Evaluating the Impact of Inward FDI and Economic Growth Upon the Carbon Emissions of South Korea

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Abstract

This study aims to evaluate the impact of inward foreign direct investment (FDI) and economic growth on carbon emissions in South Korea, a nation committed to achieving carbon neutrality by 2050. Given the dual role of inward FDI and economic growth in fostering economic development and potentially increasing carbon emissions, this study explored the complex relationships among these variables. This study uses annual time-series data from 1990 to 2021, including carbon emissions (CO_2) as the dependent variable and GDP, inward FDI, and renewable energy consumption as explanatory variables. An autoregressive distributed lag (ARDL) bounds test was employed to assess the long-term relationships between these variables. The empirical analysis confirms the long-run relationship among FDI, economic growth, renewable energy use, and carbon emissions in South Korea. This finding underscores the necessity of integrating sustainable investment practices and renewable energy solutions to mitigate the environmental impact of economic growth and FDI. Unlike previous studies, this study uniquely combines the effects of FDI, GDP, and renewable energy on carbon emissions within the context of South Korea's ambitious carbon neutrality commitment by 2050. Applying a robust ARDL model provides nuanced insights into the interactions between economic factors and sustainability efforts, offering actionable data to policymakers aiming to balance economic and environmental goals. These results highlight the importance of sustainable policies that balance economic growth and environmental preservation, especially in the context of South Korea's carbon neutrality goals.

Keywords: foreign direct investment; economic growth; carbon neutrality; South Korea

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Introduction

Public decision-makers and analysts have extensively recorded substantial trade transformations and their consequences on host economies, resulting from inbound FDI in many nations. The impact of FDI on natural environmental quality is becoming increasingly important and significant. The environmental implications of FDI can be categorized into several forms. First, there is widespread agreement on the adverse environmental repercussions of FDI. Second, FDI-induced development has been found to have negative consequences. Third, FDI often leads to the relocation of economic operations to areas with less stringent environmental laws. Finally, FDI can also drive innovation in cleaner technologies for pollution control (Wang, Luo, 2020). Globalization has significantly improved development, particularly financial globalization, and has led to an increase in the movement of money across borders, thus boosting the scale and frequency of international commercial transactions (Zameer et al., 2020).

Globalization has provided South Korea with significant opportunities, enabling it to compensate for its limited mineral and energy resources throughout its industrialization. This has led to the establishment of an export-driven economic growth model. Nevertheless, because of this tendency, Korea's industrial output constitutes a much larger proportion of the country's GDP than that of other industrialized nations (Lamb et al., 2021). The industrial sector, which plays a crucial role in driving national economic development, is also a large source of greenhouse gas emissions, and consumes a substantial amount of energy (He et al., 2022). To clarify, the economic prosperity of Korea in recent years has mostly been propelled by businesses that use large amounts of energy. These industries rely heavily on coal as their major source of fuel, resulting in a substantial national carbon footprint (Lee, Woo, 2020). Because FDI offers many advantages, including fostering economic development, building absorptive capacity, increasing exports, and encouraging productivity spillovers, its significance has grown dramatically in recent years. The need for South Korea to take on a greater share of responsibility for the conservation of energy and the reduction of emissions has also been brought about by changes in the country's international position. Korea made a commitment to raise the contributions that national governments are responsible for, including increasing financial investments in renewable energy, implementing stricter environmental policies, and actively participating in international agreements on climate change (Holmes, 2022).

It is predicted that by 2030, greenhouse gas emissions will be 40% lower than they were in 2018, while carbon neutrality is expected to be reached by 2050.[1] The industrial sector in Korea is the primary contributor to the pollution caused by carbon emissions. To achieve zero carbon emissions and sustainable development in a short amount of time, decisive action should be taken to complete the energy transformation (Oh et al., 2021). In 2020, Korea successfully reduced its greenhouse gas emissions by 7.3% compared to the previous year, resulting in a total of approximately 648.6 million tons. This marked the second year in a row, in which Korea successfully reduced its emissions. Additionally, the per capita emissions declined by 7.4% to 12.5 tons. According to the Greenhouse Gas Inventory and Research Centre, the manufacturing sector has achieved a year-on-year reduction of 7.8% and 7.1% in greenhouse gas emissions, respectively (Wang et al., 2023). The increased use of liquefied natural gas (LNG), nuclear power, and solar electricity has resulted in a reduction in the proportion of coal-fired power output from 43% to 39% as of 2020.[2]

The Korean electricity industry has achieved an unprecedented reduction in emissions intensity because of this transition. Nevertheless, the percentage of fossil fuels remains significant at 67%. Although it has seen double-digit growth over the last five years, the market share of the renewable energy sector is still just 6%. This is much lower than the market shares of the European Union, Japan, and the United States (Choo et al., 2024). Most countries have tried to reduce fossil fuel dependency by supporting the transition to clean energy (Kartal et al., 2023, 2024). Overall, Korea has experienced a decline in greenhouse gas emissions. However, the nation must continue to make significant efforts across all areas, particularly in the industrial sector, to achieve its emission-reduction targets. On the other hand, there is a limited amount of research currently accessible on the association between globalization and environmentally friendly economic growth on an industrial scale for the manufacturing sector in Korea. Different factors are responsible for the variations in the progress made toward being carbon-neutral. Among these are varying patterns of energy consumption. They also touch on energy source interchangeability. One factor is the differing degrees of strictness of the environmental rules.

The manufacturing industry in Korea has unique characteristics. These characteristics are attributed to differences in the reliance upon foreign direct investment (FDI) or international trade. The outcome is a varied and complex industrial landscape. Thus, policy suggestions derived from macro-level factors such as nations or sectors may have certain deficiencies.

Research gaps exist regarding the specific association between globalization, inbound FDI, and environmentally friendly growth in Korea's manufacturing sector. While many studies have discussed macro-level influ-

[1] https://www.opm.go.kr/en/policies/carbon-neutrality-scenarios.do, accessed 14.03.2025.

[2] https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea, accessed 14.03.2025.

ences, there is a lack of investigation into sector-specific dynamics, particularly regarding energy source interchangeability and environmental policy strictness. This study addresses these gaps by examining how inbound FDI and economic development influence carbon emissions in Korea's manufacturing industry. Focusing on this underexplored area, this study aims to provide targeted policy recommendations to guide sustainable industrial practices.

The following sections include an extensive review of the literature, an explanation of the data and methodology used, a discussion of the results, and finally, our conclusions.

Literature Review

Developing countries are aiming to become technologically advanced and achieve rapid industrialization (Aysan et al., 2020; Kayani 2021). FDI enhances domestic competitiveness and stimulates technical innovation among local firms, resulting in improved carbon emission efficiency and reduced environmental pollution. (Aysan et al., 2020; Kayani 2021). For developing nations, the transfer of sophisticated technology and expertise via inbound FDI has a positive impact on both the upstream and downstream sectors, leading to higher labor productivity and ultimately sustainable development (Negash et al., 2020). FDI can be considered one of the major driving forces behind GDP growth, and it also acts as a means of transferring the latest technologies to the host countries (Kayani, Sadiq, 2022; Kayani et al., 2024). Conversely, industrial operations situated at the lower end of the global value chain not only produce limited amounts of additional value but also have a more substantial negative impact on the environment. The inflow of FDI into an economy may lead to the establishment of polluting companies. This may result in the receiving country experiencing the pollution shelter effect, which in turn harms Gross Total Factor Productivity (GTFP) (Sun et al., 2023).

Several studies have examined the positive effects of FDI on promoting sustainable and environmentally friendly economic development, but have also investigated its influence on greenhouse gases, carbon emission efficiency, the destruction of the environment, and contaminants in the air. For example, Apergis et al. (2020) contend that green technology, trade, and FDI are the main factors responsible for the reduction of carbon emissions, based on panel data collected from 30 OECD nations from 1996 to 2013. FDI allows recipient nations to incorporate and develop cutting-edge technology as part of their local industrial procedures. FDI often leads to a rise in pollution in emerging nations, while simultaneously decreasing pollution levels in affluent nations (Xie et al., 2020). Nur Mozahid et al. (2022) examine the connection between FDI and emissions resulting from energy consumption in developing nations. The findings suggest a bilateral correlation between FDI and emissions resulting from energy use; however, this link is seen only in seven specific nations. Furthermore, a cause-and-effect relationship exists between the emissions resulting from energy usage and FDI. By contrast, FDI led to pollution across nine different countries.

Similarly, De Vita et al. (2021) argued that inbound FDI has the potential to introduce sophisticated technology and new products that may lower energy intensity and replace energy-intensive commodities with energy-efficient alternatives. This, in turn, can lead to a decrease in environmental pollution in the United States. More trade openness may lessen the increase in carbon emissions for ASEAN-5 countries, particularly in low- and high-emission countries, as shown by Guzel and Okumus (2020). FDI has a negative effect on carbon emissions. Khan et al. (2022) demonstrate that carbon emissions are positively influenced by economic policy uncertainty (EPU), commerce, and GDP. FDI inflows and sustainable energy enhance the environmental conditions of East Asian economies including China, Korea, and Singapore. However, several studies suggest no substantial correlation between inbound FDI and carbon emissions. For example, Cai et al. (2021) employed a simultaneous equation framework to analyze the influence of FDI on air pollution. They divided this impact into three components: size, composition, and method effects. These findings indicate that the impact of FDI on air pollution in Korea is not statistically significant. This is because the technique effect, which mitigates the negative effects of FDI, counterbalances the additional pollution resulting from the magnitude and composition of FDI.

Musa et al. (2024) examined the co-integration link between FDI, economic development, industrial framework, sustainable and nuclear resources, urbanization, and Korean greenhouse gas emissions by employing the ARDL limits test. The findings show that FDI inflows result in an increase in greenhouse gas emissions, but the impact is minimal. Economic development has resulted in an increase in greenhouse gas emissions in the near term, but the use of renewable and nuclear energy tends to result in a reduction of greenhouse gas emissions. Both FDI and urban expansion have very little influence on the increase in greenhouse gas emissions. Habiba et al. (2021) suggest that FDI directly impacts economic development, however, it was not associated with an increase in carbon emissions in the G20 nations between 1971 and 2009. According to Cai et al. (2021), FDI has a favorable impact on carbon dioxide (CO2) emissions over a prolonged period. Nevertheless, the magnitude of the favorable impact diminishes as income rises. Wang et al. (2023) analyzed a sample of around 20 developing countries and observed a noteworthy decline in energy intensity that coincided with an increase in FDI. This decline may be attributed to the use of modern technology combined with FDI, which marks a substantial shift from the outdated technologies used in other countries. This change has led to a decrease in ecologically detrimental emissions.

Recently, considerable debate has revolved around the relationship between FDI and environmental degrada-

tion. Hussain and Rehman (2021) examined the impact of foreign investments on greenhouse gas emissions. They propose several aspects and an intricate connection between FDI and CO2 emissions. Bhasin and Garg (2020) provided valuable insights into the impact of FDI on environmental conditions in emerging nations. Tang and Tan (2015) conducted a study that showcased the use of Granger causality analysis to examine the relationship between FDI and CO2 emissions. Nur Mozahid et al. (2022) looked at the effect that FDI has on CO2 pollution in nations that are oil exporters. Their study specifically focused on calculating emissions based on territory, rather than consumption. Their research suggested that FDI has the potential to reduce emissions when accompanied by suitable environmental measures. Ullah et al. (2022) showed that FDI in some industries has resulted in a significant increase in CO2 emissions. Nadeem et al. (2020) examined the impact of FDI on environmental degradation indicators, focusing specifically on CO2 emissions. Their research revealed that FDI had an initial detrimental impact on the environment. FDI has a beneficial impact on the improvement of environmental conditions through the expansion and development of the host nation's economy.

Naseem et al. (2021) explored whether there was a correlation between the BRIC countries' progress in terms of their economic growth and the degradation of the natural environment. This study found a direct relationship between higher levels of FDI and improved environmental standards, even in cases where economic growth initially leads to greater pollution levels, including CO2 emissions. This trend may be attributed to the use of more environmentally friendly technologies. Udemba and Keleș (2022) primarily focus on the impact of FDI on environmental conditions, with a particular emphasis on Turkey. After conducting the research, it was discovered that FDI had a negative impact on the environment in the short term but a positive impact in the long run. This indicates a period of transition in which there was a rapid rise in industrialization, resulting in an initial growth in emissions, followed by gradual improvements. The importance of sustainability and the environment cannot be ignored.

Several studies have been conducted on the potential correlation between pollution, economic development, and trade integration owing to the interconnectedness of countries in economic activities and commerce. In 1995, Holtz-Eakin and Selden performed a fundamental investigation into the correlation between the Carbon Index and its influence on economic advancement. The authors developed their hypotheses under the assumption that lowering trade barriers and encouraging economic activity would have an impact on the environment. This study aimed to provide empirical evidence for evaluating the relative magnitude of these three consequences of the implementation of market deregulation in Mexico. Aslam et al. (2022) used the ARDL approach and the Johansen co-integration process to explore the long-term correlation between economic growth and the environment. The findings of this investigation indicate a temporary correlation between company activities and CO2 emissions.

Bekun et al. (2021) used the Kuznets curve paradigm to examine the correlation between GDP and CO2 emissions in E7 countries. The findings suggest that institutional misalignments throughout the energy development process have a detrimental impact on sustainable development in economies. According to these findings, the Kuznets curve hypothesis is correct. Additionally, the research demonstrated that the utilization of alternative sources of energy and the expansion of economic growth led to a reduction in pollution. To evaluate the correlation between FDI and energy use intensity, Cao et al. (2018) conducted research that included a selection of developing nations as participants. The results indicated a notable decline in energy concentration as the level of FDI increased. This decrease may be ascribed to the use of contemporary technology in conjunction with FDI, indicating a significant improvement in comparison with the antiquated technologies that are utilized in other nations. This transformation led to a decrease in the number of ecologically detrimental pollutants.

Research Methodology

Data

The ARDL approach over the period 0f 1990-2021 was employed to investigate the effects of inward foreign direct investment and economic growth on carbon emissions in South Korea. In this study, carbon emissions were used as the dependent variable, and FDI, GDP (economic growth), and renewable energy were used as independent variables. These independent variables were selected because of their significant influence on environmental outcomes. FDI is a critical driver of economic growth and technological transfer, which can either exacerbate or mitigate environmental degradation depending on the nature of the investments (Wang, Luo, 2020). GDP is a direct measure of economic activity and growth and is often associated with increased energy consumption and emissions, highlighting its relevance in analyzing carbon emissions (Zameer et al., 2020). Renewable energy consumption was chosen because of its potential to reduce dependency on fossil fuels, thereby contributing to sustainable energy transitions (Kartal et al., 2024). By examining these variables, this study seeks to uncover the nuanced relationships between economic activities and environmental sustainability. Details of the dependent and independent variables are presented in Table 1.

Methods

This study examined the impact of inward foreign direct investment, and economic growth on carbon emissions. We use the Autoregressive Distributed Lag

Table 1. **List of Variables**

Variables	Symbols	Description & Measurement Scale
Carbon Emissions	CO_2	Metric tons per capita
Foreign Direct Investment	FDI	Foreign Direct Investment, net inflows (% of GDP)
Economic Growth	GDP	GDP growth (annual %)
Renewable Energy Consumption	REW	Renewable Energy Consumption (% of total final energy consumption)

Source: World Development Indicators, 2024 (https://databank.worldbank.org/source/world-development-indicators, accessed 07.03.2025).

Bounds test for the analysis. Furthermore, we used Equation 1 to check the relationships among the variables.

$$CO_2\ emissions = f(FDI, GDP, REW) \quad (1)$$

Representation in regression form,

$$Y\ (CO_{2\ emissions}) = \alpha + \beta_1(FDI) + \beta_2(GDP) + \beta_3(REW) + e, \quad (2)$$

Where, β_1, β_2 & β_3 refer to the coefficients of the respective independent variables, α is the intercept of the regression model, *FDI* represents the foreign direct investment, *GDP* is the gross domestic product growth, *REW* is renewable energy consumption and *e* reflects the residuals.

To check the stationarity of the variables, we employ the ADF test, which is given below in equation 3.

$$\Delta x_t = \varphi x_{t-1} + \Sigma_{i=1}^{m} \delta \Delta x_{t-i} + e_t \quad (3)$$

Where Δ is the difference operator, *t* refers to time, φ is the symbol of the coefficient showing the process root, δ refers to the time trend coefficient, *m* shows the number of lags autoregressive model, and e_t is the random error term.

Empirical Results & Discussion

Descriptive Statistics

Initially, we ran descriptive statistics, and the results are presented in Table 2. The data were normal and did not have any outliers. The mean value of CO2 was 9.93, with a minimum value of 5.77 and a maximum of 12.21. This finding suggests substantial variability in carbon emissions across the years studied, which is indicative of shifts in energy policy and industrial output. Inward FDI exhibited a mean value of 0.85, minimum value of 0.21, and maximum value of 2.15, indicating moderate variability that may be associated with fluctuations in economic openness and foreign investment attractiveness. The GDP growth rate, with a mean value of 4.99 and a standard deviation of 5.12, reflects economic volatility due to global and domestic factors, including economic crises and recoveries. Finally, the mean value of Renewable Energy Consumption (REW) is 1.41, with a range of 0.40 to 3.60, indicating the gradual yet steady integration of renewables into Korea's energy portfolio. The findings underscore the multifaceted trends in the independent variables and their potential ramifications for carbon emissions, reinforcing the significance of this analytical investigation for the formulation of policies and the promotion of sustainable development.

Augmented Dicky Fuller (ADF) Unit Root Test

To check the stationarity of the variables, we applied the augmented Dickey–Fuller (ADF) unit root test proposed by Dickey and Fuller (1979). We find that our variables are stationary at I(0) and I(1). The findings presented in Table 3 reveal that carbon emissions (CO2) and renewable energy consumption (REW) reach a state of stationarity after the implementation of the first differencing, indicating their integration of order one I(1). Conversely, inward FDI and GDP growth are stationary at Level I(0), indicating the absence of a unit root issue at the original level. These findings corroborate the efficacy of the ARDL approach for further analysis, as it can accommodate variables with mixed integration orders. This ensures robust results when analyzing long- and short-term relationships among the variables.

ARDL Bounds Test

The ARDL Bounds Test helps estimate the long-run relationships among the variables of a model. Table 4 presents the results of the ARDL bound test. The F-statistic value of 12.83301 exceeded the upper critical bound values across all significance levels, confirming the presence of co-integration in the model. This indicates a long-term equilibrium relationship between carbon emissions, FDI, GDP, and renewable energy consumption.

Table 2. **Summary Statistics for the Selected Variables**

Var	Mean	Median	Max	Min	StDev
CO_2	9.939809	10.07126	12.21646	5.777465	1.840736
FDI	0.854976	0.779788	2.155979	0.211961	0.494646
GDP	4.993311	4.852400	11.46694	–5.129448	3.565381
REW	1.416129	1.000000	3.6000000	0.400000	0.943786

Source: authors.

Table 3. **ADF Unit Root Test for Stationarity**

Variables	Symbol	ADF (Level)	ADF (1st Difference)
Carbon Emissions	CO_2	Non-Stationary	Stationary
Inward Foreign Direct Investment	FDI	Stationary	N/A
GDP Growth	GDP	Stationary	N/A
Renewable Energy	REW	Non-Stationary	Stationary

Source: authors.

Table 4. **ARDL Bounds Test Results**

Test Statistics	Value	K
F	12.83301	3
Critical Value Bounds		
Significance level	**I(0)**	**I(1)**
10%	2.72	3.77
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

Source: authors.

Table 5. **ARDL Long-Term Estimate Results**

Variables	Coefficient	Standard Error	T-statistics	P-value
FDI	0.783249	0.966417	0.810467	0.4256
GDP	–1.160617	0.514524	–2.255709	0.0335
REW	0.966291	0.606921	1.592121	0.1244

Note: Dependent variable = CO2 & Independent variables = FDI, GDP, and REW.
Source: authors.

The results in Table 4 show that the F-statistic value (12.83301) was higher than the upper critical bound (I(1)) at all significance levels, including 10%, 5%, 2.5%, and 1%. This indicates a strong cointegration relationship among the variables in the model, suggesting that carbon emissions, inward FDI, economic growth (GDP), and renewable energy consumption share a long-term equilibrium relationship. The critical value bounds define the thresholds for determining co-integration, and surpassing the upper bound confirms this relationship. These findings validate the use of the ARDL approach to examine both the short- and long-term dynamics of the model.

ARDL Long-Term Estimates

The long-term ARDL estimates are presented in Table 5. The results indicate that GDP has a significant negative impact on carbon emissions, as evidenced by its coefficient of -1.160617 and p-value of 0.0335, which is below the 5% significance threshold. This suggests that economic growth in South Korea may lead to reduced carbon emissions, potentially due to increased efficiency or a shift toward sustainable practices. Conversely, FDI and renewable energy consumption (REW) do not exhibit statistically significant impacts on carbon emissions in the long run, as their p-values (0.4256 and 0.1244, respectively) exceed the common significance thresholds. The positive coefficient of FDI (0.783249) implies a potential increase in emissions associated with foreign investment, but the lack of significance suggests that the relationship is weak or inconsistent. Similarly, the positive coefficient for REW (0.966291) indicates that renewable energy consumption alone may not be sufficient to significantly reduce carbon emissions, possibly because of its relatively low share in South Korea's energy mix.

These findings illustrate the complex dynamics among economic growth, foreign direct investment, renewable energy, and carbon emissions in South Korea. While GDP appears to play a significant role in reducing emissions, further investigation is needed to understand why FDI and renewable energy consumption lack statistical significance and how their potential contributions can be enhanced in the future.

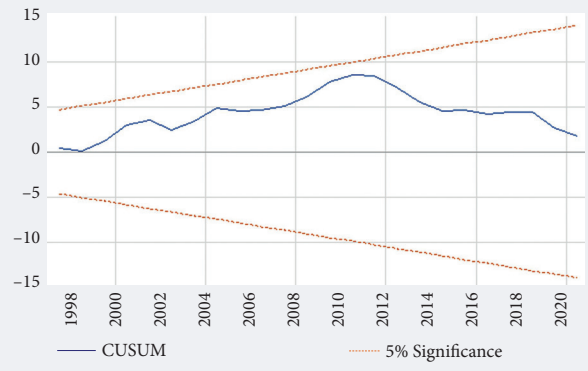
Stability Diagnostic Test

To evaluate the stability of the long-term coefficients, we employed Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMSQ) tests of recursive residuals. Figures 1 and 2 show the results of the tests. Figure 1 demonstrates that the CUSUM statistic remains within the 5% significance bounds throughout the sample period, indicating that the model's coefficients are stable over time. Similarly, Figure 2 shows that the CUSUMSQ statistic also lies within the 5% significance bound, further confirming the stability of the model's parameters. These stability diagnostic tests suggest that the model is robust and reliable for making inferences about the relationships between the variables.

Granger Causality Test

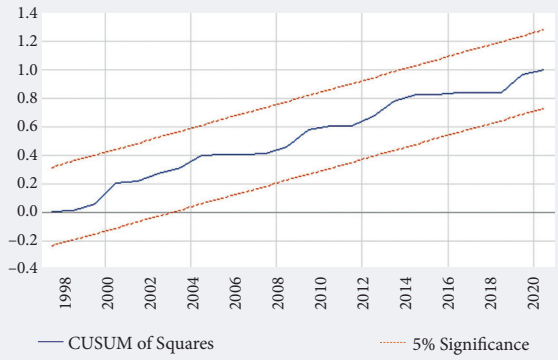
A Granger causality test was conducted to determine the direction of causality between the variables. The results presented in Table 6 reveal that carbon emissions (CO2) unidirectionally impact GDP and renewable energy consumption (REW). Additionally, renewable energy consumption unidirectionally affects GDP, suggesting that the expansion of renewable energy contributes to economic growth. The results indicate that, while FDI does not exhibit causality with any other variable, CO2 and REW demonstrate significant unidirectional causal relationships with GDP. These findings emphasize the importance of controlling renewable energy and carbon emissions when fostering economic growth in South Korea. Further exploration

Figure 1. **Cumulative Sum of Recursive Residuals**



Source: authors.

Figure 2. **Cumulative Sum of Squares of Recursive Residuals**



Source: authors.

of these causal links may offer insights for optimizing environmental and economic policies.

Discussion

The relationship between FDI, economic growth, and environmental quality, particularly carbon emissions, has generated considerable interest and debate among policymakers, economists, and environmental scientists such as (Wang, Luo, 2020; Oh et al., 2021; Holmes, 2022). This study examines this relationship in South Korea's manufacturing sector, where the dual forces of economic growth and FDI interact with South Korea's commitment to carbon neutrality by 2050. This sector, which is essential to the country's economic success, also represents a substantial source of greenhouse gas emissions due to its reliance on coal and other fossil fuels (He et al., 2022). As nations such as South Korea strive to balance economic prosperity with environmental responsibility, understanding the nuanced effects of FDI on carbon emissions is crucial.

The Dual Role of FDI in Economic Development and Environmental Degradation

FDI can significantly influence a host country's economy by promoting industrial competitiveness, advancing technological innovation, and spurring economic growth (Wang, Luo, 2020). However, FDI's environmental impacts are complex, and sometimes contradictory. Although FDI can introduce cleaner technologies, it may also lead to the establishment of carbon-intensive industries, especially if environmental regulations are lax. The results of this study align with previous literature indicating that FDI, when concentrated in high-emission sectors, such as manufacturing, tends to increase greenhouse gas emissions if stringent environmental standards are not enforced (Negash et al., 2020; Kayani, Sadiq, 2022).

The findings underscore the "pollution haven hypothesis," where FDI flows into countries with relatively lenient environmental regulations, potentially increasing emissions and exacerbating environmental degradation (Sun et al., 2023). As South Korea attracts FDI, it simultaneously faces the challenge of managing emissions. This phenomenon suggests the need for policies that promote "green FDI," which involves investment in sectors that prioritize sustainability and environmental responsibility. This approach aligns with the arguments presented by Apergis et al. (2020), who found that environmentally focused FDI can play a crucial role in reducing emissions if regulations incentivize the adoption of clean technologies.

Table 6. **Granger Causality Test Results**

Variables	F-statistics	P-value	Causality
FDI — CO2 CO2 — FDI	0.68218 0.08549	0.4161 0.7722	No No
GDP — CO2 CO2 — GDP	0.22477 19.4141	0.6392 0.0002	No Yes
REW — CO2 CO2 — REW	0.10449 20.4590	0.7490 0.0001	No Yes
GDP — FDI FDI — GDP	2.34815 0.35106	0.1371 0.5584	No No
REW — FDI FDI — REW	0.84662 0.67730	0.3657 0.4177	No No
REW — GDP GDP — REW	4.55710 1.52883	0.0420 0.2269	Yes No

Source: authors

Economic Growth and its Environmental Trade-offs

Economic growth, as seen in South Korea, often results in increased energy consumption and greenhouse gas emissions, particularly in rapidly industrialized nations. Korea's economic model, heavily reliant on its manufacturing sector, has significantly contributed to its carbon footprint because of its dependence on coal (Lee, Woo, 2020). While the initial stages of economic growth typically lead to higher emissions, the Environmental Kuznets Curve (EKC) hypothesis posits that beyond a certain point, economic growth may reduce environmental degradation through increased investments in green technologies and improved energy efficiency (Lamb et al., 2021).

The ARDL bounds test results suggest the potential for Korea's economic growth to decouple from carbon emissions over the long term, contingent upon proactive policy measures. For instance, government interventions promoting renewable energy adoption, energy-efficient technologies, and emission regulations could help reduce the environmental impact of growth (Holmes, 2022). By implementing such measures, South Korea can manage its environmental footprint even as it continues to grow economically. However, as Choo et al. (2024) highlight, although renewable energy represents a promising solution, the share of renewables in Korea's energy mix remains low. Consequently, Korea's transition toward cleaner energy infrastructure requires substantial policy support and investment.

Renewable Energy as an Underutilized Resource

The role of renewable energy is critical for reducing carbon emissions, however, its current usage remains limited in South Korea. The findings reveal that, while renewable energy adoption shows potential, its short-term impact on emissions reduction is statistically insignificant. This is due to the relatively low share of renewables in South Korea's energy portfolio—currently only around 6%—compared to more mature markets such as the EU, Japan, and the US. (Wang et al., 2023). These findings align with those of (Kartal et al., 2023, 2024), who found that the transition from fossil fuels to renewable energy requires robust policy interventions, including subsidies and investment incentives, to achieve meaningful emission reductions.

Despite its slow progress, South Korea has made notable advances in the use of liquefied natural gas (LNG) and solar energy, which have helped reduce the proportion of coal-fired power (Oh et al., 2021). The findings underscore the need for a broader, long-term strategy to significantly boost renewable energy adoption, especially in the manufacturing sector, which remains one of the largest sources of emissions. By integrating renewables into industrial processes, South Korea can reduce its carbon footprint while maintaining its economic competitiveness.

Directional Influence on Economic and Environmental Dynamics

The results of the Granger causality test provide insights into the directionality between carbon emissions, economic growth, and renewable energy consumption. The test reveals unidirectional causality from carbon emissions to GDP growth, suggesting that environmental degradation may drive economic responses such as increased production to compensate for environmental losses. This finding is consistent with research indicating that environmental challenges often prompt economic diversification and innovation (Guzel, Okumus, 2020).

In addition, the causality between renewable energy and GDP highlights the economic growth potential of clean energy sources. As renewable energy adoption increases, so does economic output, supporting the argument that renewable energy is a viable pathway for sustainable economic growth. This finding aligns with studies such as that by De Vita et al. (2021), who argue that clean energy adoption has a compounding effect, reducing emissions while simultaneously boosting GDP. These insights emphasize the need for preemptive and forward-looking policies that mitigate emissions through sustainable growth strategies rather than reactive measures after environmental degradation occurs.

Conclusion

This study examines the long-run relationship between FDI, economic growth, and carbon emissions in South Korea. We employed the most effective ARDL Bounds test for the period ranging from 1990 to 2021. The empirical relationship revealed the existence of a long-run relationship between the variables in our model, and the results are consistent with those of previous empirical studies. Furthermore, we also found that CO2 emissions impacted GDP and renewable energy unidirectionally, and renewable energy affected GDP unidirectionally. The only limitation of this study is that it is restricted to the South Korean economy, and future studies can apply the panel methodology to other East Asian economies. Based on the findings of this study, several policy recommendations have emerged. First, South Korea should enhance regulatory frameworks governing FDI to ensure that incoming investments align with environmental standards. Encouraging FDI in sectors that prioritize sustainability and green technology could help offset the environmental costs associated with industrialization. The government could establish tax breaks, subsidies, or other incentives for foreign companies to invest in clean technologies and low-carbon industries.

Second, South Korea's energy policy must prioritize the development of renewable energy. Increasing the share of renewables beyond the current 6% would significantly contribute to emission reduction, particularly in the manufacturing sector. Policymakers may consider implementing stricter regulations on coal usage while simultaneously increasing investments in solar, wind, and nuclear energy. Such initiatives would contribute to reducing the country's carbon dependency and position Korea as a leader in the global green economy.

Finally, fostering innovation and technological transfer through FDI can reduce emissions. By promoting partnerships between local firms and foreign investors specializing in green technologies, Korea can leverage FDI to achieve sustainable industrialization. These partnerships would facilitate technology transfer, improve carbon efficiency, and support Korea's transition to a low-carbon economy.

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