Carbon Management Through Sustainable Energy Demand

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Unveiling the Carbon Footprint of Europe and Central Asia: Insights into the Impact of Key Factors on CO2 Emissions

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ABSTRACT

This study delves into the intricate relationship between carbon dioxide (CO2) emissions and crucial variables in Europe and Central Asia from 1990-2021. By examining the impact of renewable energy, industry value added, foreign direct investment (FDI), gross domestic product (GDP) per capita, and population density on CO2 emissions using the autoregressive distributed lag (ARDL) method, the study uncovers intriguing findings. The study reveals a significant negative correlation between linear per capita income and CO2 emissions in both the short and long run. Moreover, it confirms the inverted N-shaped environmental Kuznets curve (EKC) relationship between the variables. The study further highlights the unfavorable impact of renewable energy and industry value added on CO2 emissions, pointing to the fact that their growth increases CO2 emissions. On the other hand, population density is found to be a vital factor in reducing CO2 emissions. FDI is identified to have a negative and insignificant impact on CO2 emissions, suggesting that it may not be an effective tool for reducing carbon emissions in the region. The insights from this study have significant implications for policymakers in the region to design and implement effective strategies to reduce CO2 emissions.

Keywords: Carbon emissions; Economic growth; Renewable energy; FDI inflows; Industry value added, Population density; ARDL estimator.

1. INTRODUCTION

In recent years, climate change has emerged as one of the most significant challenges facing humanity, despite its seeming distance and theoretical nature for many individuals. The threats of global warming pose a serious risk to people all over the world, with human activities being the primary contributors to this problem. Greenhouse gas emissions, particularly carbon dioxide (CO2), have been identified by scientists as the most significant factor driving climate change (Lv and Xu, 2019). Researchers have extensively investigated the factors underlying greenhouse gas emissions, and it is widely acknowledged that CO2 output resulting from the combustion of renewable energy sources is the primary natural variable contributing to greenhouse gases. In 2011, the use of renewable energy sources to promote economic growth and improve human health resulted in 33.2 billion metric tons of global carbon emissions (Wang et al., 2018).

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Carbon dioxide, which accounts for 58% of overall global energy consumption, is one of the most important greenhouse gases. CO2 is a significant warmth (greenhouse) gas that is released into the atmosphere through human activities such as deforestation and fossil fuel combustion, as well as natural processes such as volcanic eruptions and respiration. While global temperatures have been fairly stable and benign, over the past two centuries, 97% of climate scientists and experts believe that human activities have significantly altered the Earth's atmosphere, leading to global warming. As temperatures continue to rise, the greenhouse gas effect typically absorbs a certain amount of energy in a way that protects the environment from extreme cold, but the significant contribution of human-generated greenhouse gases to global warming cannot be ignored. This is due to the presence of fossil fuel emissions in the atmosphere, which increase the volume of greenhouse gas emissions (Shahzad et, al ,. 2015). In the IPCC 5th assessment study, it was found that human action had caused more than 95% of the temperature increase on our planet (Afridi et al., 2019). The emission of radiation serves to warm the planet, while the accumulation of radiation from the sun by aerosols actively warms the air, rather than allowing sunlight to be absorbed by the research carried out by various agencies for climate and environmental research.On the other hand, analysis has shown that CO2 emissions are lower in high-income nations, as they recognize the importance of their environment and work to maintain balance. This paper aims to explore the factors that are contributing to massive CO2 emissions in Europe and Central Asia. Many nations are reducing their agricultural practices and transitioning towards more developed sectors, such as industry. However, estimates indicate that reducing agricultural development can negatively impact the environment, leading to global pollution. Deforestation is also a significant concern, with many countries having already exceeded the limits of total forest cover. People in rural areas often rely on natural resources for their livelihood, with forests being a major source. These forests are essentially factories that utilize excessive CO2 from the environment for their life, but economies are destroying this wealth at an alarming rate.

During the early stages of development, the primary concern for many nations is earning money at any cost, regardless of the impact on natural resources. Low levels of literacy and poverty among people are other factors that contribute to CO2 emissions. Many of the world's most environmentally polluted cities are in low-income countries, where people are generally less concerned about the environment and natural resources. Cities are the centers of energy consumption and consequently face significant environmental pressure. Sustainable use of natural resources has become increasingly important in recent years, as industrial revolutions have changed the economic landscape, with nations competing with each other in this rapidly evolving environment (Chen, 2023).Environmental degradation is the phenomenon that occurs when any disturbance is perceived to have a negative impact on the environment. The collapse of the earth, the destruction of the atmosphere through the consumption of natural resources such as air, water, and soil, and the extermination of wildlife are all examples of environmental degradation. This degradation results from the deterioration of the environment through the depletion of air, soil, and water resources, as well as the extinction of wildlife, the destruction of ecosystems and habitats, and pollution.

In recent years, global climate change has become a common concern for humanity. The characteristic nature of current ecological problems is that they are triggered by human-induced processes, rather than natural ones. Reckless commercialism and economic development have begun to show harmful effects on humanity. The primary cause of greenhouse gas emissions is human activity, including the burning of fossil fuels, which releases CO2 and other organic compounds into the atmosphere (Ahmad et al., 2017).Urbanization, industrialization, under-population development, and deforestation are some of the leading causes of environmental degradation, which results in a reduction in the variety and quality of natural resources. When water supplies become more damaging to the environment due to urbanization and industrial development, it contributes to the destruction of ecosystems (Tyagi et al., 2014).Various forms of greenhouse gases contribute to the degradation of the climate, resulting from significant increases in population, per capita income, and the use of exhaustible and polluting technology resources. The natural resources of the earth are being depleted, and the climate is being damaged by pollution of the air, water, and soil, which ultimately leads to environmental degradation.According to the United Nation report (2017) of Sustainable Development Goals 2017 global warming has a significant and disturbing effect throughout the world. Global average temperatures have steadily increased, breaking the record over the pre-industrial age of around 1.1 degrees Celsius. The size of worldwide glaciers in 2016 declined to 4.14 million square kilometers, the second lowest ever. Climatic CO2 concentrations exceeded 400 parts per million.

Environmental degradation has become one of the top ten hazards formally warned by high ranking Panel on Risks, Challenges as well as Transition. Earth degradation takes different forms. When ecosystems are destroyed or natural resources are depleted, leading to climate change and pollution, the environment is ultimately degraded (Andersen et al. 2023). Different types of human activities contribute to environmental degradation, such as substantial population growth, constantly rising per capita income, and the use of exhaustible and polluting technology resources. Various drivers of environmental degradation include increasing population, persistently rising economic growth, polluting and resource-depleting technologies, and the destruction of natural habitats (Chertow, 2000).Countries face environmental challenges at every level of income, with some managing the challenges of managing natural resources and pollution more effectively than others (Norway, as compared to China). Rapid population growth, the use of fossil fuels, and per capita income growth pose serious threats to climate stability and the diversity of ecosystems in both developing and developed nations. Reliance on fossil fuels, overfishing, deforestation, pollution, overuse of water resources, and waste accumulation tend to deteriorate (Ahmed et al. 2022).

FDI represents a significant driver of carbon dioxide emissions, although the precise relationship between FDI and environmental degradation remains uncertain (Seker et al., 2015). FDI is a prominent feature of the modern global economy, and its potential impact on environmental sustainability is a fiercely debated issue. Developed nations face a particularly critical challenge, as they are perceived as attractive havens for polluting industries worldwide (McGuire 1982, Copeland and Taylor 1995). Various factors such as political instability, country risk, and interest rates can influence foreign investment. In such contexts, weak environmental regulations may increase FDI inflows. In recent decades, FDI globalization has significantly expanded, bringing not only mutual funds but also incentives to transfer technology from investors to host nations. This has led to job growth, managerial and technical expertise inflows, and improved organizational skills, along with increased competitiveness (Kobrin, 2005). According to Haug and Ucal (2019), FDI has no long-term statistically significant impact, although export declines can reduce per capita carbon dioxide emissions in the long run. However, export increases do not have a positive significant impact, and they can drive up carbon dioxide emissions per capita. Developing nations lack essential infrastructure and are hampered by economic and social instability, uneducated and unskilled populations, and constrained economies that impede their development. Thus, the transition of technologies in such countries is crucial to advance their economic growth (Bengoa, M., & Sanchez-Robles 2003). However, foreign investment has had a negative impact on environmental protection in India and China, according to Baek et al. (2009). FDI inflows rose significantly from $317.430 billion in 2004 to $2516 billion in 2012, largely due to less strict regulations.

The relationship between economic growth and environmental degradation, particularly the emission of carbon dioxide, has been extensively studied in the literature (Imran et al. 2023; Wang et al. 2023). Numerous studies have found a positive association between GDP growth and carbon emissions, particularly in emerging nations (Imran et al. 2022; Shaheen et al. 2022). The Atmosphere Kuznets Curve, which shows an inverted U-shaped relationship between economic growth and environmental degradation, has been used to explain this association. However, recent studies have suggested that positive growth in real income may decrease CO2 emissions and nonrenewable energy usage, while increasing N20 (Yahya& Lee, 2023).The relationship between economic development and the environment is often seen as conflicting, particularly in developing countries where economic development, industrialization, and resource use are given top priority. However, some studies have suggested a negative and nonlinear relationship between CO2 emissions and economic development (Zaman et al. 2022; Anser et al. 2022).The choices made regarding economic development and environmental protection in the present world will have an impact on future generations. Concerns about climate change and global warming have led to increased research into the relationship between economic development and pollution. Increasing income leads to increased production of goods and services, which can have a positive impact on the economy but also increase greenhouse gas emissions. Therefore, the development agenda should focus on the use of modern technologies and the creation of new applied research, which are the main drivers of economic growth, to minimize the negative impact on the environment.In addition to population density, urbanization is also a key factor in carbon dioxide emissions (Akhtar et al. 2022). Urbanization is often associated with economic growth and higher standards of living, but it also leads to increased energy use and transportation emissions. According to Zhang et al. (2021), urbanization has a significant positive effect on carbon dioxide emissions in China. In addition, the type of energy used for electricity generation also plays a significant role in carbon dioxide emissions. Countries that rely heavily on coal as an energy source tend to have higher emissions compared to those that rely more on renewable energy sources such as solar or wind power (Pombo et al. 2023). Furthermore, it is worth noting that population growth and density are not the only factors that contribute to carbon dioxide emissions. The behavior of individuals and businesses also plays a crucial role in the level of emissions. The choices that people make regarding transportation, energy use, and waste management can significantly impact emissions. Policies and regulations can also play a critical role in reducing emissions, such as promoting the use of public transportation, incentivizing the use of renewable energy, and implementing carbon pricing mechanisms (Lim & Prakash, 2023).

It is important to address the impact of carbon emissions on the environment and human life. The focus on population density, FDI, GDP, and renewable energy as potential factors affecting carbon emissions in Europe and Central Asian countries is a significant step in addressing this issue. By understanding the relationship between these factors and carbon emissions, policymakers can develop effective strategies to reduce greenhouse gas emissions.It is worth noting that population density, FDI, GDP, and renewable energy are interconnected factors that may influence carbon emissions in different ways (Khan et al. 2022; Jia et al. 2022). For example, higher population density may result in more energy consumption, which can lead to increased carbon emissions. FDI and GDP may also be related to energy consumption and hence contribute to carbon emissions. In contrast, renewable energy sources like solar and wind power may offer an alternative to fossil fuels, thus reducing carbon emissions.

Overall, this research can provide valuable insights into how different factors impact carbon emissions and inform policies that can lead to a more sustainable future.It is true that a healthy environment is closely linked to a stable and sustainable economy. However, increased economic activities have led to environmental degradation, which poses a threat to sustainability efforts. Climate change is a major consequence of this degradation and has gained significant attention in the literature.

The present study is therefore motivated to examine the impact of various factors, such as FDI, renewable energy, and industry value added, on CO2 emissions in Europe and Central Asia. This research is important in understanding the underlying factors that contribute to carbon emissions and can help inform policies to mitigate their impact on the environment.The research aims to address important questions regarding the impact of human activity on the environment in Europe and Central Asia. Specifically, the objectives are to investigate the effects of different factors, such as industries, renewable energy, population density, and per capita GDP, on carbon dioxide emissions. The study seeks to identify the relationship between these variables and the level of CO2 emissions, in order to better understand the environmental challenges facing the region and inform policy decisions aimed at achieving a more sustainable future. By exploring these factors, the research will provide insights into the key drivers of emissions and the most effective strategies for reducing them.

2. LITERATURE REVIEW

This section offers a high-level summary of the research conducted on the effects of the energy mix, businesses, Capital, Income per capita, and demography on CO2 emissions. One way to maintain a stable economy is to safeguard the environment. Unfortunately, human interference in the form of expanded economic activity has led to a deterioration in air sustainability. The study by Honma (2015) examined the connection between international commerce and sustainability reporting in 98 countries from 1970 to 2008. The global economy was shown to improve sustainability impact, although its effect on climate varied with countries' GDP per capita. To evaluate the effect of trade on diverse natural indicators, the research also presented an ecological effectiveness measure. The effects of free trade, productive capacity, trade deepening, and air quality were studied by Hua and Boateng (2015) across 167 countries from 1970 to 2007. Researchers observed a U-shaped correlation between the quality of life and economic damage in these countries, a phenomenon known as the EKC. The research urged world leaders to consider environmental concerns while allocating resources and expanding economies throughout the globe. From 1976 to 2009, Tang and Tan (2015) analyzed data on emissions, FDI, power usage, and wage activity in Vietnam. Co2 emissions were shown to be positively influenced by energy use and economic growth and negatively influenced by urbanization. The EKC was also supported by the data, demonstrating that with industrial prosperity comes an increase in biodiversity loss followed by a decline. The research suggested using green technology to cut down on pollution. Ohlan (2015) examined the relationship between CO2 emission in India and factors such as energy consumption, wealth creation, open trade, and population size from 1970 to 2013. A positive correlation between carbon pollution and each outcome variable was discovered immediately and during the research. The research suggested legal measures to reduce the impact of these causes on carbon output. Shahbaz et al. (2015) examined the connection between development and CO2 emissions in India from 1970 to 2012. Asymmetry in information was found among the components by co-integration and asymmetric causality analysis. Negative thermal efficiency and adverse financial growth shocks affected productivity expansion. Using the structural VAR method, Ahiakpor et al. (2019) looked at the connection between Ghana's monetary stimulus and trade linearization during 2012-2017. Inflation has been rising in Ghana as the country's trade volume has increased, and this study aimed to determine how well the financial system has been at stemming that tide. According to the research, policymakers should consider the degree of trade linearization when setting interest rates. Khan and Ozturk (2020) analyzed yearly balanced data from 17 Asian countries between 1980 and 2014 to examine the correlation between FDI and emissions. A positive impact of FDI on carbon footprint was discovered, lending credence to the "Pollution Haven Hypothesis." Nevertheless, open trade and ecological sustainability were also significant effects of Capital. According to the findings, healthy growth and development may be attained if economic policies are devised to direct foreign resources towards ecologically friendly enterprises. Leitao (2018) used time series data from 1980-2013 to analyze Portugal's EKC and its association with climate change. The research indicated that although high9r per capita income raises emissions, higher annual income quadratic decreases them. Carbon output was shown to be inversely linked to free trade and FDI. The analysis found that Portugal has a high dependence on its energy infrastructure. Using time series data from 1975-2016, Naz et al. (2018) looked at the connection between REC, Investor influx, wage activity, and emissions. The research concluded that fossil fuels rise with wealth creation and Capital inflows, but they drop dramatically with the use of renewables. The research results contradicted the EKC hypothesis, which found a reverse U-shaped correlation between a nation's economy and carbon footprint. The findings also backed up the "Contamination Haven supposition," the theory that FDI might harm a country's ecosystem. The report suggests enforcing environmental and economic regulations to integrate REC into existing energy assets, which may decrease CO2 emissions and boost personal income and FDI inflows. Using ten-year balanced panel data from 1996-2005 for 84 countries, Chang and Li (2019) looked at the impact of FDI and economic growth on emissions across demographics. Using inhabitants and estimated numbers as threshold parameters, the researchers discovered an inverted U-shaped EKC connection between CO2 emissions and economic growth across various demographic groupings. Pollutants rose sharply with rising FDI in low-population systems. The research shows that greater carbon pollution is associated with higher manufacturing value creation, whereas decreased emissions are associated with increased energy utilization. Based on the stated discussion, the study's first hypothesis is as follows:

H1: There exists an inverted N-shaped relationship between CO2 emissions and economic growth, such that emissions increase initially with economic growth, decrease after a certain threshold level is reached, but increase again at higher levels of economic growth.

The relationship between India's labour force and Financial development was a wash across the research period. Using social network analysis, Aller et al. (2015) analyzed the connections between commerce and the natural world in 177 nations between 1996 and 2010. Significant environmental implications were discovered for the trade network and total commerce. The economic influence of the trade network improved the efficiency of the atmosphere in low-income countries while negatively impacting the climate in high-income ones. The research backed up the pollution heaven theory and demonstrated that the entry of multinational firms into developing nations is terrible for the environment. Capital structure, open trade, and environmental integrity were all studied by Al-Mulali et al. (2015) across 23 European nations between 1990 and 2013. The research found that carbon emissions rise with commercial, urban, and financial growth but fall with free trade. It was suggested in the report that incentives for pure energy firms and investments, free trade to promote non-polluting firms and levies on polluting industries would all help businesses make the switch to clean, ecologically sustainable sectors.Using data from 1971 to 2010, Alvarado and Toledo (2017) examined the connection between production and environmental loss in Ecuador. A long-term link between plant cover, urbanization, and actual Output was discovered using co-integration and error correction models. These factors were also shown to have short-term correlations, albeit no evidence of Granger causality was discovered. According to the research results, environmental rules in Ecuador should be independent of the country's expanding economy and metropolitan areas. Energy conservation, FDI, urbanization, and Pollutant emissions were all factors that Behera and Dash (2017) investigated for 17 nations in the South and Southeast Asia area between 1980 and 2012. Power consumption, FDI, and CO2 emissions were found to be co-integrated across all income levels using the Pedroni co-integration approach. It was shown that middle-income nations' carbon emissions co-integrated with the use of conventional energy, capital formation, and urbanization. The research found that carbon emissions in the SSEA area were most affected in middle-income nations where conventional energy consumption and FDI play a role. Ozturk and Oz (2016) looked at the connection between energy requirements, jobs, direct investment, and Pollutant emissions in Turkey from 1974 to 2011. Long- and short-term EKC hypotheses were supported in Turkey. FDI improved the state of the climate, especially in the near term, but a negative FDI coefficient indicated a reciprocal causal relationship between FDI and carbon emissions. In Turkey, too, evidence corroborated the development theory, pointing to a one-way causal relationship between energy use and progress. Including electricity usage, wealth creation, and economic progress.The effects of increased productivity and globalization on environmental stewardship in 36 Sub-Saharan African nations were examined by Kwabena et al. (2017). According to Kuznet's hypothesis of the ecological impact of financial development and productivity, the researchers concluded that the latter two factors improved ecosystem sustainability and quality. In contrast, internationalization had a detrimental effect on wildlife preservation and stewardship of natural resources. Investment in fuel cells, greenways, and evolution goods was suggested in the research as a means of fostering sustainability. From 1994 to 2012, Allard et al. (2017) analyzed 74 countries' CO2 emissions, Income per capita, open trade, scientific advances, use of clean energy, and democratic accountability. Except for the upper middle class, they discovered a negative relationship between REC and CO2 emissions and an N-shaped EKC. The research suggested that eco-friendly technologies be promoted to counteract global warming. From 1970 to 2011, Adams et al. (2017) analyzed data from 38 African countries to see whether there was a correlation between urbanization and ecological pollution. Despite political factors, they nevertheless discovered a long-term equilibrium between urbanization and resource depletion. To resolve the link between urbanization and biodiversity loss, the research suggested considering the impact of political factors. From 1980 to 2010 Özokcu and Özdemir(2017) compared the environmental issues of developing economies in 52 low-income nations with those of 26 high-income countries. For the first model, they discovered an N-shaped connection with a cubic functional form, while for the second model, they discovered an inverted N-shaped curve. Researchers concluded that a rising economy could not save the planet by itself. The impact of overseas investment, power usage, wealth maximization, and inclusive growth on carbon dioxide emissions in Kuwait was studied by Salahuddin et al. (2015). As revealed by the authors' co-integration analysis, short-term and long-term CO2 emissions are triggered by economic growth, resource utilization, and overseas investment. The report suggested that Kuwait cut down on its emissions by increasing its carbon capture, synthesis, and silos, decreasing domestic power system subsidies, and investing in decarbonizing. From 1971 to 2013, researchers Aye and Edoja (2017) looked at 31 emerging countries and the impact of economic growth on CO_2 emissions. Instead of a U-shaped link between economic expansion and Pollutant emissions, they discovered no EKC. The rise in population and reliance on oil also increased atmospheric carbon output. The study suggested using alternative energy and switching to systems with lower emissions. Based on the stated discussion, the following hypotheses are as follows:

H2: There exists a negative relationship between CO2 emissions and renewable energy demand, such that higher demand for clean and green energy sources leads to lower emissions.

H3: There exists a positive (negative) relationship between CO2 emissions and FDI inflows, consistent with the pollution haven (halo) hypothesis, whereby foreign investment in countries with weaker (higher) environmental regulations leads to higher emissions.

The E7 countries were studied by Tong et al. (2020) to determine the relationship between power use, wealth creation, and air pollution. Research conducted on Turkey, Mexico, Indonesia, and the People's Chinese Republic revealed no evidence of a correlation between rising productivity, rising power usage, and rising carbon emissions. The research concluded that we need to switch to renewable energy sources like wind and solar. Thermal efficiency and industrial growth were analyzed in terms of their impact on air pollution in Pakistan by Khan et al. (2020). CO_2 emissions were shown to be positively correlated with both fuel use and national activities. From 1990 to 2015, Danish et al. (2020) studied the OECD countries' transportation of atmospheric co2 in connection to their growth, analysis, transportation, real income, and other factors. The research concluded that production negatively impacts the environment, whereas population size and real income are positive. The study suggested that OECD countries lessen their carbon impact by switching to more fuel-efficient automobiles.Research into the causes of atmospheric CO_2 emissions has been done several times.In order to determine what aspects of society are responsible for shifts in CO_2 emissions, Rahman et al. (2022) undertook research in Malaysia. The authors analyzed data from 1982 through 2018 using ARDL. Findings suggested that using natural gas and electricity did not affect carbon pollution. Nonetheless, CO_2 emissions were positively impacted by the use of coal and oil and the presence of foreign workers and tourists. It was also concluded that there was an increase in CO_2 emissions at the outset and a subsequent drop as national wealth climbed. From 1990 to 2019, Hafeez et al. (2022) analyzed data from China to determine what variables influence the country's CO_2 emissions from economic activity. The study used the ARDL and NARDL regression methods to examine the information. Long-term CO_2 emissions from either production or use were shown to not correlate with output growth. Although several factors contribute to rising CO_2 output, energy use in the economy stood out as particularly important. The NARDL findings also revealed that economic growth only served to lower spending CO_2 emissions. The findings also revealed that rising CO_2 emissions are tracked by increasing electricity use in the economy. Kwakwa (2022) examined CO_2 emissions in Ghana between 1971 and 2018 to see how economic progress, war expenditure, and other factors affected production. The study used ECM for temporal analysis and co-integration for a longer-term perspective. According to the results, overpopulation, modernization, and warfare, all contributed to higher CO_2 emissions, but public spending was associated with a gradual decline in emissions over time. The data supported the EKC, which posits a U-shaped link between CO_2 emissions and income. The study suggested using sustainable methods to cut down on carbon output. Based on the literature, the study's ext hypothesis is as follows:

H4: There exists a negative (positive) relationship between CO2 emissions and industry value added, consistent with the hypothesis that sustainable (unsustainable) production and consumption practices can lead to lower (higher) emissions.

Human interference due to rising economic activity threatens a clean environment, which is essential to continue economic progress. Alternative sources, enterprises, capital flows, national income, and current population are only some areas that have been the focus of research into their potential roles in CO_2 emissions. Power consumption, ecotourism, and the employment of immigrant labour have contributed to rising CO_2 emissions in the Malaysian economy, which Rahman et al. (2022) investigated. Their findings revealed that although power demand and the employment of overseas labour had no noticeable influence on CO_2 emissions, coal and oil usage did. The research also discovered an initial rise in CO_2 emissions and a subsequent drop as national wealth climbed. The energy sector was determined to be a significant contributor to CO_2 emissions in China's economy from 1990 to 2019, according to an analysis by Hafeez et al. (2022). Despite the lack of a correlation between Income and manufacturing CO_2 emissions over the long run, an increase in income was associated with a decrease in CO_2 emissions from both sources. From 1971 through 2018, Kwakwa (2022) analyzed the effects of manufacturing, advancement, and non-developmental spending, as well as warfare, on Ghana's emissions. CO_2 emissions increased with demographic, modernization, and military while decreasing with expenditure. Evidence from the research was consistent with an EKC, which indicates a U-shaped link between emissions and wealth but in the opposite direction. To lower carbon output, the research suggested eco-friendly technology. Seri and de Juan Fernandez (2022) examined the relationship between income and emissions in twenty-one Latin American countries. According to their findings, national knowledge, technology, and policy were more critical than Affluence in explaining differences in CO_2

emissions across countries. The final hypothesis of the study is as follows:

H5: There exists a positive relationship between CO2 emissions and population density, consistent with the population-led emissions hypothesis, whereby higher population densities lead to higher emissions due to increased energy consumption and transportation demands.

2.1. Contribution of the Study

Based on the given hypotheses and variables, the study has the following contribution of the study, i.e.,

- **Economic Growth Hypothesis**

This research has the potential to add to the current discussion concerning the link between economic development and environmental sustainability by presenting evidence for a U- or N-shaped connection between CO2 emissions and economic growth. Considerable ramifications may result for those tasked with balancing economic development and environmental conservation in light of this finding.

- **Renewable Energy Demand Hypothesis**

This research has the potential to add to the expanding body of literature on renewable energy's ability to cut GHG emissions and slow global warming. The study's findings might emphasize the significance of policies and incentives that encourage the development and use of clean energy sources by demonstrating a negative link between CO2 emissions and demand for renewable energy.

- **FDI Inflows Hypothesis**

Either the pollution haven or pollution halo theory might be supported by the findings of this research, adding to the ongoing discussion regarding the environmental effects of overseas investment. The results might be used to improve environmental regulations and the policies that govern how international corporations operate in host nations.

- **Industry Value Added Hypothesis**

Evidence supporting the link between CO2 emissions and industrial value added might be gathered from this research, which could be a valuable addition to the growing body of literature on environmentally responsible production and consumption. The results might be used to shape policies and procedures that encourage environmentally responsible and sustainable manufacturing.

- **Population Density Hypothesis**

This research has the potential to provide light on the factors that contribute to carbon emissions in highly populated regions and shed light on the link between population density and these emissions. The results help shape urban emission reduction strategies and initiatives, including those prioritizing public transit, green construction practices, and renewable energy.

3. MATERIALS AND METHODS

3.1. Introduction

In this section, the study discuss the methodology used for collecting data, including sample size, data sources, indicators, and their definitions. The study also provides an overview of the estimation technique used for the empirical analysis.

3.2. Sample Data

The analysis is based on time series data collected from Europe and Central Asian economies from 1990 to 2021.

3.3. Data Source

The data ranges from 1990 to 2021 and comes from the World Bank (2022). The effect of population density (POP), renewable energy (RENG), GDP per capita (Y), foreign direct investment (FDI), and industrial value addition (IND) on carbon emissions (CO2) is studied using aggregate data for Europe and Central Asia.

3.4. Theoretical Foundations

3.4.1. Green Inverted-N Growth Hypothesis

According to this view, economic development and environmental protection may coexist if we adopt measures to foster a green economy. In particular, it suggests that the correlation between economic development and greenhouse gas emissions follows an inverted-N pattern, with emissions rising with GDP expansion until a tipping point is reached and then falling further as the economy shifts to a greener, more sustainable model. The hypothesis proposes that investments in renewable energy, green infrastructure, sustainable manufacturing techniques, and eco-friendly policies might ease this shift. It also hints at the potential for these investments to have beneficial knock-on impacts in other areas of the economy, such as employment growth, innovation, and competitiveness. Overall, the green inverted-N growth hypothesis serves as a framework for academics and policymakers to examine the dynamics of green growth and the tensions between economic progress and environmental safeguards.

3.5. Econometric Framework

The goal of the empirical approach is to identify the factors that contribute to CO2 emissions. The study develops the following model for time series data for empirical research:

$$CO2_t = \beta_0 + \beta_1 FDI_t + \beta_2 IND_t + \beta_3 POP_t + \beta_4 RENG_t + \beta_5 Y_t + \beta_6 Y^2_t + \beta_7 Y^3_t + \mu_t \quad (1)$$

For a more in-depth look at how these variables interact over time, we use the ARDL estimate strategy and the following model version.

$$\Delta CO2_t = a_0 + \sum_{i=1}^{l} b\Delta CO2_{t-i} + \sum_{i=1}^{l} c\Delta Y_{t-i} + \sum_{i=1}^{l} d\Delta FDI_{t-i} + \sum_{i=1}^{l} e\Delta IND_{t-i} + \sum_{i=1}^{l} f\Delta RENG_{t-i} + \sum_{i=1}^{l} g\Delta Y2_{t-i} + \sum_{i=1}^{l} h\Delta Y3_{t-I}$$
$$+\sum_{i=1}^{l} i\Delta POP_{t-I} + \beta_1 CO2_{t-1} + \beta_2 Y_{t-1} + \beta_3 FDI_{t-1} + \beta_4 IND_{t-1} + \beta_5 RENG_{t-1} + \beta_6 Y2_{t-1} + \beta_7 Y3_{t-1} + \beta_8 POP_{t-1} + E_t \quad (2)$$

Where Δ denotes the first difference operators.

In order to determine the presence of a long-term relationship, an F-test, also referred to as ARDL-Bounds testing (Pesaran et al., 2001), is conducted using equation (2) and the null hypothesis. The stationarity of the variables at the first difference is irrelevant for this F-test. If the calculated F-value exceeds the upper limit, the null hypothesis is rejected, and a long-run relationship is concluded. On the other hand, if the F-value is less than the smaller of the two critical values, the null hypothesis is accepted, and no relationship exists between the variables. It is important to note that there is no interdependence among the variables. While the error correction term (ECT) determines the long-run connection, the ECT model helps assess the short-run model coefficient. The equation is as follows:

$$\Delta CO2_t = \partial_0 + \sum_{i=1}^{l}\partial_{1i}\Delta CO2_{t-i} + \sum_{i=1}^{l}\partial_{2i}\Delta Y_{t-i} + \sum_{i=1}^{l}\partial_{3i}\Delta FDI_{t-i} + \sum_{i=1}^{l}\partial_{4i}\Delta IND_{t-i} + \sum_{i=1}^{l}\partial_{5i}\Delta RENG_{t-i} + \sum_{i=1}^{l}\partial_{6i}\Delta Y2_{t-i} + \sum_{i=1}^{l}\partial_{7i}\Delta Y3_{t-i} +$$
$$+\sum_{i=1}^{l}\Delta\partial POP_{t-1} + \pounds ECT_{t-1} + E_t \quad (3)$$

Where Δ denotes the first difference operators.

4. RESULTS AND DISCUSSION

The study investigates the relationship between CO2 emissions and several independent variables. Table 1 shows the descriptive statistics of the variables. The mean value of CO2 emissions per capita is 7.655 metric tons. Over the period from 1990 to 2021, the minimum and maximum values of CO2 emissions are 6.576 and 9.477 metric tons, respectively. The standard deviation for CO2 emissions is 0.701, based on a sample of 32 observations.

Table 1: Descriptive Statistics

Methods	CO2	FDI	IND	POP	RENG	Y
Mean	7.655	3.379	25.068	32.054	10.088	19996.390
Median	7.600	3.229	24.501	31.806	8.447	20704.030
Maximum	9.477	8.890	30.224	33.631	19.006	24298.910
Minimum	6.576	1.1946	22.865	30.742	5.706	15659.940
Std. Dev.	0.701	2.407	2.011	0.897	3.756	2880.040
Skewness	0.750	0.527	1.098	0.454	0.927	-0.204
Kurtosis	3.600	2.740	3.1891	1.876	2.742	1.648

Note: CO2 shows carbon emissions, FDI shows foreign direct investment, IND shows industry value added, POP shows population density, RENG shows renewable energy generation, and Y shows income.

On average, 32,054 people live every square kilometre in Europe and Central Asia. Over this same period, the lowest population density was recorded at 30.742/square km, while the highest was at 33.631/square km. The standard deviation for population density is 0.897. The average value-added in Europe and Central Asia's industrial sectors is 25.086. Throughout the period covered by the data, the greatest value created by the industry was 30.224%, and the lowest was 20.742%. For the same set of 32 data, the standard deviation of industries' value added is 2.011%. Ten percent of the energy used in cities comes from renewable sources. For the same time frame, the highest and lowest percentages of renewable energy were 19.00% and 5.706%, respectively. The standard deviation of renewable energy is 3.755%. In terms of GDP, the typical person in the country has a total of $2,996.39 in their bank account. During this period, the GDP per capita peaked at $24299.91 and bottomed out at $15659.94. The GDP per capita standard deviation is $2,880.04. Between 1990 and 2021, Europe and Central Asia will get around 3.379% of incoming Investment. FDI inflows peaked at 8.890% and bottomed at -1.194% throughout the same period, suggesting a general upward trend. According to data from 32 cases, the standard deviation of FDI inflows is 2.407%. The average GDP per capita squared is 4.08%. During that period, the square of GDP per capita peaked at 5.90% and dropped to 2.451 %. A statistical analysis of 32 data yields a standard deviation of 1.141% for the square of GDP per capita. There is an average 8.470% increase in cubic GDP per capita. The GDP per capita cube peaked at 13.431% and bottomed at 3.84% throughout the same period. The standard deviation of the cube of GDP per capita is 3.410%. The correlation matrix is shown in Table 2.

Table 2: Correlation Matrix

Variables	CO2	FDI	IND	POP	RENG	Y
CO2	1					
FDI	-0.226 (-1.272) [0.213]	1 ----- -----				
IND	0.812 (7.644) [0.000]	-0.309 (-1.784) [0.084]	1 ----- -----			
POP	-0.656 (-4.767) [0.000]	-0.029 (-0.161) [0.872]	-0.808 (-7.519) [0.000]	1 ----- -----		
RENG	-0.550 (-3.613) [0.001]	-0.133 (-0.737) [0.466]	-0.726 (-5.797) [0.000]	0.979 (26.930) [0.000]	1.000 ----- -----	
Y	-0.640 (-4.566) [0.000]	0.220 (1.239) [0.224]	-0.881 (-10.22) [0.000]	0.932 (14.120) [0.000]	0.877 (9.998) [0.000]	1 ----- -----
Y2	-0.630 (-4.452) [0.000]	0.185 (1.036) [0.308]	-0.862 (-9.345) [0.000]	0.945 (15.868) [0.000]	0.896 (11.063) [0.000]	0.998 (97.746) [0.000]
Y3	-0.619 (-4.325) [0.000]	0.150 (0.832) [0.411]	-0.841 (-8.536) [0.000]	0.955 (17.686) [0.000]	0.912 (12.248) [0.000]	0.993 (48.624) [0.000]

Note: small bracket shows t-value while large bracket shows probability value.

According to the data, a positive relationship exists between carbon emissions and the value created by industries (r=0.812). However, FDI (r=-0.226), population density (r=-0.656), RENG (r=-0.550), and economic growth (r=-0.640), as well as their square (r=-0.630) and cubic (r=-0.619) transformations, all exhibit a negative connection with CO2 emissions. Population density, RENG, income, the square of income, and the cubic of income are all negatively correlated with the value contributed by industries. In addition, the level, square, and cubic forms of economic growth are all positively correlated with the demand for renewable energy, suggesting that higher demand for renewable energy is connected with better economic growth. Based on these results, it is plausible that carbon emissions could be reduced by enacting laws that boost the use of renewable energy, encourages sustainable economic development, lower population density, and put constraints on the value provided by industries. The estimated unit roots are shown in Table 3.

Table 3: Unit Root Test Estimates

Variables	Level	First Difference	Decision
CO2	-1.507	-2.292**	I(I)
FDI	-2.371	-5.314*	I(I)
IND	-1.222	-7.587*	I(I)
POP	-3.693**	-1.301	I(0)
RENG	-1.925	-3.799**	I(I)
Y	-2.437	-5.646*	I(I)
Y^2	-3.172	-6.100*	I(I)
Y^3	-3.724**	-6.498*	I(0)

Note:* and ** denotes 1% and 5% level of significance respectively.

The outcomes of the stationary test utilizing the ADF test are shown in Table 3. According to the test, population density and the cubic transformation of GDP are both confirmed to be stable at their starting levels, with no discernible long-term trend. Although some variables seem to follow a random walk with drift, evidence of stationarity appears only after the data has been differentiated once. The validity of future time series analysis and policy consequences relies heavily on these discoveries. Testing estimates for ARDL-Bounds are shown in Table 4.

Table 4: ARDL-Bounds Testing Estimates

Estimation model	**CO2 = f (FDI, IND,POP, RENG, Y ,Y^2 ,Y^3)**
Lag order	(1, 0, 0, 0, 0, 0, 1, 0)
Test statistics	Value
F-statistics	9.305

Source: Author's estimate.

The results of a bound test were done on the ARDL model to check for the presence of a long-run relationship. All of the independent variables, including FDI, IND, POP, RENG, Y, Y2, and Y3, have calculated F-statistic values that are more than the upper critical limit value of 3.9 at the 1% significance level, indicating a statistically significant long-term connection with the dependent variable CO2. These results suggest that the impacts of the independent factors on CO2 are likely to be long-lasting and have significant policy consequences. Prices for the diagnostic tests are shown in Table 5.

Table 5: Diagnostic Test Estimates

R^2	0.941
Adj. R^2	0.916
DW	1.646
Jarque–Bera normality test	0.870 (0.646)
Breusch–Godfrey serial correlation LM test	2.366 (0.120)
Heteroskedasticity test: White test	0.804 (0.617)
Ramsey's RESET test for the functional form	1.059 (0.302)

Note: Parenthesis values are the probability value.

The outcomes of the ARDL model's diagnostic tests are shown in Table 5. The model fits the data well, as shown by the high R-squared value of 94%, and the modified R-squared value verifies this with no loss of degrees of freedom. According to the Jarque-Bera normality test results, this model is regularly distributed. According to the LM test, no serial correlation exists between the variables in question. The diagnostic test results show that the ARDL model is robust for analyzing the correlations between CO2 and the other variables (FDI, IND, POP, RENG, Y, Y2, and Y3). The ARDL interim and final projections are shown in Table 6.

Table 6: ARDL Estimates

Variables	**Coefficient**	**Std. Error**	**t-statistic**	**Probability**
Long-run Estimates				
FDI	-0.043	0.033	-1.301	0.207
IND	0.347	0.154	2.252	0.035
POP	-4.055	1.005	-4.034	0.000
RENG	0.926	0.240	3.855	0.000
Y	-0.024	0.008	-2.859	0.009
Y^2	1.321	4.221	3.123	0.005
Y^3	-2.331	6.971	-3.346	0.003
C	265.042	83.402	3.177	0.004
Short-run Estimates				
D(Y^2)	8.391	7.791	10.769	0.000
CO2(-1)	0.368	0.194	1.894	0.072

Variables	Coefficient	Std. Error	t-statistic	Probability
FDI	-0.027	0.023	-1.192	0.246
IND	0.219	0.101	2.174	0.041
POP	-2.562	0.713	-3.592	0.001
RENG	0.585	0.100	5.814	0.000
Y	-0.015	0.006	-2.319	0.030
Y^2	8.391	3.301	2.545	0.018
Y^3	-5.741	2.191	-2.619	0.016
ECT_{t-1}	-0.631	0.058	-10.754	0.000

Note: CO2 shows carbon emissions, FDI shows foreign direct investment, IND shows industry value added, POP shows population density, RENG shows renewable energy generation, and Y shows income.

Table 6 displays the estimated model's short- and long-term outcomes. Population density negatively influences carbon emissions, statistically significant at the 1% level. Hence, a long-term reduction in CO2 emissions of 4.055 metric tonnes per person results from a one-unit rise in population density. This finding is consistent with the theory that, as a nation develops, its citizens become more conscious of the dangers posed by CO2 emissions and take steps to safeguard the environment, such as cutting down on their energy use, as a response. Table 6's findings have economic ramifications that imply strategies to promote population density sustainably may aid in the long-term reduction of carbon emissions. The carbon footprint of cities may be reduced by government support for sustainable urbanization laws that promote the growth of compact, energy-efficient communities with well-planned public transit networks, green areas, and access to basic amenities (Nasr et al. 2023). By incentivizing individuals to live more sustainably, these policies can improve people's quality of life, boost economic growth, and reduce carbon emissions (raihan et al. 2023). Similarly, the data suggests encouraging clean energy sources like renewable energy and decreasing the economy's reliance on companies that produce large amounts of carbon emissions. This is a means for governments to promote sustainable development while reducing the negative impacts of climate change. In sum, the results stress the need for a more all-encompassing strategy for sustainable development that considers the interconnected nature of economic development, environmental security, and social progress. Sustainable development policies can improve economic growth, environmental quality, and social well-being, all while lowering national emissions (Bondarenko et al. 2023).

At the 5% level of significance, the coefficient of industries is likewise significant, suggesting that a one-unit shift in industries leads to a 0.347 metric tonne increase in CO2 emissions per capita in the long term. This finding agrees with prior research that linked industrialization to higher CO2 emissions. There are substantial economic ramifications stemming from companies' beneficial impact on CO2 emissions, especially for emerging nations looking to industrialize and expand their economies. The leaders of these nations must strike a delicate balance between economic progress and environmental protection if they want to achieve sustainable development. Governments should create laws and regulations that encourage green and sustainable industries to lessen the adverse effects of industrialization on the environment and reduce carbon emissions (Fang, 2023). Politicians would look at less carbon-intensive and more ecologically friendly ways to boost the economy, such as encouraging the service industry (Ulucak & Baloch, 2023).

Regarding CO2 emissions, FDI does not make a difference in the long or short term. Nevertheless, other research has indicated that FDI may help reduce carbon emissions and increase energy efficiency over time if green technology is used. In this case, the investment technology may already be clean and based on green technology, which might explain why the FDI coefficient was not statistically significant. This finding has substantial repercussions for the economy, politicians, and corporations. Countries that depend significantly on FDI for economic development may need to find other ways to reduce carbon emissions, such as encouraging renewable energy sources and enacting more efficient energy legislation. Companies that invest internationally may need to think about the environmental rules and practices of those nations to which they contribute (Olaoye & Sornarajah, 2023). In order to do this, they may, for example, calculate the carbon emissions caused by their investments and actively search for ways to put their money into renewable energy (Lin et al. 2023). Overall, the findings of this research show that FDI has little to no influence on CO2 emissions, suggesting that other variables, such as population density and industrialization, need greater scrutiny.

There is a negative and a positive long-term association between per capita income and CO2 emissions, whereas the squared and cubic variables indicate a negative and a neutral correlation. At the 1% significance level, the coefficients point to an inverted N-shaped EKC connection. So, there is a threshold income over which the quality of the environment improves with further economic growth. Consequences for the economy may be substantial due to the inverted N-shaped EKC connection revealed in the research. Developing nations often see an initial rise in carbon dioxide emissions due to industrialization, and increased energy consumption as per capita wealth rises (Ray et al. 2023). Nevertheless, if the standard of living rises over a certain point, the public and the government become more aware of the harmful impacts of CO2 emissions, prompting more spending on green technologies, energy efficiency measures, and environmental legislation. Carbon emissions may fall as a result of this, despite the rising wealth (Wang et al. 2023). This research hints at the potential success of programmes that seek to boost economic development while minimizing environmental deterioration. It is worth noting, nevertheless, that different nations may have different economic, social, and environmental thresholds at which environmental quality begins to improve.

Both the long- and short-term CO2 emissions are favourably affected by the coefficient of renewable energy. Most studies have shown that renewable energy is critical in lowering emissions; therefore, this finding goes against that trend (Dogan et al. 2023). The research could have missed the mark since it needed to consider the availability of advanced, low-cost renewable energy generation methods that would help eliminate the discrepancy. This finding might be explained by the fact that renewable energy sources still need to be competitive with conventional, nonrenewable ones (Mohideen et al. 2023). High upfront investment costs for renewable energy infrastructure, the lesser energy efficiency of renewable sources, and a lack of government incentives and subsidies are all to blame (Sun et al. 2023). Another explanation might be that different kinds of renewable energy sources should have been considered in the research, which could affect CO2 emissions. A rise in CO2 emissions could result from a country's reliance on hydropower, which necessitates the building of big dams and can have substantial environmental repercussions (Kulat et al. 2023).

Finally, the error correction coefficient is statistically negative, meaning that the system corrects for imbalance at a rate of 63% every year. This indicates that the variables rapidly recover to long-term equilibrium values following a shock.

5. CONCLUSIONS

Insights are provided into the interplay between CO2 emissions and critical economic and social factors throughout Europe and Central Asia from 1990 to 2021. Evidence from this research supports the presence of an inverted N-shaped EKC in which CO2 emissions climb in tandem with increasing per capita income up to a certain threshold when they begin to fall and then increase. The research also discovered a substantial negative link between per capita income and CO2 emissions in both the short and long term, indicating that policies focused on increasing income development may have a good influence on lowering CO2 emissions. The significant adverse effect of renewable energy and industrial value added on CO2 emissions is also highlighted. Expanding these industries must be managed appropriately, and using cleaner energy sources must be bolstered if plans to reduce CO2 emissions are to be successful. Policymakers should consider population density when crafting carbon emission reduction plans, as suggested by the research. Regarding reducing carbon emissions in the area, the study's conclusion that FDI has a negative and small influence suggests that authorities should look at other approaches.

The results of this research have important significance for regional policymakers, especially in creating efficient methods to cut down on CO2 emissions. According to the findings, policymakers should manage the expansion of companies with a large carbon footprint while prioritizing policies that encourage renewable energy and efficient resource use. Decreased CO2 emissions also depend on policies seeking to raise incomes while protecting the environment. Policymakers should also explore steps to lower population density in high-emission regions when promoting sustainable urbanization. Given that FDI has a negative and negligible effect on CO2 emissions, governments should look elsewhere for ways to cut carbon output in the area. Possible actions include strengthening pollution restrictions, encouraging the use of renewable energy, and funding research into emission-cutting innovations. This research has certain caveats, one of which is its limited applicability to areas with differing economic and social situations because of its narrow geographical emphasis. The research also uses secondary data, which might include measurement errors or other forms of bias. Additionally, the study only analyses a small subset of the potential factors that influence carbon emissions; future studies should include more variables. This study lays the groundwork for further investigation into the effects of factors like energy efficiency measures and technological advancement on carbon emissions. To better understand the environmental difficulties in the area, a more critical study of the connection between CO2 emissions and other environmental variables like air pollution or deforestation is needed. Finally, comparing and generalizing the results might be beneficial by expanding the research to include other locations with diverse economic and social situations.

Ethical approval

Not Applicable.

Informed consent

The study was conducted with equal participation by all authors.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

The data is freely available at World Development Indicators published by World Bank (2022) at
https://databank.worldbank.org/source/world-development-indicators

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