate that carbon emissions could decrease as the share of eco-friendly energy increases. Instead, CO_2 outflows could rise as the size of sustainable power increases. The examination also identified the presence of the EK theory in the selected countries. Commercial services trade curtails the carbon emission from the environment in the major developing economies.

Dong et al. (2018) employed 128 nations and studied the nexus between green power usage, population expansion, CO_2 depletion, and GDP output in different regions, and employed the unbalanced panel data set during the annual time spinning1990-2014. A series of estimation methods have been employed that deal with the cross-section dependency and slope homogeneity issues of panel data. The CCEMG results revealed that economic growth and an increase in population exert a positive and considerable contribution to greenhouse gas emissions levels. In comparison, some regions' ecological energy sources lower CO_2 emissions at varying proportions. It depends mostly on the volume of the clean application of energy in the overall energy use for a selected group of countries. Lastly, the findings of the casualty approach showed heterogeneous casual associations with the economic determinants across different regions.

In addition, Koengkan (2018) estimated the reactions of sustainable power generation in mitigating climate damage for the annual periods from 1980 to 2014 in the case of five MERCOSUR nations. Novel panel data estimation techniques along with ARDL in terms of an Unrestricted ECM to estimate the short-term and long-period effect of economic indicators are employed in current research. The outcomes confirmed the inverse interconnection of green energy utilization with atmosphere pollution in the selected sample. The analysis findings also exhibit that the economic enlargement and the burning of fossil fuels soar emissions in both (loner-shorter) time periods. The study also showed a cross-sectional dependence between environmental pollution and renewable energy consumption. The study also noticed that economic growth surges the gas pollution of the selected sample countries.

Bilgili et al. (2016) study the correlation between the environment and economic output and estimate the participation of clean power sources under the environmental quality framework. The study also examined the growth-environment nexus under the premises of traditional environmental EKC. This paper utilized the panel data from 1977–2010 for 17 OECD economies. The study employed the panel FMOLS and DOLS testing procedures for empirical estimation purposes. The outcomes indicated that renewable energy consumption is proving advantageous in reducing eco depletion. The results of the study supported the EKC theory in these OECD nations. Also, they noticed that the GDP per capita increases the CO_2 and GDP^2 per capita can help to diminish CO_2 emissions.

Bölük and Mert (2015) analyzed the linkage between economic advancement and greenhouse gas outflows and checked the evidence of the EKC concept in Turkey from 1961 to 2010. Research work also investigated how renewable energy consumption plays a role in decreasing greenhouse gas emissions. The study implemented the ARDL econometric technique to measure the interconnection among electricity generation by using clean power production, economic progress, and carbon pollutants. The analysis concluded that in the long term, the consumption of renewable energy sources diminishes greenhouse gas outflows. On the contrary, in the short run, this effect is significant and positive, meaning that electricity generation by using renewable energy sources increases carbon emissions in the short term. In addition, the finding predicted a U- shaped (EKC) association between income and greenhouse gas emissions in Turkey.

2.5 Relationship between Technological Change and CO_2 emissions

Technological innovation is viewed as one of the latest areas of study in the growth-environment relationship. It has been stated that the environment-innovation nexus significantly contributes to improving environmental quality. The study regarding technological innovations and CO_2 emissions is an important research area for achieving a sustainable environment and sustainable economic growth. The innovation-pollution connection can be divided into further two branches. In the first place, the impact of technological change in reducing CO_2 emissions and, in the second place, the decisive impact of technological innovation in encouraging the utilization of renewable energy. Many researchers have studied the relationship between technological advancement and CO_2 emissions but noted the varying findings.

Chien et al.(2021) examined the role of technological innovation, renewable energy, and globalization in mitigating environmental pollution over the time 1980-2018 in the case of Pakistan by using the quantile ARDL model as an estimation technique. Research supports the presence of environmental KC hypothesis in Pakistan. Furthermore, renewable energy and technological innovation reduce environmental depletion. The study also revealed that globalization is the main determinant of increased pollution emissions in Pakistan. The outcomes also showed that bidirectional causality exists among renewable energy, GDP, and innovation to CO_2 emission. Moreover, unidirectional causality running from GDP to globalization is also present in the perspective of Pakistan.

Dauda et al. (2020) have examined an interesting link among trade openness, technological progress, and carbon emissions for the time of 1990–2016 for the 9 African economies context. This paper used CADF (cross-sectional augmented Dickey-Fuller) unit root technique. Westerlund and Johansen cointegration tests, GMM i-e generalized method of moments and fixed effect models for numerical results. At the panel level and in some individual economies, the study supports the evidence of an inverted U-type relationship of technological progress with the quality of the environment, whereas as for the concern of the full panel outcomes the renewable energy sources diminish the carbon emissions. The findings of the studies also confirmed the reliability of the EKC pattern pollution haven-halo theory. According to the results of some single economies and the full panel, the outcomes revealed that human capital has a significant influence in reducing emissions.

Ahmad et al. (2020) presented a divergent method for analyzing the nexus between technological innovation and environmental performance for the annual periods straddling from 1993 to 2014 in 24 OECD economies. The study employed CO_2 emission as a proxy for environmental pollution, research and development expenditure for technological progress, and country-by-country technological transfer as a proxy for FDI. The study used three models consisting of production, environmental depletion, and energy consumption under a simultaneous equation approach. The following outcomes are found in the study. Firstly, bidirectional causality is present in economic growth and per capita use of energy. Secondly, this exploration rejected the validity of the EK structure in 24 OECD economies. Thirdly, FDI, non-renewable energy consumption, and technological progress positively anticipate CO_2 emissions.

Chen and Lee (2020) analyzed an interesting role of technological change in mitigating the CO_2 emissions for the panel data of 96 countries by dividing them into groups according to their development level and overall during the annual periods 1996-2018. The study employed different econometrics techniques for estimation by collecting the WDI data. The study concluded no significant correlation exists between technological change and carbon emanation for the full panel. In contrast, the estimation techniques suggested interesting results when they were applied to the separated groups according to their development levels. In comparing the other two groups of countries, for high-income, high-technology, and high-CO_2 emitter economies, the impact of technological change is significant in mitigating carbon emissions. Furthermore, the role of technological innovation is considered more important in the presence of globalization in these countries.

Similarly, Mushtaq et al. (2020) applied the different panel data econometric techniques over the annual periods from 1995 to 2015. They studied reactions of income inequality and economic output on environment performance by incorporating the moderating participation of technical advancement at national and regional levels in the case of China. The empirical outcomes confirmed the mediator effect of technological advancement in the connection amid income inequality, conventional growth, and production of emissions. Also, they stated that economic progress and income inequality affect carbon emissions in China.

In Addition, Töbelmann and Wendler (2020) explored the consequence of technology change on CO_2 production over the periods of 1992-2014 for the 27 European Union countries. GMM model has been utilized for the investigation technique and patent application is used as a proxy of technology change. The results demonstrate an insignificant effect of innovation in reducing carbon emissions and the common innovation activities (pursuits) also do not affect carbon emissions. The findings also suggested that the impact of technology change varies among regions and nations such as the less developed EU economies, which showed a higher level of heterogamous effect.

The outcomes also stated that compared to the increased economic activities, the effect of technological innovation might be small on the natural environment.

Cansino et al. (2019) have investigated the influence of institution quality and technological advancement on environmental quality. The study has used the set of panel data over the periods 1996-2013 by the 18 Latin American economies. The empirical findings showed a significant relationship between GDP growth and GHG (greenhouse gas) outflows and validated the traditional environmental curve structure. The outcomes also suggested that technological advancement and institutional quality are inverse to greenhouse gas emissions, which means both variable help improve environmental quality. In contrast, international trade and FDI are positively related to increased greenhouse gas emissions and reveal a negative effect on the environment.

Saudi et al. (2019) examined the association among sustainable power consumption, growth in the economy, change in technology, fossil fuels use of energy and release of CO_2 pollution over the period 1980-2017 for the Malaysian context. However, the latest econometrics techniques are employed for empirical findings and utilize the ARDL bound testing approach to measure the long-term relationship of all economic components. The study supports the evidence of Kuznet theory in Malaysia. The empirical outcomes of the ARDL method present the long-run interconnection among renewable energy consumption, economic development, technological innovation, and energy usage with environmental quality. The study also postulated an inverse association between improvement in technology and green use of energy with pollutants production, while economic enhancement and nonrenewable energy have a positive link with emissions in the long term in the case of the Malaysian economy.

Chen and Lei (2018) studied the contribution of technological progress and pure energy use on environmental sustainability in the case of 30 countries under the framework of environment-energy growth relationship for the periods 1980-2014. A quantile regression procedure has been employed to estimate the influence of friendly consumption of energy and advancement in technology. The result of the study reported an inverse association of technological change with ecological quality. The outcomes of the study also suggested that increased investment in technological advancement projects is profitable in reducing carbon emissions in top carbon emitter nations. The outcomes related to the high CO_2 emitter nations stated that green energy usage has a limited impact in mitigating the CO2 emissions because the ratio of renewable energy usage is small.

Mensah et al. (2018) analyzed 28 OECD economies separately over the time of 1990 to 2014 and analyzed the relationship among renewable and non-renewable energy, GDP per capita, R&D, and CO_2 emissions. Three important models were used in this study i-e, the economic-EKC growth model, the STIRPAT test, and the technical-EKC mechanism. The examination outcomes indicated that research and development expenditures are beneficial in mitigating carbon emissions and that conventional energy sources and output expand the carbon damage. The findings also suggested that technology innovation can be beneficial for improving environmental quality across the OECD nations. The results also identified that the GDP growth and non-purifying electricity sources expand the level of CO_2 emission while pure sources of power shrink the level of CO_2 emissions. The findings did not verify the environmental curve in most OECD nations. However, a few OECD countries confirmed the validity of the innovation-EKC hypothesis and the development-environment theory.

Hodson et al. (2018) investigated the effects of fuel costs, technological advancement, and an Emission mitigation strategy on the electricity generation and end-use sectors by analyzing the results of four U.S. energy economy models until the year 2050. Findings of the study found that because improved power efficiency and environmentally friendly production have become more cost-competitive, attaining technological targets reduces CO_2 emissions across all models, irrespective of the cost of fossil fuels. Accomplishing innovations targets decrease wholesale energy prices for the models that consider the country's natural gas markets, although this benefit as predicted natural gas prices rise. Yet, fewer coal plant retirements are due to increased natural gas costs, which raise wholesale power prices. In the long run, achieving innovation targets leads to a generation mix with comparable Pollutant emissions to the CO_2 policy but with less of a rise in wholesale power prices. The proportionate impact on wholesale pricing varies by the model in the short run. As costs of natural gas rise and innovation targets are achieved, the proportion of renewable sources that seem economically feasible to construct and start operating increases over time. At the same time, the growth of a natural gas-fired generation, which would be expected to be the dominant generation subcategory in 2050 under equilibrium conditions, is decreased.

Alvarez-Herranz et al. (2017) studied the interconnection between economic advancement and environmental damage by investigating the contribution of energy innovation in the environmental framework. The analysis employed the panel series across the periods 1990–2012 regarding 17 OECD nations. This investigation also checked the existence of the ecological Kuznets idea in the selected sample economies. The empirical conclusion stated that innovation is beneficial in the economy's transition to a sustainable source of energy and production. The outcomes affirmed the N-form EK association amid economic advancement and ecological destruction. Finally, the paper concluded that energy consumption increased CO_2 emissions and that green energy is crucial in mitigating CO_2 emissions and improving environmental quality.

In the same direction, Su and Moaniba (2017) utilized different estimation techniques and examined the effects of technological innovation on the quality of the environment in 70 countries. The study's findings suggested that technological innovation attenuates the carbon emissions in the selected sample economies. In the study, technological innovation has been measured in terms of patent count and environmental degradation in terms of CO_2 emissions.

Similarly, Jin et al. (2017) employed the ARDL and VECM estimation techniques over the annual periods 1995-2012. They analyzed the impact of technological innovation affiliated with the energy sector and environmental compatibility for China. This piece of work investigated the existence of the environmental curve scheme, according to the empirical findings, technological innovation related to the energy sector is an essential feature in mitigating pollution emissions. The study concluded that the government of

China needs to upgrade technological innovation affiliated with the energy sector, to amplify energy efficiency and turn down emissions simultaneously. This analysis did not discover any proof to validate the EKC structure from the perspective of China.

Santra (2017) studied the BRICS economies over the time 2005–2012. The latest panel data econometrics estimation procedures have been employed for empirical findings. According to the empirical results, the study concluded that technological advancement assisted inefficient energy consumption in the manufacturing and production process and curtailed CO_2 emissions from the environment in the context of BRICS economies. Moreover, pollution taxes can encourage the manufacturing and production units to invest in the latest technologies, reducing the pollution emissions from the environment and improving environmental quality without affecting their output level.

Sohag et al. (2015) examined the impacts of technological innovation on energy utilization over the period 1985 to 2012 in the case of Malaysia. This investigation has applied the autoregressive distributed lag testing technique for estimating on a long-term basis the relationship among independent and dependent economic components. The empirical verification revealed that technological growth is a key driver in curtailing the application of non-friendly power sources and fostering the use of sustainable power sources in the production process; the result is low carbon emission in Malaysia. Outcomes also showed that trade openness and rapid GDP progress are the key drivers of more energy consumption in the country. The results have confirmed the short-term and long-order relation between variables.

Lin and Wang (2015) explored the empirical responses of technological enhancement and efficient technology used on environmental performance over the periods 2000-2011 in China. The findings of the study demonstrated that more investment in technological development and less investment in carbon production projects play an essential role in decreasing toxic pollutants under consideration in China.

Moreover, Cai and Zhou (2014) identified the key variables empirically influencing eco-innovation adoption in Chinese organizations. This is accomplished by employing hierarchical regression analysis to evaluate a conceptual model on a sizable dataset of organizations from diverse industries. According to the findings, internal and external drivers work together to promote eco-innovation. Within China, internal forces partially impact eco-innovation due to external constraints such as environmental restrictions, consumer demands, and rivals. The study additionally indicates that the association between economic drivers and eco-innovation performance is partially mediated by firms' integrative ability, which is the capacity to develop suitable eco-innovative actions by merging internal and external capacities. In addition, businesses that operate more effective external networks frequently engage in eco-innovative initiatives.

Carrión-Flores & Innes (2010) explored the participation of technology development on climate change in the context of 127 manufacturing units for the annual periods from 1989 to 2004. Innovation has been measured in terms of patent count and the environment is measured in terms of air pollution in this study. The results demonstrated bidirectional causalities between innovation and air pollution. According to the empirical outcomes of the study, technological innovation can serve as an essential component in reducing toxic outflows in the selected countries.

(Ang, 2009) investigated the reactions of technology transfer and growth expenditure on sustainable environment along with the other determinants of environmental pollution and used the data from the Chinese perspective. The outcomes stated that both in shorter and longer time periods, the technology transfer and development expenditure has curtailed the carbon emissions in the Republic of China. The findings demonstrated that higher energy consumption, excessive trade openness, and higher income lead to higher CO_2 emissions in China.

2.6 Relationship between Trade Openness and CO_2 emission

The economic links between free trade and environmental performance have been a topic that has attracted numerous scholars over the past few decades, with the trade-environment nexus being regarded as an important aspect of trade policies. Despite the extensive research, studies have produced diverse findings and conclusions regarding the impact of trade liberalization on environmental performance. Prevailing studies identify three types of impact trade openness has on environmental performance: positive, negative, and inconclusive. While some researchers argue that trade openness worsens environmental quality, others suggest it helps improve it. Additionally, some studies have found no significant correlation between environmental quality and trade openness, leading to ambiguous results.

Chhabra et al. (2022) examined the effects of innovation and trade openness on eco quality in 23 middle-income economies over 25 years (1994-2018) with the primary goal of improving environmental quality in these countries. The study employed two statistical methods, the D-H causal technique and GMM, to assess the variables' cause-and-effect relationships and long-term connections. The conclusions of the study contradicted the validity of the inverted U-like interaction amid technological advancement and fossil fuel emissions. Furthermore, the results indicated that free trade increases CO_2 emissions in low-middle-income territories as opposed to nations with upper-middle incomes. This research work supports the presence of the environmental Kuznets theory in both income group countries. To mitigate CO_2 emissions, the study recommends that middle-income economies prioritize increasing green innovation.

Ding et al. (2021) used data from the period spanning 1990-2018 to explore the impact of free trade (with a focus on imports and exports), energy productivity, eco-innovation, and ecological energy use in executing environmental performance in G-7 economies. The study employed second-generation estimation techniques, such as CSD, panel stationary test, slope homogeneity, CS-ARDL, AMG and Westerlund co-integration approach for empirical analysis. An empirical investigation of the study suggested that imports and GDP growth increase CO_2 release, while green technical change, energy production, and use of energy help mitigate climate depletion in G-7 states. Furthermore, the study indicated an inverse association between exports and CO_2 emissions and that exports can help improve environmental quality in the selected region.

Essandoh et al. (2020) used panel data spanning 1991-2014 to study the impact of trade and FDI on environmental degradation in 52 developed and unindustrialized economies.

The analysis utilized PMG-ARDL to calculate the long-term nexus between variables. The empirical findings illustrated an inverse correlation of flexibility regarding trade with pollution in advanced countries. The study also predicts that trade enhances knowledge spillover, which, in turn, curtails emissions from the environment among the sample countries. If the absorption abilities are developed regarding human assets and other sources to channel this spillover throughout the economy, then the economies could take full advantage of the spillover of knowledge.

In the same vein, Mahrinasari et al. (2019) analyzed the interaction of free trade with environmental quality in the Asian region, namely Indonesia, Thailand, Malaysia, the Philippines, and Singapore. The study used novel econometric panel strategies, mainly Fully Modified OLS, Kao cointegration, panel DOLS (Dynamic Ordinary Least Square) method, bootstrap integration, and Pedroni cointegration technique to estimate empirical outcomes. The findings indicated that every component is stationary after the first difference and that all the variables have a cointegration relation in the longer horizon. The outcomes of the study demonstrated a positive association between openness to trade and carbon emissions in the selected Asian region. The findings also revealed that an increase in openness to trade is responsible for the poor environmental conditions.

Additionally, Agboola and Bekun (2019) investigated the impact of trade openness, FDI, agricultural value-added, and energy consumption on carbon pollution under the ecological Kuznets shape conceptual structure. This estimation utilized annual series during the period 1981- 2014 from Nigeria. Paper employed different approaches to check the stationarity properties of data i-e augmented DF, PP, and Zivot and Andrews root test in the presence of structural break. ARDL and latest Bayer and Hanck integrated techniques were utilized to measure the cointegration between variables. Furthermore, Granger causal analysis was employed to check the cause-and-effect relation between the economic factors. The results confirmed the EK curve mechanism and pollution halo hypothesis in Nigeria. The findings of the study also suggested that trade openness, agricultural value-added, and energy consumption were the key drivers of carbon pollution. The findings also confirmed a long-base interconnection among the indicators under observation. Furthermore, the empirical calculations exhibited that foreign direct investment proves helpful in reducing the level of CO_2 discharge in Nigeria.

Balsalobre-Lorente et al. (2019) analyzed the role of trade openness, economic development, energy consumption, mobile phone usage, electricity consumption, and agricultural activities on CO_2 emissions and also checked the evidence of EKC conceptual idea in BRICS economies during 1990-2014. The study applied the DOLS and FMOLS procedures to measure the direction of long-order linkages in macroeconomic indicators under observation. The turnout showed that openness to trade, energy consumption, and agricultural activities give rise to carbon emissions and have unfriendly impacts on environmental quality. On the contrary, the usage of mobile phones mitigates carbon pollution in the long term. The examination also validated the EK hypothesis throughout the BRICS nations.

Hasanov et al. (2018) investigated the environmental effects of international trade in establishing environmental quality across nine oil-exporting states during the annual period 1995 to 2013. The study utilized advanced econometric methods along with cointegration tests and error correction modeling for further investigation. Additionally, the impact of imports and exports was analyzed separately. The findings of the study stated that greenhouse gases (CO_2) are positively impacted by imports together with conventional production. On the flip side, by considering the role of consumption-based emissions, carbon footprints are adversely affected by exports. By incorporating the impact of territory-based emissions, the study found positive effects of imports and exports on pollution. As opposed to that, GDP increases emissions and decreases the state of the atmosphere in selected countries.

Shahbaz et al. (2017) explored the presence of the EK hypothesis. They estimated the influence of trade openness, traditional production (GDP), implementation of green electricity, and oil prices on poison (carbon) release in the U.S. from 1960 to 2016. Bounds assessment integration was employed in the investigation in which structural breaks determine the long-order basis nexus amid economic determinants and the VECM

Granger causality test with structural breaks to measure the causal interrelations between all variables for empirical data analysis. The analysis concluded the validity of the inverted-U-shaped association and an N-shaped relationship simultaneously under the condition of structural breaks between economic development and carbon pollutants. The study further noted that trade openness, imports-exports, and clean application of power play a key part in mitigating carbon emissions. Similar direction, the utilization of biomass energy consumption cuts down CO_2 emissions. The study also identified the confirmation of two-way causal linkage in the middle of emissions and use of energy while detecting one-way causal links from economic growth to CO_2 emissions.

Azam et al. (2016) used time series from 1975 to 2013 in the perspective of Greece and examined the socioeconomic drivers of energy consumption. The stationary nature characteristics of the data set were examined using the Augmented DF (Dickey-Fuller) test and the KPSS analysis and to measure the causal links among the under-observation economic drivers. The results of the ADF and KPSS showed that at the initial difference, every parameter was stable. The research demonstrated a favorable relationship among trade openness, FDI growth, urbanization, economic output, population, and infrastructure growth. Conclusions also showed a two-directional causal connection between fossil fuel use and revenue production throughout Greece. Conversely, there is a one-way causal link involving international trade and infrastructure with the use of power.

Bernard and Mandal (2016) analyzed an interesting connection between trade and the environment in 60 underdeveloped and newly industrialized countries. The results of the analysis predicted that high levels of trade help improve the environmental quality index in countries under observation. The investigation found that traditional economic advancement and population negatively influenced the environment, while political factors enhanced environmental performance.

Dogan and Turkekul (2016) examined the effect of trade openness, GDP and its squared term, energy usage, financial stability, and rising urbanization over air pollution under the scheme of EKC. Measure of causality along with bounds assessment for cointegration, was employed for data analysis. The empirical study utilized data over the periods 1960-2010 from the perspective of the USA. The empirical results reflected a neutral effect between openness to trade and CO_2 emissions in the sample country, and empirical analysis could not find evidence of the EKC hypothesis. The study also indicated a bi-directional causal nexus between economy expansion and greenhouse gases, demand for energy and release of emissions, urbanization and CO_2, and development in the economy and traded goods. There was no causal link detected between CO_2 emissions and openness to trade. The study also noted the one-way causal connection in FDI and expansion of economy, output and energy consuming, and urbanization and the flow of FDI. According to the long duration, consumption of energy and urbanization leads to an increase in CO_2 emissions while trade can improve environmental quality.

In addition, Ertugrul et al. (2016) have evaluated the interlink in terms of real income, power consumption, freedom of trade, and carbon emission in 10 developing economies that are considered the top carbon emitters, i.e., Thailand, China, South Korea, India, Mexico, Indonesia, Brazil, South Africa, Turkey, and Malaysia. Moreover, the functioning of the EK Curve is also tested in the countries under consideration. The VECM Granger causality tests, The Zivot–Andrews stationary procedure in the existence of structural breakdown, and cointegration assessment with structural break have been utilized for data analysis. The study noted that openness to trade and energy consumption were the major determinants of environmental depletion. The results also indicated that the integration relationship exists among the variables under study in some individual economies. The study identified the acceptance of the EKC framework for Turkey, India, Korea and China.

Likewise, Shahbaz et al. (2013) explored the relationship among energy consumption, financial development, economic growth, trade openness, and CO_2 emissions. Data is taken quarterly during the time 1975–2011 regarding Indonesia. The Zivot–Andrews test was used to check the stationarity of the dataset, and the ARDL bounds testing with structural breaks were used for measuring the longer-term association among macroeconomic drivers. The VECM method was applied to measure the cause-and-effect linkage amongst the indicators under consideration, and the robustness of causality was analyzed by an innovative accounting approach (IAA). The outcomes identified that demands for energy and growth in the economy tend to escalate the rate of environmental abasement, while financial advancement and encouragement of trade lead to a decrease in the rate of GHG (CO_2) from the atmosphere. Results also illustrated a causal connection in two directions between the energy consumed and CO_2 emissions, development and CO_2 emissions, while the single-way linkage started with financial development to CO_2 emissions. Outcomes also showed that in economies where environmental standards and regulations are considered just a formality, the motion in production and trade openness factors may shift the polluted industries in these countries, which are supposed to be the pollution heaven economies.

Frankel and Rose (2005) studied the connection between environmental degradation and trade using cross-country data. The study highlighted that the openness of trade is beneficial in mitigating three types of pollution from the environment, specifically NO_2, particulate matter, and SO_2.

Antweiler et al. (2001) utilized panel data from 43 economies. The analysis constructed a theoretical model to measure the role of trade liberalization on ecological destruction in terms of three effects: scale, technique, and composition effect. In this research work, sulfur dioxide concentrations are used as a proxy for environmental pollution. The research's outcomes demonstrated that trade openness improves environmental performance through technique and scale effect.

Ecological studies have made significant strides, but there is still need to explore more about this field and fill the literature gape. However, after a detailed assessment of the previous research, some limitations have been highlighted. Firstly, the existing studies have more focused on GDP growth, with a less emphasis on the investigation of green growth (GRE). Secondly, the prior literature regarding GRE-CO_2 relationship consists on Europe and some OECD and Non-OECD countries (Feng et al., 2017;Dogan et al. 2022). Thirdly, there is limited research on the relationship between green growth, technological change, renewable energy and CO_2 in Asian countries. Fourthly, according to the previous research no studies have been tested the existence of green EKC and also its shape. Therefore more research is required to fill the aforementioned literature gap.

CHAPTER 3

MODEL and METHODOLOGY

3.1Introduction

The comprehensive assessment of the strategies used in a research area is known as the methodology. It also includes the theoretical research of both the set of procedures and rules relevant to a topic of study. Generally, it incorporates ideas such as frameworks, existing theories, stages, and statistical or subjective methodologies. It is important to note that a study design is unlike a technique because it does not aim to suggest a solution. Conversely, a research design establishes the theoretical foundation for determining which tool, series of approaches, or appropriate procedures may be used in a certain scenario, for instance, to generate a particular outcome.

In contrast, a model that represents the study objectives, method of investigation, relevant factors, and empirical layout constructed as a result of research operations is said to be based on reality. This research investigates the impact of traditional growth, green growth, renewable energy consumption, technological innovation, and trade openness on environmental degradation in selected Asian economies, namely South Korea, Brunei, Bahrain, China, Turkey, Russia, Kazakhstan, India, Bangladesh, Iran, Sri Lanka and Pakistan. For this purpose, time-series panel data is used from 1990 to 2018.

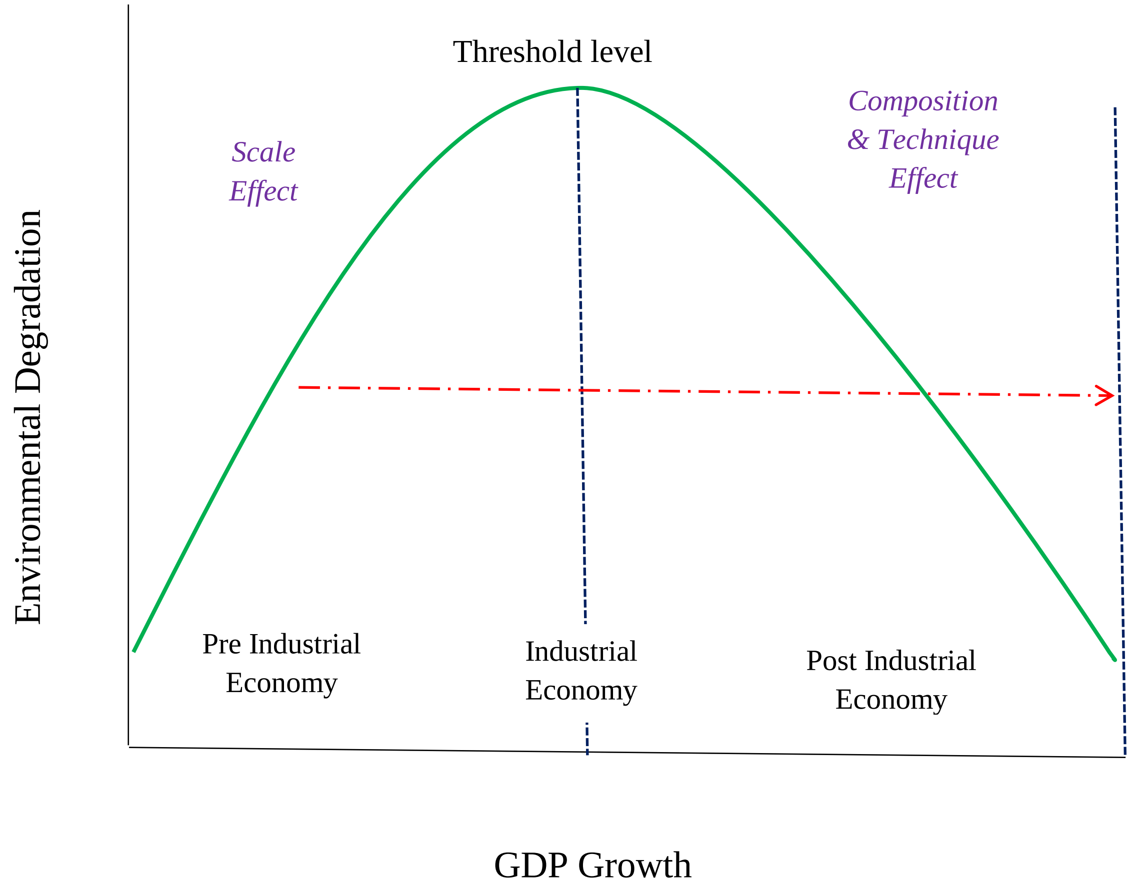
The introduction of this chapter describes segment 3.1. The theoretical framework and the reduced-form equations under the current study are depicted in the second segment, 3.2. The econometric models, presented in section 3.3 and sub-sections 3.3.1 and 3.3.2, consist of model 1 and model 2, respectively. Section 3.4 comprises the description of the data. The systematic diagram of the methodology workflow visualization is represented in section 3.5. Section 3.6 incorporates all the econometric techniques for the empirical analysis of the study

3.2 Theoretical Framework

Theoretically, the conventional concept of economic growth demonstrates that as economies move towards development and industrialization, the use of energy sources also increases. Due to increased non-renewable energy demand and rapid economic activities, the level of CO_2 emission in the environment also increases, polluting the global environmental quality. Theoretically, the nexus between Growth and Environment has been expressed under the Environmental Kuznets curve (EKC) premises. The EKC scheme, coined by Grossman and Krueger in 1991, states that in the initial stages of economic growth, economies have focused more on industrialization and development and did not give much attention to environmental health. However, after reaching a certain level (threshold level) of development, economies have focused more on environmental protection and made environmental-friendly government policies and public awareness programs.

Existing research studies have explored the relation between the quality of the environment and per capita income. Thus, based on their investigations have identified various patterns of the EKC, including U-shaped (Shahnazi and Dehghan Shabani (2021), inverted U-shaped (Sun et al. 2021), N-shaped (Alvarez-Herranz et al. 2017), and inverted N-shaped (Bekhet and Othman 2018) relationships. The findings imply that the link between GDP per capita and the environment may change over time. Moreover, Grossman and Krueger (1991) were among the first to study the theory of the EKC using three proxies: suspended elements, SO_2 and dark matter. Their research was based on the conceptual framework of the Environmental Kuznets Curve (EKC). Later, the literature extended its analysis of the EKC by utilizing a range of pollution indicators, which can be broadly classified into global and local measures. Studies on air pollution, specifically CO_2 emissions, are the main focus of global indicators, whereas urban air concentration, NO_2 emissions, SO_2 emissions and particulate substances are among the many variables included in local indicators. Furthermore, the literature has examined elements like the presence of heavy metals and pathogens when examining water pollution. Nonetheless, the literature's main goal continues to be comprehending how economies' macroeconomic performance and pollution emissions are related, all the while testing the EKC hypothesis.

Figure: 1



Source: Manipulated by author and originally sourced from (Usman et al., 2019).

Figure 1 illustrates that the EKC study has three stages of development, i.e., scale effect, composition effect, and technique effect. Suppose the composition and technical effects stay constant in any economy's first stage. In that case, the scale effect postulates the positive association between GDP growth and environmental quality, wherever the increment in economic productivity worsens the quality of the environment due to inefficient production units. The composition effect states that enlargement in economic growth could negatively or positively affect CO_2 emissions. At this point, there could be a noteworthy structural transformation and a transformation in economic activity in a given economy due to an increase in GDP growth, and this structural change leads to an increase or decrease in environmental pollution. Categorically, at the initial stage of development, which consists of a structural transformation of the economy from the agricultural sector to the industrial sector, this economic development is expected to result in environmental deterioration.

Moreover, at the later stage of economic expansion related to the transformation of the economy from the industrial sector to the services sector or from the jump from energy-intensive to the technology-intensive production process, the level of carbon emission is expected to reduce from the environment (Kearsley and Riddel 2010). The third stage is the technique effect under the EKC framework, which states that a change in the production process regarding technology shock negatively affects carbon emissions (Rezek and Rogers 2008). Technique effects stipulate using cleaner and higher technology to improve the ecological quality (Lin et al. 2016).

Regarding the mechanism of the Kuznets curve (EKC), the technique effect concedes the greater use of clean technologies in manufacturing operations. Therefore, the technical effect, being an important component, plays a vital part in measuring the improvements in environmental quality (Bekhet and Othman 2018). Apart from the technique, scale, and composition effects, various other determinants of environmental quality in terms of income elasticity, trade openness, policy, and regulation significantly impact the environment under the framework of the EKC hypothesis (Dinda, 2004). As mentioned earlier, all these factors can define that sustainable environment and economic development can be achieved and explained under the EKC. Furthermore, energy is considered a prerequisite for economic progress concerning enhancements in productivity (Shahbaz et al., 2013). Through the structure of the EKC hypothesis, the energy-environment association has been debated extensively (Balsalobre-Lorente et al. 2018). Growth attained by using non-renewable sources of energy increases environmental depletion.

On the other hand, sustainable economic growth can be achieved through renewable energy sources, which can lower the rate of fossil fuels (CO_2) discharge from the environment and improve environmental quality. Renewable energy contribute as a key component in mitigating carbon emissions in the premises of the EKC model, and innovation in technology is an essential element in the depletion of CO_2 emissions (Chien and Hu 2007). Many studies have found that technological change has noteworthy effects on economic growth (Fang 2011; Inglesi-Lotz 2016). The level of CO_2 emissions could be minimized by utilizing technological innovation. Consequently, the efficient use of energy consumption and the lessening dependence on fossil fuel consumption can be gained by promoting green technology (Sohag et al. 2015).

Many researchers have analyzed the interrelationship between environmental quality and other economic drivers, ranging from CO_2 emissions, GDP growth, technological innovation, trade openness, green growth, energy sources, and other economic variables under the EKC format (Baskaya et al. 2022; Dogan et al. 2022; Pata 2018; Bilgili et al. 2019; Li et al. 2022; Zeraibi et al. 2021).

This study employed the traditional theoretical framework in equation (1) for empirical estimation and investigated the association between the growth of the economy and climate depletion.

The econometric model of the study can be written in terms of the reduced form as follows;

$$\mathbf{CO_{2it} = \alpha_1 + \alpha_2 Y_{it} + \alpha_3 (Y_{it})^2 + \alpha_4 X_{it} + \mu_{it}} \qquad \mathbf{(1)}$$

In the above equation, CO_{2it} is the number of carbon emissions per person, indicating an environmental decline. Y_{it} indicates the level of individual economic progress, while X_{it} denotes additional macroeconomic factors impacting the state of the environment. The coefficients of economic output and other independent variables are represented by $\alpha 2$, $\alpha 3$, and $\alpha 4$, which are used to estimate the impact and relationship among all these explanatory economic drivers on CO_2 emissions.

Following the framework of EKC, we can now explore the relationship between green economic advancement and environmental performance. To achieve eco-friendly development and a sustainable environment, green growth is essential. Green growth can simultaneously address economic advancement and environmental quality (Lee 2011). Green growth is a prerequisite for any country to attain sustainable growth (S. Wei et al., 2023) and has become necessary for developing less developed economies. Green growth can lead the way for economic and social benefits (OECD, 2013). According to OECD statistics (2020), green growth refers to the efficient use of natural resources. Green growth measures whether economic advancement transforms the economy from traditional to green. It estimates a country's environmental quality and the productivity of natural assets. Green growth captures the steps a nation is taking to achieve environmentally sustainable development and growth, while carbon neutrality analyzes the quality of the environment (Tawiah et al., 2021). Thus, green growth is the key determinant in mitigating environmental destruction. Consequently, countries that focus more on greening their output are more attractive for reducing their environmental pollution.

Figure: 2

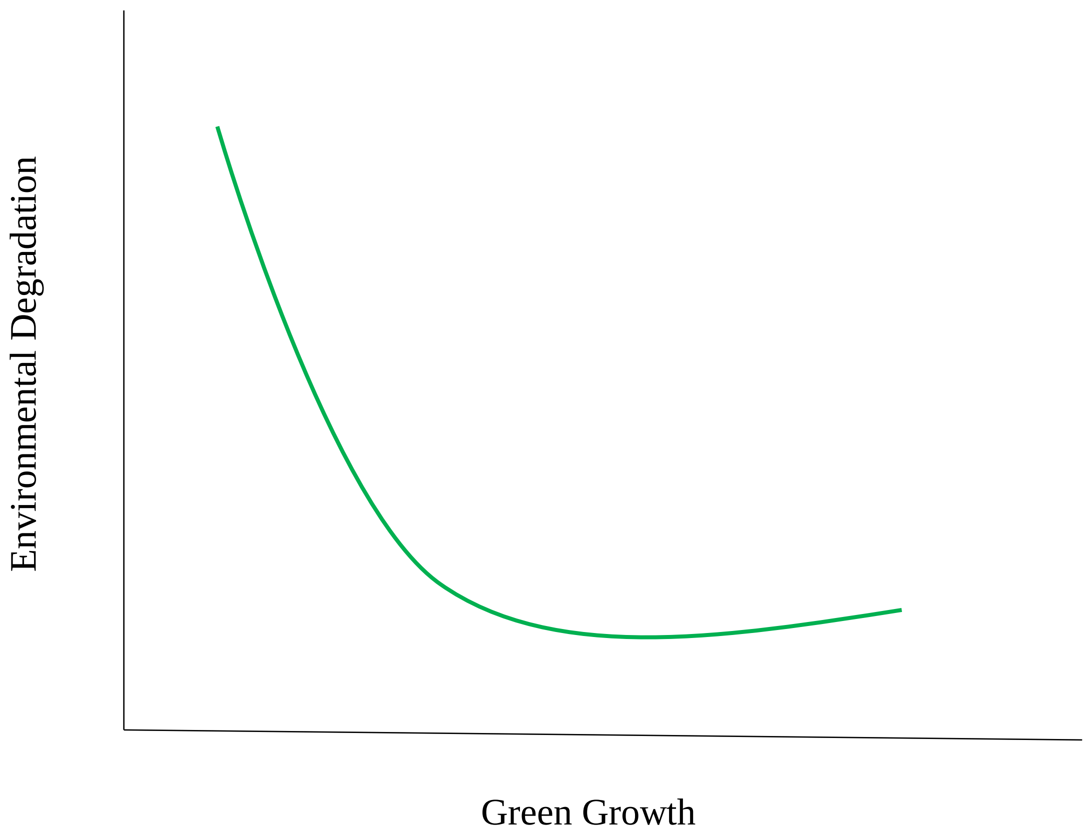


Figure 2 illustrates that the green growth is becoming evident as a progression towards improving the environmental condition in the selected Asian economies. Green growth is inversely and significantly related to the production of carbon dioxide across the Asian region. Convex shape green EKC means that if we double the size of the economy the emission is increases but with decreasing rate.

To conduct the empirical assessment, this research utilizes the comprehensive theoretical structure in Equation (2) to evaluate the correlation between environmental performance and the advancement of green initiatives.(Saleem et al. 2022; Chien et al. 2021) . The econometric pattern can be expressed in a simplified manner within the EKC concept as stated below:

$$\mathbf{CO_{2it} = \alpha_1 + \alpha_2\, GYit + \alpha_3(GY_{it})^2 + \alpha_4 Z_{it} + \mu_{it}} \qquad \mathbf{(2)}$$

In the above equation, CO_{2it} depicts the amount of carbon emissions per capita, a proxy for environmental deterioration. GY_{it} refers to the degree of green economic advancement per capita, and Z_{it} represents the other macroeconomic variables that affect environmental quality. Coefficients of green output and other independent variables are indicated by α2, α3, and α4 to estimate the impact and relationship of these explanatory economic drivers on CO_2 emissions.

3.3 Empirical Econometrics Models

Following the econometric models of Saleem et al. 2020; Hao et al. 2021and Tawiah et al. 2021,this study has constructed two empirical econometric models to estimate the EKC framework with other macroeconomic determinants of environmental quality.

3.3.1 Model 1

Nexus among growth-environment and other explanatory variables.

$$\mathbf{CO_{2it} = \alpha_1 + \alpha_2 GDP_{it} + \alpha_3(GDP_{it})^2 + \alpha_4 REW_{it} + \alpha_5\, TI_{it} + \alpha_6 TO_{it} + \mu_{1it}} \qquad \mathbf{(3)}$$

where CO_{2it} refers to the level of carbon emissions consumption per capita, GDP depicts the gross domestic product, GDP_{it}^2 is the square term of GDP used to present the EKC, REW_{it} indicates renewable energy consumption, TI_{it} demonstrates the technological change and TO_{it} represents the trade openness, α_1 is a constant, α_2, α_3, α_4, α_5 and α_6 are the coefficients of each assumed variable, μ_{1it} is an error term, and it represents cross-sections and time.

3.3.2 Model 2

Nexus among Green growth- environment and other macroeconomic variables.

$$\mathbf{CO_{2it} = \beta_1 + \beta_2 GRE_{it} + \beta_3 (GRE_{it})^2 + \beta_4 REW_{it} + \beta_5 TI_{it} + \beta_6 TO_{it} + \mu_{2t}} \quad \textbf{(4)}$$

In the above equation, CO_{2it} depicts the carbon emissions per capita, GRE_{it} indicates green growth, GRE_{it}^2 represents the square term of green growth used for EKC, REW_{it} refers to renewable energy consumption, TI_{it} represents technological change, and TO_{it} represents trade openness. β_1 is a constant, and β_2, β_3, β_4, β_5, and β_6 are the coefficients of each assumed variable. μ_{2it} is an error term representing cross-sections and time.

3.3.3 Log-Linear Transformation

This study applied a log-linear transformation to the above-mentioned models (1) and (2) because the measuring unit of each variable is different from the others. Therefore, the study measured the entire set of variables in the same form, i.e., percentage, rather than different units.

$$LnCO_{2it} = \alpha_1 + \alpha_2 LnGDP_{it} + \alpha_3 Ln\ (GDP_{it})^2 + \alpha_4 LnREW_{it} + \alpha_5 Ln\ TI_{it} + \alpha_6 LnTO_{it} + \mu_{1t} \quad (5)$$

$$LnCO_{2it} = \beta_1 + \beta_2 LnGRE_{it} + \beta_3 Ln\ (GRE_{it})^2 + \beta_4 LnREW_{it} + \beta_5 LnTI_{it} + \beta_6 LnTO_{it} + \mu_{2t} \quad (6)$$

3.4 Data Descriptions

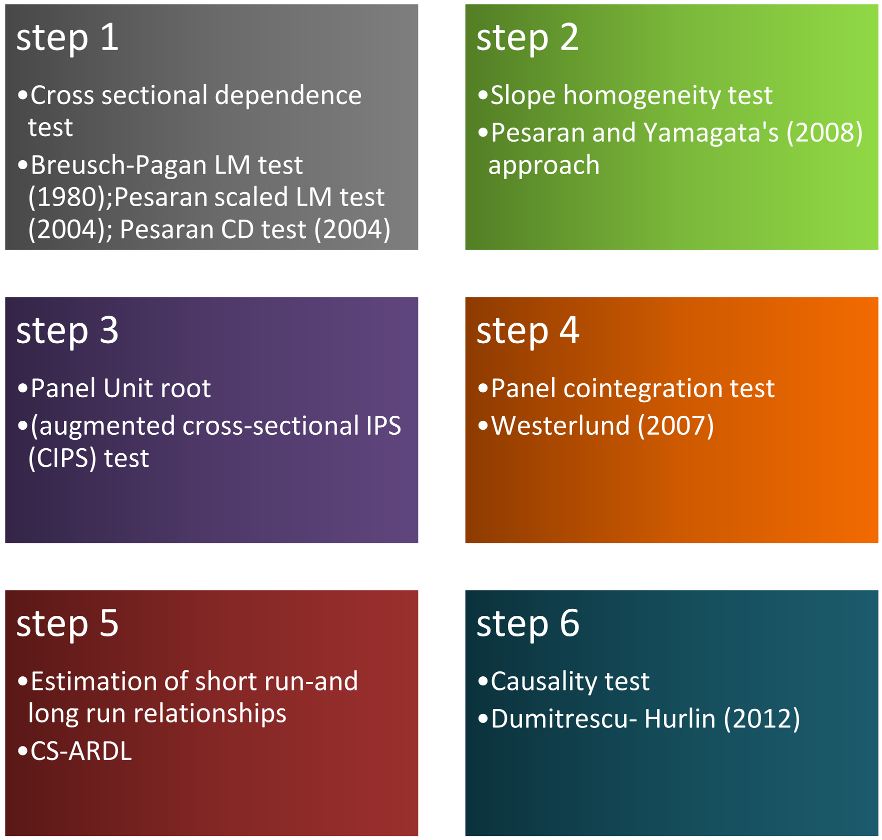
This study employed annual time series panel data from 1990 to 2018. Data on environmental degradation, economic development, renewable energy usage, openness to trade, and innovative technology are collected from WDI. Data on green growth (Environmental & resource productivity) were drawn from the OECD. The proxy of green growth 'Environmental and resource productivity' refers to the efficiency with which resources are utilized to generate economic output. High levels of productivity in this context indicate that economic growth is achieved while minimizing any adverse effects on the environment, aligning with the objectives of sustainable development. Environmental and resource productivity metrics play a vital role in achieving this objective by assessing the efficient utilization of resources. These measures are closely associated with environmental preservation since they are important in determining how effectively societies manage natural resources and mitigate their environmental footprints (Tawiah et al. 2021) and (Saqib et al., 2024). Carbon emissions (CO_2) were used as the dependent variable. Table 1 presents all the information regarding the measuring unit of each variable, symbol and source of data.

Table1Summary of Data Description

Variable	**Symbol**	**Measuring unit**	**Data source**
Environmental degradation	CO_2 emission	Metric tons per capita	WDI-2022
Economic growth	GDP	GDP per capita at constant 2015 US$	WDI-2022
Green growth	GRE	Environmental & resource productivity (Per US$) 2015)	OECD Stat (2022)
Renewable energy Consumption	REW	% of total final energy consumption	WDI-2022
Technological innovations	TI	Total patent applications (residents & non-residents)	WDI-2022
Trade openness	TO	Sum of imports & exports (% of GDP)	WDI-2022

Note: WDI is the World Development Indicator and OECD is an organization of Economic Cooperation and Development.

3.5 Methodology Workflow Visualization



3.6 Econometric Techniques

3.6.1Testing for Cross-Section Dependency (CSD)

The empirical analysis begins with the cross-sectional dependence (CSD) estimation technique, which is necessary to select the appropriate methodology and establish the panel data model. As mentioned above, since it is panel data, dependency in error terms is likely to arise due to undetected components and common shocks (Hoyos and Sarafidis 2006). In panel data, cross-sectional dependence can result in inconsistent and inefficient regression estimators, and therefore, the cross-sectional dependence in disturbance terms should be considered. Investigating cross-sectional dependency is a key step in selecting suitable panel unit root testing techniques. If CS dependency is found in the first stage, second-generation panel unit root estimation procedures should be employed; otherwise, first-generation panel unit root estimation methods can be applied. Three major tests, such as the BP Lagrange Multiplier method (1980), Pesaran LM (2004a) and Pesaran CD test (2004), are used to examine CSD.

The Pesaran CD test (2004) is an empirical estimation procedure used to measure the cross-sectional dependency among the estimated parameters. The Pesaran CD test can be written as follows:

$$CD = \sqrt{\frac{2}{N\,(N-1)}} \sum_{i=1}^{N-1} \sum_{J}^{N} T_{ij} \breve{\rho}_{ij} \sim N(0,1) \qquad (7)$$

In the above equation, N and T indicate cross-sectional size and the time length. $\breve{\rho}_{ij}$ is pairwise correlation of the residuals. This test is also useful in the context of a heterogeneous panel model.

Pesaran scaled is written below in equation form;

$$LM = \sqrt{\frac{1}{N^2-1}} \sum_{i=1}^{N-1} \sum_{J=i+1}^{N} \left(T \breve{\rho}_{ij-1}^{2}\right) \sim N(0,1) \qquad (8)$$

In the above equation, T and N both are considered large, the Breusch-Pagan LM test equation can be written below as follows.

$$LM = \sum_{i=1}^{N-1} \sum_{J=i+1}^{N} T \breve{\rho}_{ij}^{2} \sim X^2 \frac{(N^2-N)}{2} \qquad (9)$$

3.6.2 Homogeneity Test

Testing homogeneity/heterogeneity is another crucial issue in panel data modeling. Pesaran and Yamagata (2008) introduced a delta (Δ) test to check whether the parameters are homogenous or heterogeneous. The null hypothesis (i.e. coefficients are homogenous) is tested against the alternative hypothesis (i.e. coefficients are heterogeneous). This estimation technique is applicable without any restrictions on extending the time dimension (T) and cross-section units (N) when the disturbance terms are normally distributed.

3.6.3 Panel Unit Root Tests

Unit root techniques are implemented to estimate the stationary of the panel data. Panel data unit root analysis consists of two generations, i.e., the 1st-generation and 2nd-generation unit root estimation inferences. If cross-section dependence is not present in the data, then the first-generation unit root technique is the best tool to check the stationary properties of the panel series. If CSD is detected, then the panel unit root analysis of the 2nd generation is more appropriate to measure the stationary of the data. 2nd-generation unit root methods are proposed by (Pesaran 2007) and Choi (2006) to deal with the problems of first-generation unit root tests. This procedure takes into consideration the important issue of cross-sectional dependency. The problem of CSD is found in the present study; therefore, the CIPS procedure is applied to test the unit root among the series. CIPS is usually utilized as a second-generation unit root analysis developed by Pesaran (2007). It is the extension of the CADF regression examination. CIPS computes the lagged mean version of each cross-sectional individual yt for investigating the impacts of common components. CIPS is calculated by employing the empirical technique of IPS (Hossfeld 2010).

The structure of the CADF regression model is shown in Equation (10)

$$\Delta CO_{2it} = \alpha_{it} + \delta_i CO_{2i,t-1} + \rho_i T + \sum_{j=0}^{k} \gamma_{it} \Delta CO_{2i,t-j} + \mu_{it} \qquad (10)$$

Where CO_{2it}, i, t, and μ_{it} are the analyzed variables, the CD in the panel, the period and the residuals of the model, respectively.

More precisely, CIPS test statistics rely on the average of individual CADF values, as illustrated in Equation (11).

$$CIPS = \left(\frac{1}{N}\right) \sum_{I=1}^{N} CADF_i \qquad (11)$$

Where $CADF_i$ is the CD-augmented Dicky Fuller statistic.

3.6.4 Panel Cointegration Test

After measuring the data's stationary properties, the next step is utilizing appropriate econometric techniques to explore cointegration between variables with the help of panel cointegration econometrics procedures. For this motive (Westerlund 2007), a cointegration test is employed in our study. Westerlund (2007) developed an error correction panel procedure to gauge the long-term basis cointegration between carbon emissions and their drivers. This technique is based on four distinct categories to measure long-term cointegration i-e, two for the mean group class and two for the statistical panel class.

The equation for Westerlund's (2007) cointegration method is below as follows;

$$\Delta CO_{2it} = \delta_i d_t + \alpha_i CO_{2i,t-1} + \beta_i X_{i,t-1} + \sum_{j=1}^{p} \alpha_{ij} \Delta CO_{2i,t-1} + \sum_{j=q}^{p} \gamma_{ij} \Delta X_{i,t-1} + \varepsilon_{it} \quad (12)$$

Where i, t, d_t and $\mathcal{E}_{it}$ are the cross-sections, the period, the model's deterministic components and the residuals of the model, respectively, the vector of the cointegration among the explanatory and explained variables is denoted by αi in Eq. (12.1). The test statistics are as follows.

The equation furnished below presents the statistical measures for Westerlund's co-integration analysis.

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\alpha_i}{SE_{(\alpha_i)}} \quad (12.1)$$

$$G_a = \frac{1}{N} \sum_{i=1}^{N} \frac{T_i}{\alpha_{i(1)}} \quad (12.2)$$

$$P_t = \frac{\alpha}{SE_{(\alpha)}} \quad (12.3)$$

$$P_a = T\alpha \quad (12.4)$$

G_t, G_a represents the mean group categories, and P_t and P_a indicate the statistical panel categories. The alternative hypothesis of cointegration across the panel is tested versus the null argument that no cointegration exists across the full panel. However, in Westerlund (2007), the test error correction term is denoted by ((α) in Eq. 12.4) to measure the rate of readjustment to reach the long-term basis equilibrium. The error correction term (α) can be calculated by rearranging the value of $P_a = T\alpha$ (equation 12.4). Thus, the error correction parameter is $\alpha = P_a / T$; Thus, the error correction parameter indicates the error percentage points to be corrected each year if short-run disequilibrium exists.

3.6.5 Cross-sectional Autoregressive Distributed Lag

After the implication of stationary tests and cointegration inferences, the next step is to figure out both the variables' short- and long-term association. For this purpose, the present study employs a rigorous empirical approach, such as the cross-section ARDL. Chudik and Pesaran (2013) is proposed this econometric approach. CS-ARDL can solve the problems caused by endogenous variation, cross-section reliance, and differing slope parameters within panels of datasets (Khan et al., 2020). CS-ARDL can also be applicable if the order of integration is mixed. Due to the interconnection of social and economic situations, the panel data may encounter the CSD. Therefore, the cross-sectional autoregressive distributed lag (CSARDL) approach provides stable outcomes even with the cross-section reliance issue detected in the panel (Su et al., 2021).

$$\Delta CO_{2it} = \alpha_i + \sum_{l=1}^{p} \alpha_{1il} \Delta CO_{2i,t-1} + \sum_{l=0}^{p} \alpha_{2il} X_{i,t-1} + \sum_{l=0}^{1} \alpha_{3il} \bar{Z}_{i,t-1} + \varepsilon_{it} \quad (13)$$

Carbon emission per capita based on its consumption is indicated by ΔCO_{2it}, independent variables represented by X_{it-1} and $\bar{Z}$ denotes the cross-section average by ignoring the trends accounting for the spillover effects (Liddle 2018). The cross-sectional autoregressive distributed lag (CSARDL) technique forecasts the long-term coefficient using short-term coefficients as the inputs.

3.6.6 Panel Causality Procedure

This research used a scrupulous approach developed by (Dumitrescu and Hurlin, 2012) to explore the causal links between dependent and independent variables. This econometric approach considers the panel heterogeneity and is a non-causality method to measure the causal effects. The key supremacy of this technique is that it can estimate the two aspects of heterogeneity: one is to measure the Granger causal links of the regression model and the other is to explore the heterogeneity between causal relationships. The analyzing method accounts for the heterogeneity of the regression model and heterogeneity of causal interconnection. Furthermore, Dumitrescu and Hurlin causality test prove beneficial in numerous ways. Firstly, this estimation approach applies to both panels balanced and unbalanced panels. Secondly, this non-causality technique does not demand any specific calculations. Thirdly Monte Carlo simulations demonstrate that panel test statistics are large in condition when the sample is comprised of limited N and T dimensions. Fourthly, the measuring procedure of this approach is very simple. Lastly, this technique is useful when N>T or T>N (Su et al., 2021), and also deals with the problem of homogeneity caused by the traditional Granger causality approach.

The following equation indicates the linear heterogeneous model of the Dumitrescu-Hurlin non-causality test:

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} \gamma_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \quad (14)$$

In the above equation, X and Y identify the two stationary variables detected for N individual cross-section in T periods, $\beta_i = (\beta_i^{(1)}, \ldots, \beta_i^{(k)})$, $\gamma_i^{(k)}$ is lag parameter, k is lag length and the individual impacts α_i are supposed to be constant in the periods.
This causality test examines the null hypothesis of no causal interaction among cross-sectional units against the alternative hypothesis of at least one causal association in the cross-sectional dimensions.

$$H_\circ = \beta_i = 0 \; for \; i = 1, \cdots, N$$

$$H_1 = \begin{pmatrix} \beta_i = 0 \\ \beta_i \neq 0 \end{pmatrix}$$

For this non-causality examination, No established criteria exist for determining the most appropriate lag length.; researchers usually use up to 3 or 5 lag lengths in their research work. One assumes a causal nexus between the variables if 2 out of 3 or 3 out of 5 outcomes identify a causal connection between two variables.

CHAPTER 4

RESULTS and DISCUSSION

4.1 Introduction

This chapter covers the results and discussion section of the entire research work. The illustration of obtained outcomes and a detailed discussion of these findings are essential in the research dissertation. The results section also reports tables and diagrams that demonstrate the numerical findings of different statistical methods. The discussion is based on the economic explanation of the calculated findings and how these results support or contradict existing literature. The results segment begins with a descriptive statistical examination and then employs the latest econometric approaches to evaluate the significance of the research questions.

The introduction of this chapter is described in segment 4.1. The second segment, 4.2 depicts the descriptive analysis of the data. Section 4.3 presents the pairwise correlation between the variables. The exploration of cross-section dependence is presented in section 4.4. Section 4.5 examines the homogeneity of slope coefficients. The investigation of the stationary properties of the data is presented in section 4.6 by employing the CIPS unit root procedure. Section 4.7 incorporates the cointegration analysis among all the under-study variables. The estimation of the longer periods and shorter terms relation among parameters is reported in section 4.8 of model 1 and section 4.9 of model 2. Section 4.10 is based on the causal relationship among economic variables.

4.2 Descriptive Statistics

Table 2 describes the results of descriptive statistics. Descriptive statistics provide short, informative values that summarize specific observations. Descriptive and inferential statistics are divided into three categories: measures of dispersion, central tendency, and examination of normality. Furthermore, the standard deviation and variance of the variables are used to quantify volatility. The mean, median, mode, minimum, and maximum are used to analyze central tendency, while kurtosis and skewness measure the normality of the dataset. Skewness is used to analyze the degree of asymmetry of the distribution, whether it is normally skewed (0), positively skewed (>0), or negatively skewed (<0). Moreover, the kurtosis values examine the convexity of the curve. The kurtosis value provides information about the peaks and flatness of the series, whether it is Mesokurtic or normal distribution (value=3), Leptokurtic (>3), or Platykurtic (<3).

Table 2 summary of Descriptive Statistics

	LCO_2	LGDP	LGRE	LREW	LTI	LTO
Mean	1.253	8.482	1.205	1.838	7.445	4.009
Median	1.666	8.583	1.109	1.912	7.296	3.926
Minimum	2.277	6.239	0.352	1.906	1.707	2.741
Maximum	3.229	10.487	2.883	4.358	14.248	5.347
SD	1.456	1.252	0.739	1.975	3.235	0.521
Skewness	-0.567	-0.068	0.304	-0.594	-0.417	0.281
Kurtosis	2.125	1.837	2.356	3.113	2.997	2.617
Obs	348	348	348	348	348	348

A descriptive research design is carried out first to determine whether all the series are normal, adequate, and relevant. Table 2 lists the outcomes of the descriptive statistical analysis for every factor included in the regression model from 1990 to 2018. The total number of observations is displayed in Table 2. The range of LCO_2 emissions is from 2.277 to 3.229, with the maximum value increasing annually due to the region's rising economic activity and increased energy consumption. The standard deviation of the range is 1.456, which illustrates the variation from the mean value. The value of skewness is -0.567, which shows that the distribution is slightly skewed. The value of kurtosis is 2.125, indicating a flatter curve that is platykurtic because the value is lower than 3. The mean LGDP growth stands at 8.482, with a lowest value of 6.239 and a highest value of 10.487. The standard deviation of 1.252 indicates the degree of variation from the central value. The skewness value of LGDP is -0.068, suggesting that the distribution is slightly skewed. The kurtosis value is 1.837 indicates a platykurtic distribution of the series since the value is less than 3 and shows the flattened curve. The average LGRE (green growth) value is 1.205, ranging from a minimum of 0.352 to a maximum of 2.883, which explains how much change there is in green growth over time, while the standard deviation is 0.739 , showing the dispersion from the mean. The skewness value of 0.304 portrays the normal distribution about its mean. The value of kurtosis is 2.356, which means the distribution is platykurtic because the value is lower than 3, resulting in a flatter curve. The average LREW (renewable energy) value is 1.838, encompassing a range from 1.906 as the minimum to 4.358 as the maximum. The measure of variability (SD) of 1.975 anticipates the dispersion from the average mean value. The negative skewness is -0.594 which showed that the distribution has the left tailed. The value of kurtosis is 3.113 which are leptokurtic because its value is greater than 3, showing the peaked curve of the distribution.

The distribution of LTI (technological innovation) has a mean value of 7.445 and a median value of 7.296, making it statistically mean to the median. The lowest and highest LTI values are 1.707 and 14.248, correspondingly indicating the variation in technology change over the annual period. The standard deviation value of LTI is 3.235, reporting the variability from the mean value. The values of skewness and kurtosis are -0.417and 2.997, respectively, indicating a slightly skewed and platykurtic curve.

The mean and median values of LTO (trade openness) are 4.009 and 3.926, respectively, representing the central tendency of the series. The minimum and maximum values of LTO are 2.741 and 5.347, respectively, indicating the variation in technology over the annual period. The standard deviation value of LTO is 0.521, evaluating the variation from the mean value. The value of skewness and kurtosis are 0.281 and 2.617, respectively, indicating a normal distribution and platykurtic curve because the value of kurtosis is less than 3.

4.3 Results of Pair-wise Correlations

A pairwise correlation table illustrates correlation coefficients between pairs of variables, with each cell indicating the relationship between two specific variables. The correlation matrix summarizes the data and serves as input for more advanced analysis or as a diagnostic tool in further investigations.

Table 3 Pair-wise Correlations

	LCO_2	LGDP	LGRE	LREW	LTI	LTO
LCO_2	1.0000					
LGDP	0.8967 0.0000	1.0000				
LGRE	-0.6977 0.0000	0.3307 0.0000	1.0000			
LREW	-0.8145 0.0000	0.7842 0.0000	0.4941 0.0000	1.0000		
LTI	-0.2845 0.0000	0.0944 0.0904	0.5516 0.0000	0.1545 0.0077	1.0000	
LTO	0.6816 0.0000	0.7664 0.0000	-0.2182 0.0000	-0.5472 0.0000	0.1686 0.0024	1.0000
VIF		3.10	2.91	4.85	2.94	1.96
1/VIF		0.3225	0.3441	0.2063	0.3399	0.5097
Mean VIF	3.66					

Table (3) depicts the results of the pairwise correlation coefficients of LGRE, LGDP, LREW, LTI and LTO with environmental depletion. The coefficient of each variable demonstrated their linear and significant association with the LCO_2 emission. The coefficient value of LGDP growth and LTO are 0.8967and 0.6816 respectively showing a liner, positive and significant correlation relationship of both variables with LCO_2 emissions, as 1 % increase in both variable leads to rise in environmental destruction or vice versa. In addition, the coefficient value of LGRE, LREW and LTI has negative signs displaying a negative and significant correlation of these three variables with LCO_2 emissions. The lower part of Table 3 demonstrates that the model has no multicollinearity issues because the Correlation coefficients (VIF) are fewer than five and the relative tolerance value of each variable is more than 0.10.

4.4 Results of Cross-Section Dependence

Table (4) reports the statistical outcomes of three CS reliance tests i-e, the Breusch-Pagan Lagrange Multiplier technique, the Pesaran LM procedure and the Pesaran CS-dependency method. The results confirm rejecting the null hypothesis (no cross-section dependence) based on the P-values at a 1% significance level and accept the alternative hypothesis. Accepting the alternative hypothesis means that CSD is found among all the variables under investigation. In today's globalized world, most nations are interconnected, which is one of the main drivers of CSD. Any factor that shocks one of the sample nations would significantly affect all the other sample nations. Therefore, due to the spillover effects, the variables are cross-sectional dependent.

Table 4 Test of Residual Cross-Section Dependence

Test	Statistic	Prob.	Null hypotheses	Conclusion
Breusch-Pagan LM	7.476***	0.0000	No CSD in residuals	Reject
Pesaran scaled LM	5.684***	0.0000	No CSD in residuals	Reject
Pesaran CD	-3.623***	0.0022	No CSD in residuals	Reject

Note: Rejection means that the null hypothesis is rejected at a 1 % significance level

4.5 The Heterogeneity and Homogeneity Testing

Table 5 presents the results of the Pesaran and Yamagata (2008) homogeneity test. Before applying a relevant unit root approach, it is essential to examine slope homogeneity. The results presented in Table 5 show that the p-values of Δ and adjusted Δ in both models are less than 0.01, indicating the rejection of H0 (coefficients are homogenous) and acceptance of the alternative hypothesis (coefficients are heterogeneous).Heterogeneity suggests that the coefficient is different for each cross-section. To address heterogeneity, a standardized estimation technique is required; otherwise, the results may be inconclusive (Su et al. 2021). Additionally, at the one percent (1%) level of effectiveness, the null argument favoring homogeneity is invalidated.

Table 5 Test of Heterogeneity and Homogeneity of Co-efficient

MODEL 1	
$\mathbf{CO_{2t} = f(GDP_t, GDP_t^2, REW_t, TI_t, TO_t)}$	
Delta (p-value)	Adjusted – Delta (p-value)
14.905***	17.121***
(0.0000)	(0.0000)
MODEL 2	
$\mathbf{CO_{2t} = f(GRE_t, GRE_t^2, REW_t, TI_t, TO_t)}$	
Delta (p-value)	Adjusted – Delta (p-value)
21.547***	24.739***
(0.0000)	(0.0000)

Note: *** signifies that 1 % is a significant level

4.6 Unit Root Test

This research is restricted to employing the 2nd-generational CIPS (Pesaran 2007) observation, which addresses the existence of CSD and slope heterogeneity among the economic indicators reported in table 4 and 5, respectively. It compares an alternate statement (presence of stationary) to the null prediction of non-stationarity between under-study indicators. The results of CIPS root diagnostic statistics suggest that Carbon emission, GDP per capita, technological change, and openness to trade are stationary at the level .Green growth and renewable energy are stationary at the first difference, according to the P-values of the CIPS test statistics. Therefore, we affirm the alternative hypothesis while rejecting the null assumption. The parameters' stationary characteristics at first difference indicate that the mean and variance vary over time in both models for these variables. Thus, the study concludes that the order of integration among the economic indicators is mixed, i.e., I (0) and I (1).

Table 6 Panel Unit Root Test

	At level I(0)	At first difference I(1)
Variable names	CIPS t- statistics	CIPS t- statistics
LCO_2	-2.416***	_
LGDP	-2.816***	_
LGRE	_	-5.167***
LREW	_	-3.912***
LTI	-2.245**	
LTO	-2.219**	

Note: **, *** represents the level of significance at 1 % and 5% level of significance.

4.7 Westerlund (2007) ECM-based Cointegration

The Westerlund cointegration test (2007) works better in cross-section dependence than traditional cointegration tests. The main reason for using this test is the presence of cross-section dependency among the panel series. The technique uses the bootstrap test statistic method, which can produce effective results when the cross-sections are interdependent. The results of the panel cointegration test are presented in Table 7. The outcomes demonstrate the rejection of the null point of view of not having cointegration against the alternative hypothesis in both models 1 and 2. The acceptance of H1 indicates that longer-term equilibrium relationship exists, including the carbon dioxide released and its contributors. It is possible to measure the elasticity of the independent variables to CO_2 emissions when a long-term relationship has been confirmed.

Table 7 Results of Cointegration Analysis

Westerlund (2007) ECM-based cointegration

	Value	Z-value
Model-1		
$\mathbf{CO_{2t} = f(GDP_t , GDP_t^2, REW_t, TI_t, TO_t)}$		
	Value	Z-value
Gt	-1.863	2.847***
Ga	-3.690	4.743***
Pt	-6.028	1. 960**
Pa	-4.735	2.735***
Model-2		
$\mathbf{CO_{2t} = f(GRE_t , GRE_t^2, REW_t, TI_t, TO_t)}$		
Gt	-0.942	6.193***
Ga	- 4.329	5.605***
Pt	-2.817	4.999***
Pa	-1.898	3.915***

Note; ‘**’& ‘***’ shows the level of significance at 5% and 1%.

4.8 Results of CS- ARDL Model 1

The next step is after confirming the cointegration association among all the variables based on the findings presented in Table 7, and this study proceeded to discover the parameters' short-run and long-run impacts. The CS-ARDL method by Chudik and Pesaran (2013) explored the effects of green growth, technological change, clean energy, trade openness, and GDP expansion on CO_2 abasement. The overall long- and short-term results of Model 1 are summarized in Table 8.

Table 8 Results of CS- ARDL Model 1

Model 1

$CO_{2t} = f(GDP_t, GDP_t^2, REW_t, TI_t, TO_t)$

High Income

Variables	**Short-run analysis**		**Long run-analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGDP_{it}$	0.56	0.000***	0.99	0.025**
$L(GDP_{it})^2$	-0.03	0.005***	-0.05	0.031**
$LREW_{it}$	-0.54	0.087*	-0.70	0.040**
LTI_{it}	-0.25	0.034**	-0.49	0.074*
LTO_{it}	0. 02	0.000***	0.11	0.081*
ECT(-1)	-0.76	0.000***		

Upper Middle Income

Variables	**Short-run analysis**		**Long run-analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGDP_{it}$	1.59	0.036**	1.88	0.025**
$L(GDP_{it})^2$	-0.09	0.050**	-0.10	0.041**
$LREW_{it}$	-0.33	0.000***	-0.64	0.021**
LTI_{it}	-0.05	0.018**	-0.14	0.016**
LTO_{it}	0.07	0.045**	0.25	0.033**
ECT(-1)	-0.69	0.000***		

Lower Middle Income

Variables	**Short-run analysis**		**Long-run analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGDP_{it}$	0.45	0.022**	0.66	0.019**
$L(GDP_{it})^2$	0.02	0.040**	0 .06	0.085*
$LREW_{it}$	-0.02	0.002 ***	-0.10	0.000***
LTI_{it}	-0.01	0.021**	-0.06	0.008***
LTO_{it}	0.12	0.060*	0.19	0.041**
ECT(-1)	-0.85	0.000***		

Full Panel

Variables	**Short-run analysis**		**Long-run analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGDP_{it}$	1.30	0.001***	1.57	0.006***
$L(GDP_{it})^2$	-0.07	0.051 **	-0.08	0.038 **
$LREW_{it}$	-0.26	0.009 ***	-0.43	0.011**
LTI_{it}	-0.24	0.046**	-0.28	0.000***
LTO_{it}	0.35	0.029**	0.45	0.016**
ECT(-1)	-0.78	0.000 ***		

Table (8) illustrates the key findings of the CS-ARDL test across the entire panel comprising 12 selected Asian economies, including high-income nations (South Korea, Brunei, Bahrain), upper-middle-income countries (China, Turkey, Russia, Kazakhstan), and lower-middle-income economies (India, Bangladesh, Iran, Sri Lanka, Pakistan). The statistical estimation showed a relationship between LCO_2 and LGDP in the panel of 12 Asian nations, following the estimates of model 1 of the full panel of CS-ARDL. More specifically, a change in one percent LGDP (per capita) will increase environmental damage by 1.30% in the short term and 1.57% in the long period. The outcomes of the square term of LGDP illustrate that if all other factors remain constant, a 1% increase in the $LGDP^2$ term will reduce -0.07% and -0.08% in the LCO_2 outflows in short run and long run. This positive and negative association with CO_2 confirmed the presence of EKC in the selected sample region following the findings of the entire panel. Because in the early phases of economic development, people frequently devote more of their financial resources to purchasing items without considering the potential environmental effects of the manufacturing processes. When their standard of living rises above a certain point, though, people begin to expect improved environmental quality. The outcomes of this study are consistent with the investigations carried out by (Khan et al., 2020 Hanif 2018), while the results of the current analysis are contradictory with the studies of (Zhou et al. 2018) and (Abid 2016) because they could not found the presence of EKC in their research work. The entire panel estimates also reveal that renewable energy (LREW) has a negative and, at the same time, significant influence on the outflows of carbon. The findings of the study show that an upsurge of a 1% in environmentally friendly energy consumption tends to curtail -0.26% and -0.43% of emissions from the environment in short term and long term respectively. The result could be associated with the potential substitution between the LREW usage and consumption of fossil fuels and that of renewable energy, which can be achieved by cutting back on the former energy use while raising that of green energy. Thus, this region, more focus on the consumption of renewable energy is required, and implications of such policies which enhance the use of clean energy. The same results are confirmed by the research work of (Mehmood 2022), (Shahnazi and Dehghan Shabani 2021), (Erdogan et al. 2020) because they also obtained that LREW significantly minimize the amount of pollution from the environment . These results are different from the investigation of (Le et al., 2020) related to the developing countries' conclusions as their study identified that environment friendly energy consumption could not prove to be helpful in the reduction environmental damage in the developing world. The outcomes of traditional model 1 also evaluate that a 1 percent increment in technological change will reduce the level of LCO_2 emissions by-0.24% in short run and -0.28% in long run , which means the inverse and significant connection amid technology change and CO_2 damage. The environment may be considerably improved by technological innovation and eco-friendly use of technology. Based on the statistical findings, these results also confirmed by the research work of, (Chien et al., 2021; Saudi et al. 2019; Cansino et al. 2019), because they also found inverse association between LTI and LCO_2. The results also indicate that a one-percent change in openness to trade (LTO) may increase the level of air pollution by 0.35% and 0.45% in short and long run, due to the weak formulation of LTO in Asian economies . These results show the positive and significant interconnection of trade openness with CO_2 emission, which correspond with the most recent research by (Mahrinasari et al. 2019) and (Ertugrul et al., 2016). However, our trade-environment results contradict the findings of (Dogan and Turkekul, 2016) and (Shahbaz et al. 2017) that LTO raises the standard of the environment. The computed value of the ECT-1 (error correction) term is statistically significant and negative on the basis of economic theory. The coefficient value of ECT is -0.78, suggesting that the economy moves towards the equilibrium in the long run, and 78% of disturbances are corrected in the short time period to get the long-term equilibrium.

Threshold level of EKC formula = $-\alpha_2/2 * (\alpha_3)$, where $\alpha_2$is $LGDP_{it}$ and α_3 $L(GDP_{it})^2$.α_2 and α_3 represent the marginal impact of GDP on CO_2 emissions in model 1, considering income levels lower and higher than a predetermined threshold limit. Consistent with the findings of Model 1, we observed that the effect is negative and statistically significant when income exceeds the turning point, whereas it is positive and statistically significant when income falls under the threshold level, as evidenced by the results of the current study. This robustly supports the validity of the EKC theory. An examination of the threshold level reveals that the pivotal point, according to model (1), is 18260.58, 19930.37 and 12088.38 per capita US$ in full panel, high income economies and upper middle income economies respectively.

4.8.1Results of High-Income Economies

The table additionally presents the CS-ARDL statistics for the chosen Asian economies categorized by their income levels, which include high-income, upper-middle-income, and lower-middle-income economies. The short-run and long-run findings of high-income and upper-middle-income nations support the validity of the environmental Kuznets curve theory. Regarding both income classifications, LGDP is directly attached to greenhouse gases (CO_2). Compared to the high-income group, the coefficient value of LGDP is 0.56% and 0.99% concerning the production of LCO_2 in both time periods, respectively, meaning that it considerably raises CO_2 emissions. The square term of LGDP has a negative sign, suggesting an improvement in the environmental situation after reaching a threshold level of economic growth and development. This demonstrates that only upper-middle-class and high-income countries have attained the level of income necessary to cut CO_2 pollution via economic expansion. This suggests that upper-middle-class and high-income countries have effective climate standards, a modern energy system, and increased environmental consciousness, allowing them to cap CO_2 emissions and lessen environmental damage. The coefficient value of renewable energy to LCO_2 emissions is -0.54% in short run and -0.70% in long run, resulting in the upgrading of environmental quality and low carbon emissions. These findings align with the economic theory regarding the interconnectedness of the environment, economic growth, and energy. (Khan et al., 2021).

Technological innovation (LTI) has an inverse and noteworthy relationship in both the short and long periods in the context of the high-income group. This relation postulates that a 1% change in LTI leads to -0.25% and -0.49% depletion of CO_2 in the short-term and the long-term, respectively. Nevertheless, technological change is needed for improving environmental quality and reducing reliance on energy resources originating from fossil fuels. The LTI-LCO_2 nexus is also endorsed by (Chien et al. 2021) and (Dauda et al. 2020). The statistical results of LTO illustrate that a 1% increase in openness tends to a 0.02% and 0.11% rise in outflows in both time periods respectively.

Such conclusions reveal the significant and positive interconnection between trade and the environment. In short, the outcomes show that technological change and renewable energy have significantly reduced emissions, while trade openness may increase carbon emissions.

4.8.2Results of Upper Middle-Income Economies

Table (8) also indicates the estimated values of GDP advancement, clean demand of energy, technological progress, pollution of CO_2 release, and accessibility to trade of the upper-middle-income group. LGDP has a direct relationship with the level of carbon outflows, and the square term of LGDP has an inverse correlation with LCO_2 emissions based on the positive and negative signs of the coefficients, respectively. Both variables suggest a significant long-term effect on CO_2 damage. LGDP has a considerable impact on LCO_2 emissions, increasing them by 1.59% in the short run and 1.88% in the long run. It can be shown that a 1 percent rise in $LGDP^2$ on average results in a -0.09% and -0.10 declines in pollution in short run and long run. In upper-middle-income regions, these findings support the inverted U-shape hypothesis. A shift of one percent in renewable energy (LREW) results in a reduction of approximately -0.33% and -0.64% in ecological destruction in short and long run respectively. Additionally, the statistical findings of the study show that openness to trade gives rise to the level of carbon pollution. The trade openness (LTO) postulates that a 1% increase in LTO implies a short-term rise of 0.07% and a long-term upward trend of 0.25% in emission levels, which is significant. Technology innovation (LTI) has an advantageous and substantial influence on pollution. A 1% rise in LTI gives a -0.05% and-0.14% decline in the level of LCO_2 outflows in short term and long term. All the findings mentioned above correspond to the examination conducted by(Zhang et al. 2017) regarding newly industrialized nations. The empirical outcomes of the study indicate that clean energy and technological change significantly participate in lowering CO_2 concentrations and boosting the quality of the environment. At the same time, trade openness gives rise to CO_2 discharge.

4.8.3Results of Lower Middle-Income Economies

Long-term and short-term estimates related to the lower middle-income group are also reported in Table (8). The findings of the study deny the environmental curve's claim in this lower-middle-income Asian region because lower-middle-income economies continue to industrialize; they are putting more of a priority on developing their economies instead of focusing on environmental protection. Moreover, Lower middle-income nations are more concerned with swift economic expansion and less concerned with ecological sustainability. These findings are supported by (Mensah et al., 2018), which analyzed the interaction of sustainable and non-sustainable energy sources, GDP per capita, R&D, and CO_2 emissions. Three important models were used in this study i.e., the economic-environmental strategy, the STIRPAT model, and the EKC-innovation pattern. The information gathered also suggested that technological innovation can be beneficial for improving environmental quality across the OECD nations. The results also identified that GDP growth expands the level of CO_2 emission while using sustainable energy shrinks the level of pollutants emitted. The responses did not support the lower-middle group's interpretation of the ecological Kuznets curve.

Regarding the concern of lower middle-income nations, LGDP and $LGDP^2$ enhance emissions in the short run. This implies that while keeping all other variables constant, a 1% alteration in LGDP and $LGDP^2$ gives rise to 0.66% and 0 .06% in emissions in long run. Renewable energy considerably reduces CO_2 emissions in both the short and long run. In the outcomes of lower middle-income nations, the renewable energy concerning LCO_2 is calculated at -0.02% for the short term and -0.10% for the long term. A one percent rise in technology-based innovation substantially decreases the toxic discharge of -0.01 and -0.06 percent in short-long periods, similar outcomes found by the research analysis (Carrión-Flores and Innes 2010). The statistical results of the trade openness illustrated that a 1% increase in openness tends to 0.12 % and 0.19% upsurge in the rate of outflows. The results revealed the significant and direct interconnection between trade and the environment. In short, the outcomes revealed that technological change and renewable energy have significantly reduced the level of emissions and trade openness may increase carbon emissions.

4.9 Statistical Results of CS-ARDL Model 2

Table (9) presents an overview of the outcomes in both long-term and short-term scenarios. It reports the key findings of CS-ARDL across the whole panel comprising 12 selected Asian economies, including high-income nations (South Korea, Brunei, Bahrain), upper-middle-income countries (China, Turkey, Russia, Kazakhstan), and lower-middle-income economies (India, Bangladesh, Iran, Sri Lanka, Pakistan). A robust correlation exists between CO_2 and sustainable growth among the chosen group of Asian countries, Derived from the coefficient values of Model 2 within the full CS-ARDL panel. The empirical finding of green growth (LGRE) indicates that a 1% change in LGRE can minimize environmental pollution by -1.17% and -1.67% in the short and long periods. The negative signs of the coefficients suggest that green growth brings drastic changes in lowering CO_2 emissions and enhancing the ecological standards in the nations chosen for the research sample. The results of the square of green growth show that if other things hold constant, then a 1% change in $LGRE^2$ results in a 0.08% and 0.10% increase in the level of emissions with decreasing rate. The negative and positive signs of both green terms report the presence of a convex shape EKC in the selected Asian region. Empirical research reveals green growth's inverse and highly significant correlation with environmental degradation.

Environmentally sustainable energy (LREW) is also helpful in decreasing contamination. As per the research results, a 1% increase in LREW will reduce the deterioration of the environment by -0.34% in the short term and -0.51% in the longer term based on the results of the full panel of Model 2 of sample countries. These outcomes support existing studies (Le et al. 2020; Hao et al. 2021). The efforts made by several Asian nations to reduce CO_2 emissions are noteworthy. Although Asia contributes significantly to global CO_2 emission rises, these economies can reduce CO_2 emissions by implementing green growth and technological change strategies. This investigation reveals that technological change (LTI) has an advantageous impact on overall environmental performance, as a 1% increase in LTI will lead to a -0.08% and -0.17% decline in short-term as well as long-run contamination of the environment, respectively because technological change considerably raises the standard of ecological health using highly efficient machines, energy-saving technologies, and novel environmentally friendly techniques. Technological innovation and eco-friendly use of technology may considerably improve the environment. The results support the direction of (Dauda et al. 2020) and (Chen and Lei 2018). The results related to the full panel of Model 2 show a direct relationship between trade openness (LTO) and CO_2 outflows. A 1% increase in trade openness can maximize environmental destruction by 0.05% in the short run, which is statistically significant. At the same time, a one-percent change in LTO leads to a 0.09% long-term expansion of greenhouse gases (CO_2). These results show the positive and significant interconnection of trade openness with CO_2. These findings are because many Asian countries are largely dependent on imports, mostly for things like electronic trash and used goods. These products help to improve living standards and economic advancement, but their higher energy usage increases CO_2 emissions. These findings are consistent with the pollution haven hypothesis (PHH), which assumes that trade openness exacerbates environmental damage. The error correction term or ECT (-1) suggests that the economy is approaching stability under the framework of CS-ARDL. The error adjustment term confirms the short-term connection between both the independent components alongside dependent factors. The value of ECT (-1) is -0.81%, which is significantly negative, indicating the assumption that 81% of errors will be adjusted to achieve long-term equilibrium. These findings are supported by the prior studies of (Agboola and Bekun, 2019).Threshold levels of green growth is 4230.181, 12637.76, 3521.586 and 1096.633 per US$ in full panel, high income economies upper middle income economies and lower middle income economies respectively.

Table 9 Results of CS-ARDL Model 2

Model 2

$CO_{2t} = f(GRE_t, GRE_t^2, REW_t, TI_t, TO_t)$

High Income

Variables	**Short-run analysis**		**Long run-analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGRE_{It}$	-1.20	0.000***	-1.70	0.000***
$L(GRE_{It})^2$	0.07	0.000***	0.09	0.009***
$LREW_{It}$	-0.18	0.072*	-0.44	0.049**
LTI_{It}	-0.08	0.45**	-0.37	0.031**

LTO_{It}	0.17	0.023**	0.22	0.051**
ECT(-1)	-0.45	0.000***		

Upper Middle Income

Variables	**Short-run analysis**		**Long run-analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGRE_{It}$	-0.57	0.002***	-0.98	0.012**
$L(GRE_{It})^2$	0.04	0.004***	0.06	0.039**
$LREW_{It}$	-0.16	0.003***	-0.41	0.000 ***
LTI_{It}	-0.15	0.27**	-0.24	0.096*
LTO_{It}	0.12	0.042**	0.16	0.081*
ECT(-1)	-0.42	0.000 ***		

Lower Middle Income

Variables	**Short-run analysis**		**Long-run analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGRE_{It}$	-0.38	0.000***	-0.70	0.003***
$L(GRE_{It})^2$	0.03	0.001***	0.08	0.030**
$LREW_{It}$	-0.03	0.000***	-0.12	0.000***
LTI_{It}	-0.09	0.027 **	-0.11	0.023**
LTO_{It}	0.06	0.053**	0.23	0.082*

ECT(-1)	-0.49	0.000***		

Full Panel

Variables	**Short-run analysis**		**Long-run analysis**	
	Co-efficient	P-value	Co-efficient	P-value
$LGRE_{It}$	-1.17	0.000***	-1.67	0.000***
$L(GRE_{It})^2$	0.08	0.000***	0.10	0.020**
$LREW_{It}$	-0.34	0.002***	-0.51	0.051**
LTI_{It}	-0.08	0.006***	-0.17	0.000 ***
LTO_{It}	0.05	0.011**	0.09	0.046**
ECT(-1)	-0.81	0.000***		

4.9.1Results of High-Income Economies

Table 9 also reports the results of Model 2 of the CS-ARDL by the income levels of the selected Asian economies. The investigation proved that convex EKC exist in the high income and upper-middle-income Asian economies. According to statistics studies, Green growth is becoming evident as a progression towards improving the environmental condition. LGRE is inversely and significantly related to the production of carbon dioxide across the two income categories. According to the high-income group perspective, In terms of short-term and long-term emission rates of LCO_2, LGRE coefficient values are -1.20% and -1.70% correspondingly, meaning that it considerably shrinks CO_2 emission. The findings of the square of green growth show that if other things hold constant, then a 1 percent change in $LGRE^2$ results in a 0.07% and 0.09% percent increase with the diminishing rate in the emission level. The coefficient value of renewable energy to emissions is -0.18 % in the short run and -0.44% in the long run, improved environmental performance and low pollution emissions. These results align with the economic theory of the environment-green growth-energy nexus. In the setting of the high-income class, technological innovation has a short-run and long-run significant and indirect relationship with the environment. This association postulates that a 1% change in LTI leads to a -0.08% and -0.37% depletion of LCO_2 in both periods. However, technological change is the need for the betterment of environmental quality and less dependence on fossil fuel energy sources. The LTI-LCO_2 nexus is also endorsed by (Ding et al. 2021). The statistical findings concerning trade openness indicate that an elevation of 1% in openness correlates with a 0.17% surge in the short-term and a 0.22% rise in the long-term CO_2 levels. These findings reveal the significant and direct interconnection between trade and the environment in the short run and positive and significant links in the longer time, which is in line with prior estimation (Ang 2009). In short, the outcomes represent that technological change and renewable energy have significantly reduced the level of emission, and trade openness may increase carbon emissions.

4.9.2Results of Upper Middle-Income Economies

Table 9 also indicates the estimated values of LGRE growth, trade openness, technological change, CO_2 emissions, and renewable energy of the upper-middle-income group. The empirical findings of green growth indicate that a 1% change in LGRE can minimize environmental pollution by -0.57% and -0.98% in the short and long time periods. The negative signs of the coefficients suggest that green growth brings drastic changes in lowering CO_2 emissions and strengthening the state of the ecosystem in the upper-middle group. The findings of the square of green growth show that if other things hold constant, then a 1 percent change in $LGRE^2$ results in a 0.04% and 0.06% percent increase with the diminishing rate in the emission level. Both variables suggest a significant long-term effect on CO_2. Sustainable growth harms air pollution. Green growth might be quite important to achieve long-term stability and healthy environmental initiatives. For the development of the upper-middle Asian region, green economic growth seems to have the ability to provide economic advantages substantially. Environmental destruction is revealed to be negatively/positively and convexly correlated with the coefficients LGRE and $LGRE^2$. CO_2 emissions are considerably reduced by using clean energy that is renewable. One-percent change in clean energy induces a drop of -0.16% and -0.41% in carbon emanation in short and long run correspondingly. The statistical findings of the study show that openness to trade (LTO) gives rise to the level of carbon pollution.

If there is, a 1% increases in LTO causes a 0.12% rise in eco depletion in the short time and a 0.16% of growth in CO_2 concentrations in the long-range (which has a significant effect in both periods). Likewise, the influence of technological advancements on carbon emissions displayed a significant and adverse effect. A growth of 1% in technological innovations (LTI) results in a reduction of -0.24% in the long term emissions. All these conclusions align with the investigation conducted by (S. Wei et al., 2023). The empirical outcomes of the study indicate that clean energy and technological change significantly assist in controlling CO_2 emission levels and improving the quality of the environment, while trade openness gives rise to the level of CO_2 outflows.

4.9.3Results of Lower Middle-Income Economies

The short-run and long-run estimates of the lower middle-income group of Model 2 are reported in Table 9. Regarding lower middle-income nations, the results show that LGRE help mitigate CO_2 emissions in the short run and long run. Specifically, assuming all other variables remain the same, a 1% change in LGRE will lead to a reduction in carbon pollution of -0.38% and -0.70%, respectively. However a 1% change in square of LGRE will increase in carbon pollution of 0.03% and 0.08%, in short and long run respectively, it means that if we double the size of the economy the emission is increases but with decreasing rate. The negative sign with the coefficient of LGRE and the positive sign with the coefficient of $LGRE^2$ confirm the convex shape of the EKC in lower-middle-income economies. Renewable energy considerably minimizes the CO_2 emissions into the atmosphere in both periods. The findings for lower middle-income nations indicate that in the shorter to longer term, respectively, the coefficient values of sustainable energy about the release of emissions are -0.03% and -0.12%. In the short and long run, a one percentage point rise in new technology results in a substantial decrease in atmospheric pollution of -0.09% and -0.11%. The statistical results for trade openness illustrate that a 1% increase in openness results in a 0.06% and 0.23% increase in the level of outflows in the short and long period outcomes as mentioned earlier illustrate the significant and direct interrelation between trade and the environment, which is supported by (Chhabra et al. 2022). In a nutshell, the investigations imply that technological change and renewable energy have significantly reduced emissions, while trade openness may increase carbon emissions.

4.10 Causality Test Results

Furthermore, the size and direction of the relationship are confirmed by the outcomes of the CS-ARDL estimation methods. Nevertheless, the analysis of the research's last stage examines the relationship among all economic components and to examine the causal link between CO_2 emissions and other macroeconomic determinants, including green growth (LGRE), economic growth (LGDP), LREW, LTI, and LTO, Dumitrescu and Hurlin's (2012) approach has been utilized. The above approach investigates the bivariate casual interaction across several economic indicators by controlling the variability throughout the CSD by constructing the research's design (in the short run). In such analysis, the null hypothesis denotes the absence of causation and the alternative hypothesis identifies the existence of causation between all components. This research concentrates on analyzing the Wald value to assess the non-causation Granger investigation for every cross-section.

Table 10 Results of Causality Test

S.no.	Hypothesis	W-stat	z- stat	p-value	Statistical results	Decision
1	$LCO_2 \phi LGDP$	1.201	0.265	0.743	NO	
	$LGDP \phi LCO_2$	8.176	17.578	0.000	Yes	Unidirectional Causality
2	$LCO_2 \phi LGDP^2$	0.0451	0.004	0.89	NO	
	$LGDP^2 \phi LCO_2$	11.376	9.329	0.000	Yes	Unidirectional Causality
3	$LCO_2 \phi LREW$	0.512	0.818	0.562	NO	
	$LREW \phi LCO_2$	2.966	3.614	0.042	Yes	Unidirectional Causality
4	$LCO_2 \phi LTI$	1.064	0.7803	0.833	NO	

	LTIϕLCO_2	4.042	7.452	0.000	Yes	Unidirectional Causality
5	LCO_2ϕLTO	2.951	4.779	0.000	Yes	
	LTOϕLCO_2	1.913	2.236	0.025	Yes	Bidirectional Causality
6	LCO_2ϕLGRE	3.108	5.163	0.000	Yes	
	LGREϕLCO_2	3.442	5.982	0.000	Yes	Bidirectional Causality
7	LGDPϕLREW	4.651	6.010	0.000	Yes	
	LREWϕLGDP	2.534	3.596	0.021	Yes	Bidirectional Causality
8	LGDPϕLGRE	7.374	15.613	0.000	Yes	
	LGREϕLGDP	3.590	6.344	0.000	Yes	Bidirectional Causality
9	LGDPϕLTI	2.389	3.402	0.030	Yes	
	LTIϕLGDP	2.746	4.277	0.000	Yes	Bidirectional Causality
10	LGDPϕLTO	3.144	5.252	0.044	Yes	
	LTOϕLGDP	3.035	4.986	0.000	Yes	Bidirectional Causality
11	LREWϕ$LGDP^2$	2.772	-0.737	0.458	No	
	$LGDP^2$ϕLREW	8.333	5.624	0.000	Yes	Unidirectional Causality
12	LREWϕLTI	3.134	4.195	0.000	Yes	
	LTIϕLREW	5.215	2.803	0.002	Yes	Bidirectional Causality
13	LREWϕLTO	4.961	3.178	0.004	Yes	
	LTOϕLREW	3.861	0.755	0.734	No	Unidirectional Causality
14	LREWϕLGEG	6.427	5.321	0.050	Yes	
	LGEGϕLREW	7.112	6.682	0.000	Yes	Bidirectional Causality
15	LTIϕLGRE	2.923	4.710	0.000	Yes	
	LGREϕLTI	2.716	4.204	0.000	Yes	Bidirectional Causality
16	LTIϕLTO	3.322	2.239	0.036	Yes	

	LTOϕLTI	2.133	2.777	0.047	Yes	Bidirectional
17	LTOΦLGRE	4.865	3.339	0.022	Yes	
	LGREΦLTO	5.832	4.716	0.000	Yes	Bidirectional Causality

The panel causation assessments, which examined whether the economic indicators are causally related, are shown in Table (10). According to the findings of the causality test if, certain changes in policies influence the LGRE, LGDP , $LGDP^2$, LREW, LTI, and LTO in determining the environmental quality. Additionally, some structural reforms cause a decrease in environmental quality via the variability in the above-mentioned variables.

The Dumitrescu and Hurlin panel method's findings demonstrated the two-way causal relationship among LCO_2-LTO, LCO_2-LGRE, LGDP-LREW, LGDP-LGRE, LGDP-LTI, LGDP-LTO, LTI-REW, LREW-LGEG, LTI-LGRE, LTO-LGRE and LTI-LTO. The findings suggested that any policy adjustments to renewable energy consumption (REW), green growth (GRE) and Technological Innovation would reduce environmental pollution. On the other hand, if a certain strategy shock is given to LGRE, LGDP, Square of LGDP, LREW, LTO and LTI have a considerable impact on LCO_2 emissions. A significant causal link is found in LGRE, LGDP, $LGDP^2$, LREW, LTO and LTI by giving any policy shock to LCO_2. Consuming clean energy may greatly help in mitigating environmental destruction. Consequently, LREW and LCO_2 are discovered to have a cause-and-effect relationship. The findings are supported by the study of (Hao et al. 2021),(Saleem et al. 2022) and (Rasoulinezhad & Saboori, 2018). Cause and effect are limited to moving in one direction from LGDP to LCO_2, $LGDP^2$ to LCO_2, LTI to LCO_2, LREW to LCO_2, $LGDP^2$ to LREW, and LREW to LTO. In short, the findings suggested that green change, renewable energy, and technological innovation can play a significant role in lower CO_2 emissions and improving environmental quality. These outcome are in line with the work of (Saleem et al. 2020) and (Chen et al. 2022).

CHAPTER 5

CONCLUSION and POLICY IMPLICATIONS

5.1 Conclusion

This research aims to identify the critical role of green growth, economic output, clean energy, change in technology, and trade openness concerning CO2 emissions within the EKC framework. This study examined panel data from 12 Asian economies (consisting of different income level groups In addition, it depicts the long-term interconnection among CO_2 emissions, green growth, the square of green growth, GDP growth, the square of GDP growth, renewable energy consumption, technological innovation, and trade openness. However, the core variable of this study is green growth, and if the Asian economies focus more on green growth projects, it is feasible to reach the carbon neutrality goal. According to the outcomes of the CS-ARDL method of the full panel of model 1 and model 2, the negative interconnection is observed between green growth (LGRE), the square term of output ($LGDP^2$), ecologically friendly energy (LREW) and technological innovation (LTI) with CO_2 emissions in Asian economies. However, a positive relationship has been observed regarding economic growth (LGDP) and trade openness with CO_2 emissions. The existence of the environmental Kuznets curve hypothesis is confirmed by the results of full panel of model 1.

Furthermore, CS-ARDL findings of model 1 are related to the income level groups. The existence of the environmental curve has been verified by the High and upper-middle-income groups. Still, the validity of the EKC could not be found in lower-middle-income economies. Additionally, all the variables are inversely related to CO_2 except the GDP and trade openness in all income groups and the full panel. Environmental destruction is positively and significantly associated with GDP and openness to trade, resulting in increasing environmental pollution in all income groups in this research. The statistical results concluded that renewable energy and technological change can help to reduce the level of emissions and improve the quality of the environment in full pane and all income groups. According to the different income groups of economies, the estimates of model 2 depict the occurrence of the convex-shaped EKC in full and all income-level classifications. Based on the outcomes of all income groups (high, upper, and lower-middle-income economies) of model 2, most variables such as green growth, renewable energy consumption, and technological change have an inverse interconnection with CO_2 emission resulting in improving the environmental quality in Asian region. However, trade openness is positively related to CO_2 emissions in all income levels and depletes the environmental quality. Findings of causality test demonstrated the two-way causal relationship among LCO_2-LTO, LCO_2-LGRE, LGDP-LREW, LGDP-LGRE, LGDP-LTI, LGDP-LTO, LTI-REW, LREW-LGEG, LTI-LGRE, LTO-LGRE and LTI-LTO. The findings suggested that any policy adjustments to renewable energy consumption (REW), green growth (GRE), and technological innovation would reduce environmental pollution. On the other hand, if a certain strategy shock is given to LGRE, LGDP, Square of LGDP, LREW, LTO, and LTI, it would considerably impact CO_2 emissions. One-directional causation flows from LGDP to LCO_2, $LGDP^2$ to LCO_2, LTI to LCO_2, LREW to LCO_2, $LGDP^2$ to LREW, and LREW to LTO.

5.2 Policy Implications

1. The study makes an effort to meet the objectives of sustainable environmental development for academics, environmentalists, and decision-makers. The rapid increase in green growth initiatives can help achieve the environment's sustainability goals. Furthermore, these green growth initiatives can aim for carbon neutrality, which is our primary variable. However, the effects of environmental degradation can be reduced by the use of technological innovation, cleaner production methods, and supply chain innovations. Since many Asian nations rank among the top emitters in the world, green trade, green growth, and eco-friendly technology are essential to these economies' efforts to reduce CO_2 emissions. Policymakers find it challenging to achieve sustainable economic growth because of the contradictory relationships between CO_2 emissions, energy use, and growth. The main goal of this study is to give policymakers better solutions so that they can make sound sustainable economic policies in light of this conflicting relationship. Comprehensive analysis indicates that embracing the sustainable development goal and putting technological innovation into practice are essential for Asian countries to protect their environment. Consequently, this study also recommended that decision-makers focus on environmentally friendly

and sustainable ways to implement energy-saving technologies in manufacturing. These economies can recommit to attaining economic growth by implementing clean energy initiatives (SDG 7), technological advancements (SDG 9), and climate action plans (SDG 13).

2. To achieve sustainable development goals, it is imperative to extend the utilisation of renewable energy instead the non-renewable energy sources. Access to such resources not only promotes economic growth but also increases employment rates, enhances public health, and has a positive effect on the economy as a whole. The Sustainable Development Goals (SDGs) can be greatly aided by cooperative efforts among Asian nations to expand the use of renewable and sustainable energy. Lowering greenhouse gas emissions and addressing issues with energy security can be accomplished through allocating funds for the development, research, and advocacy of greener technologies as well as by organising management decisions on renewable energy sources and economic strategies. Environmental tight policies, such as those involving a carbon price, must be implemented cautiously by policymakers. They should also encourage the switch to renewable energy sources by enacting supportive policies.

3. It is recommended that governments implement policies such as tax rebates for manufacturing firms to encourage the production of environmentally friendly products. Financial aid, such as low-interest or unrequited loans, should be made available for research and development of green technologies. Support for users of environmentally friendly products is essential. Programmes to educate the public about the importance of using green products are imperative. Finally, in order to minimise CO_2 emissions, Asian policymakers should accelerate the energy system's transformation.

4. Renewable energy adoption and technology advancements are prerequisites for environmental sustainability. Green trading is growing because renewable energy technologies, which are thought to be environmentally friendly, are essential in converting fossil fuel-based energy sources to renewable ones. Thus, increased use of

renewable energy should be encouraged by policymakers in diverse sector, including mining, residential areas, and manufacturing. Furthermore, the establishment of virtual or physical forums for exchanging green innovation concepts will aid in the spread of green ideas and increase the reach of green innovation.

5. The findings show that the full panel and all income groups experience an escalation in trade-induced CO2 emissions. Regarding trading and sustainable development, Asian nations may reconsider their tight environmental strategies in this region. First, there is a need to impose limitations on economic expansion and trade openness, focusing on fostering green growth that emphasizes environmental impacts over harmful activities. Secondly, to minimize pollution, it is also critical for governments to support technological advancement and impose strict environmental policies. Lastly, a key step is implementing trade restrictions to limit practices carried out by businesses engaged in filthy production that are detrimental to the environment. Ecological deterioration has a strong relationship with trade openness and economic advancement. It could be additionally helpful in Asian economies to promote less carbon-intensive industry sectors as well as the service industry.

5.3 Limitations and Future Research

This study selected 12 Asian economies, but there is room to test the approach with other regional clusters like the BRICS, GCC, European, G-7 and African nations. To address increasing environmental issues, it is advised that future research examine how environmental taxes, green funding, green trade, government effectiveness and financial development affect ecological footprints.

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