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Growth Dynamics of Green and Brown Foreign Direct Investment in Central and Eastern Europe: Evidence from ARDL and NARDL Models

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Abstract

This paper examined the effect of green and brown foreign direct investment on economic growth in ten Central and Eastern European countries. It also examines how trade openness, inflation, and consumption of renewable energy determine long and short-term economic performance, and the asymmetric impacts of foreign direct investment composition are also highlighted. The Annual data between 1995 and 2024 was estimated by Autoregressive Distributed Lag (ARDL) and Nonlinear ARDL (NARDL) models to estimate the short-run dynamics and long-run equilibrium relationships. To establish the order of integration, stationarity tests, such as the Augmented Dickey-Fuller and Phillips-Perron, were performed. The analysis of cointegration and asymmetry effects was done to measure the relative contribution of green and brown foreign direct investment to GDP growth. Empirical evidence shows that the impact of green foreign direct investment on the GDP is positive and statistically significant both in the long-term and in the short-term (effective only limited or even negative) in the short-term. Trade openness and the consumption of renewable energy have a positive effect on the growth of the economy, which shows the advantages of entering global markets and producing low-carbon technologies. Inflation negatively impacts the GDP, which proves the significance of macroeconomic stability in investment productivity. The results of the analysis also indicate a cointegration relationship amongst variables in the long run, and the asymmetric tests indicate that positive inflows of green foreign direct investment have stronger growth effects compared to the similar effects of reductions. The paper highlights how green foreign direct investment should be encouraged with strategic significance to support the long-term economic growth of transition economies. The policy measures that promote environment-based investments, trade facilitation strategy, and energy transition strategies have a significant impact on the attainment of low-carbon and inclusive development. The findings suggest that policy frameworks should prioritize environmentally sustainable investment and strengthen renewable energy transitions to achieve long-term economic growth.

Keywords: Green Foreign Direct Investment, Brown Foreign Direct Investment, Economic Growth, Trade Openness, Inflation, Renewable Energy, Central and Eastern Europe

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1. Introduction

In the last thirty years, foreign direct investment has become a key factor of economic change in Central and Eastern Europe. After the demise of centrally planned regimes, the countries in the region undertook extensive structural reforms that were directed towards liberalisation, privatisation, and global economic integration. Foreign direct investment has been a central driver of economic transformation in Central and Eastern Europe following post-socialist transition reforms. This has seen a close relation between economic growth in CEE economies, the magnitude and form of foreign investment. Nonetheless, with the growing tendency in making global investment trends sustainably considerate, the structure of foreign direct investment and not its volume itself has become of paramount concern (Perveez, 2019; Shahabuddin & Ali, 2024; Nguyen et al., 2025; Khalid et al., 2025).

In this paper, we analyse the top ten CEE countries: Poland, the Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Ukraine, Belarus, and Moldova. The similarity between these economies is that they all have historical backgrounds of transition, yet different in terms of institutional quality, European integration, macroeconomic stability and energy structure (Ahmed & Rura, 2024; Letsou et al., 2025; Yeung & Chung, 2025). Others are part of the European Union and are highly absorbed in its regulatory and environmental systems, whereas others are still faced with intricate politics and financial matters. Such heterogeneity offers a useful environment to study the effects of alternative types of foreign investment in economic growth in different structural conditions (Ünsal, 2025; Siddique et al., 2025; Ammar et al., 2025; Ahmed & Hu, 2025).

The empirical literature traditionally considered foreign direct investment to be a homogeneous aggregate variable with implicit assumptions that all types of foreign capital have the same macroeconomic impacts. However, this assumption is refuted by recent trends in sustainable finance and environmental economics. It is possible to divide foreign direct investment into two major groups, i.e., brown, i.e. investment directing at carbon-intensive, resource-extractive, and pollution-generating activities, and green, i.e. investment focusing on renewable energy, clean technologies, sustainable infrastructure, and environmentally friendly production processes (Nasreen et al., 2025; Bukhari et al., 2025; Khalid & Abdul, 2025). Although brown foreign direct investment can lead to short-term output benefits, job creation, and export growth, it can also entrench dependence on fossil fuels and put the host economies at risk on the environment and other regulations. Green foreign direct investment, by contrast, is likely to lead to technological innovation, energy efficiency and structural change in line with long-term sustainable development goals (Willy, 2018; Aman et al., 2025; Kumar & Wu, 2025; Ha, 2026).

This difference between the green and brown foreign direct investment is particularly applicable to the CEE countries. The economies of many areas within the region are rather energy-consuming and traditionally reliant on fossil energy. Meanwhile, investment incentives are changing, as European climate commitments, the changing environmental regulations, and the decarbonization of the world move toward a global trend (Luna & Luna, 2018; Aydin & Degirmenci, 2024; Ditta et al., 2025). The shift to renewable energy and low-carbon production presupposes the large inflows of capital and technological skills, as well as institutional change. Therefore, the issue of whether or not green foreign direct investment is more effective in promoting economic growth, as compared to brown foreign direct investment, and whether or not they produce larger or smaller effects, is an important empirical and policy question (Dornean et al., 2021; Iqbal et al., 2025; Ali et al., 2025; Hanvoravongchai & Paweenawat, 2025).

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The relationship between foreign direct investment and economic growth is theoretically based on endogenous growth models and the theory of foreign direct investment-led growth. Foreign direct investment boosts growth by providing capital deepening, transfer of technology, expertise in management and spillovers of knowledge. These effects are, however, determined by how large their effects are and in what direction, with absorptive capacity, institutional quality, macroeconomic stability, and sectoral distribution of investment. Green foreign direct investment can create positive externalities by spreading a new technology and sustaining renewable energy sources, whereas brown foreign direct investment can have environmental externalities that create long-term economic burdens. Therefore, it is probable that the growth conditions of foreign direct investment would depend on its composition and overall macroeconomic context (Golub et al., 2011; Adejumobi, 2019; Diaz & Weber, 2020; Ali et al., 2025; Bary & Hakim, 2025).

In addition to this, foreign direct investment might not have a symmetric effect on GDP. Green foreign direct investment positive shocks may have more lasting and significant growth impacts than the same negative shocks, which is due to complementarities with innovation systems and renewable energy infrastructure. Equally, growth in brown foreign direct investment can spur short-run growth, and vice versa, growth in brown foreign direct investment can either slacken growth or structural upgrading (Borghesi et al., 2012; Ali et al., 2025). Such nonlinear dynamics will not be reflected in linear econometric frameworks, and thus, complete inference will not be obtained. In this regard, the study will take the Autoregressive Distributed Lag (ARDL) method and an extension of the same, nonlinear (NARDL), where the explanatory variables are broken down into positive and negative partial sums. Such an approach makes it possible to find asymmetric short and long-run implications of green and brown foreign direct investment on economic growth (Mohammadi, 2022; Ali et al., 2025; Georgescu & Kinnunen, 2026).

Besides the foreign direct investment composition, trade openness, inflation and use of renewable energy are also used as control variables. Trade openness is an indication of an opening up to world markets and helps increase access to technology and competitive forces, which can increase spillovers in foreign direct investment. Inflation is a measure of macroeconomic stability; the constant inflationary stress can lead to inefficiency in investments and a poor growth rate. The usage of renewable energy sources reflects the energy transition aspect, which embodies environmental adherence and the modernisation of the structure. The combination of these variables gives the analysis a detailed framework when determining the determinants of growth in CEE economies (Lu & Xing, 2022; Ali et al., 2025; Basuki et al., 2026).

Several global structural disruptions and shocks occurred between 1995 and 2024, including the expansion of the European Union, the worldwide economic downturn, the nation-state debt crisis, the COVID-19 pandemic, and the recent geopolitical conflicts. These happenings played a major role in capital mobility, trade patterns, the energy market, and macroeconomic stability within the region. By implying a long time horizon, the study aims to capture both cyclical and structural changes, which increases the strength and the policy implications of the findings (Oloko, 2022; Kumar et al., 2025; Adjei-Mantey et al., 2026). The major aim of the research is to examine the hypothesis of whether green and brown foreign direct investment have different and asymmetric impacts on GDP in the sampled CEE countries. Precisely, the research aims to:

H1: Green foreign direct investment exerts a positive and statistically significant effect on economic growth

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H2: Brown foreign direct investment exerts a statistically significant effect on economic growth
H3: Trade openness exerts a positive and statistically significant effect on economic growth
H4: Inflation exerts a negative and statistically significant effect on economic growth
H5: Renewable energy consumption exerts a positive and statistically significant effect on economic growth
H6: A long-run equilibrium (cointegration) relationship exists among GDP, green foreign direct investment, brown foreign direct investment, trade openness, inflation, and renewable energy consumption.
H7: The effects of green foreign direct investment and brown foreign direct investment on economic growth are asymmetric in both the short run and the long run.

The research is pertinent to the present discussions on sustainable development and investment policy in the transition economies. With governments in Central and Eastern Europe working hard to ensure the sustainability of economic convergence and, at the same time, meet the changing environmental standards, the strategic orientation of foreign investment becomes more consequential. If the green foreign direct investment proves to have greater and more consistent growth impacts, the policy structures might have to focus on subsidies to clean technologies and renewable energy initiatives and environmentally conscious multinational firms (Nguyen et al., 2025; Khan et al., 2025). In contrast, if brown foreign direct investment remains a major growth-promoting factor, the policy-makers should ensure a sensible trade-off between the economy's short-term benefits and long-term sustainability goals. Overall, the study can be deemed as a thoroughly developed and methodologically sound analysis of the growth implications of foreign direct investment composition in Central and Eastern Europe in the years 1995-2024. It is a new empirical study based on the nonlinear econometric approach and sustainability-focused vision that provides new information on the effects of the quality and the direction of foreign investment in order to understand the economic performance of transition economies. The findings should help to inform both the academic discussion and policy formulation in the environment of a changing global investment context, which is more and more determined by the demands of sustainable development (Nguyen et al., 2025; Aqeel et al., 2025).

The given research contributes greatly to the literature by clearly distinguishing between green and brown foreign direct investment and relating their specific effects on economic growth in Central and Eastern European (CEE) countries. Contrary to the previous studies where foreign direct investment is mostly assumed as a homogenous variable, this study brings out the environmental aspect of foreign direct investment composition, which shows that green foreign direct investment can promote sustainable growth, whereas brown foreign direct investment can suppress it within the short term (Khalil et al., 2025; Nguyen et al., 2025). The study uses both ARDL and Nonlinear ARDL (NARDL) models, which enable it to capture the long-term equilibrium relations as well as the asymmetric short and long-term impacts, which provide a refined picture of the interaction between investment flows and the openness to trade, inflation, and the consumption of renewable energy. This combined strategy bridges key holes in the transition economy discussion to offer useful information to policy makers that wish to advance low-carbon developmental options and develop specific investment and macroeconomic strategies that are consistent with sustainable development objectives.

2. Literature Review

There has been a lot of literature on the nexus of economic growth, foreign direct investment, trade openness, inflation and renewable energy. But the difference between green foreign

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direct investment in environmentally friendly industries and brown foreign direct investment, investments in carbon-intensive industries, has become a key variable in the analysis of the diverse effects of foreign direct investment on macroeconomic and environmental performance. In the case of the Central and Eastern European (CEE) economies that have to balance between industrial modernisation and sustainable development, the analysis of the composition of foreign direct investment offers crucial information on growth patterns and environmental outcomes. The literature review is a synthesis of the main theoretical and empirical evidence on the role played by foreign direct investment composition, trade openness, inflation, and renewable energy in determining GDP dynamics, particularly in transition economies.

2.1. Green and Brown Foreign Direct Investment and Economic Growth

Foreign direct investment has positive effects on economic growth not only by inflow of capital, but also by the transfer of technology, managerial expertise and spillover of knowledge. According to recent research, the environmental orientation of foreign direct investment plays a significant role in determining the growth and sustainability results of foreign direct investment. Green foreign direct investment, which is directed at renewable energy, energy-efficient technologies and sustainable infrastructure, has been found to promote long-term productivity, structural change, and reduced environmental externalities. It is worth mentioning that climate-linked bonds, carbon-credit financing, and sustainable investment funds, among others, are becoming increasingly popular to provide green foreign direct investment, as the post-Paris Agreement environment (Han et al., 2024; Rao et al., 2024; Nasir et al., 2025). By contrast, brown foreign direct investment, focusing mostly on fossil-intensive industries and heavy industry, can potentially have short-term economic rewards but exposes economies to the risk of getting trapped in carbon-intensive transitions, and exacerbates the severity of environmental and regulatory issues (Kumar & Lee, 2020; Anus et al., 2025).

These effects are highlighted by the empirical evidence. Green foreign direct investment has been linked to increased GDP growth as well as increased use of renewable energy, though brown foreign direct investment can increase growth in the short run but at the expense of additional environmental pressures (Ali & Rehman, 2015; Petrova, 2019; Marc et al., 2021; Ivanov & Novak, 2022; Zhang et al., 2021; Aqeel et al., 2025). The divergent effects of green and brown foreign direct investment are particularly relevant to CEE nations, whose industrial structures and energy reliance are based on the legacy, which explains why disaggregation of foreign direct investment in terms of environmental orientation is critical in empirical studies (Nguyen et al., 2025).

2.2. Trade Openness, Foreign Direct Investment, and Technology Transfer

Trade openness is a means of technology and market integration and diffusion of innovation, which may compound the growth impacts of foreign direct investment. The literature has found conflicting mechanisms in which trade and foreign direct investment composition interrelate. The Pollution Haven Hypothesis (PHH) refers to the possibility of trade, as well as foreign direct investment, to stimulate the process of moving pollution-intensive sectors to a jurisdiction with less stringent environmental regulations. The Pollution Halo Hypothesis, on the other hand, posits that foreign investment, foreign green foreign direct investment in particular, not only brings about better technologies and sustainable practices, but also enhances productivity and environmental performance (Gill et al., 2018; Wim & Wendy, 2025). Empirical data of CEE economies suggests that trade openness combined with green foreign direct investment will facilitate the introduction of renewable energy sources and

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efficiency benefits; meanwhile, brown foreign direct investment inflows, despite the high level of trade openness, will support the growth of carbon-intensive industry (Iqbal & Noman, 2025; Hamdi et al., 2026; Huang et al., 2026)

2.3. Inflation and Investment Behaviour

Inflation has a huge effect on investment and economic growth. Long-term investment, especially in renewable energy projects, can result in diminished positive growth impact of green foreign direct investment due to inflation, which is high or volatile. Macroeconomic stability, on the contrary, promotes investor confidence and increases the productivity of both green and brown foreign direct investment inflows. Price stability is vital in transition economies, such as Central and Eastern Europe, to maximise growth and environmental impact of foreign direct investment (Liu & Cai, 2025; Mahbub & Khan, 2026; Yang et al., 2026)

2.4. Renewable Energy, Foreign Direct Investment, and Growth

Utilising renewable energy is a catalyst for both the economy and the environment. The empirical research proves that the greater the adoption of renewable energy, the greater the chances of stimulating an increase in GDP and decreasing the emission of CO_2, which creates a win-win situation in the context of sustainable development (Wei et al., 2022; Sadashiv, 2023; Xuan, 2025). Green foreign direct investment is central to this process, as it funds technology-intensive and low-carbon energy development projects, and brown foreign direct investment offers modest support to renewable energy and continues to maintain dependence on fossil fuels. In the case of CEE countries, where the adoption of renewable energy is not even and is based on policies, the relations between foreign direct investment composition, trade, and inflation play a crucial role in determining sustainable growth directions (Banyen, 2022; Saidi et al., 2026)

2.5. Asymmetric and Nonlinear Effects of Foreign Direct Investment Composition

The effects of green and brown foreign direct investment on GDP will be asymmetric. The positive inflows of green foreign direct investment are likely to produce stronger and enduring growth impacts than the same amount of reduction, and variations in brown foreign direct investment can produce offsetting short- and long-term impacts. Such asymmetric dynamics have then been effectively captured using the Nonlinear Autoregressive Distributed Lag (NARDL) approach (Shin et al., 2014; Tansuchat & Thaicharo, 2025). Furthermore, innovation capacity, technological sophistication, and economic complexity all operate as mediators in the association between foreign direct investment composition and economic growth, and advanced industrial structures can use the advantages of green foreign direct investment to generate long-term productivity increases (Nasir, 2022; Georgescu & Kinnunen, 2026; Sallam & Sadraoui, 2026)

2.6. Research Gaps

Though much has been conducted in the area of foreign direct investment and growth, there are still several gaps. To begin with, there is a paucity of studies that have looked at both green foreign direct investment and brown foreign direct investment in transition economies, and therefore, what is outstanding is their relationship with one another in terms of their contribution to GDP and adoption of renewable energy. Secondly, the majority of empirical studies adopt linear models or single-country designs and thus restrict the analogy of asymmetric and dynamic impacts. Thirdly, the combined effects of trade openness, inflation, and renewable energy in dampening foreign direct investment effects are under-researched. Lastly, the policy changes of recent days, such as EU environmental policies, national energy policies, and various green financing systems, also confirm the importance of situating

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foreign direct investment analysis within modern institutional settings (Wei & Xu, 2020; Smith & Wang, 2021; Wim & Wendy, 2025; Nguyen et al., 2026).

2.7. Contribution of the Study

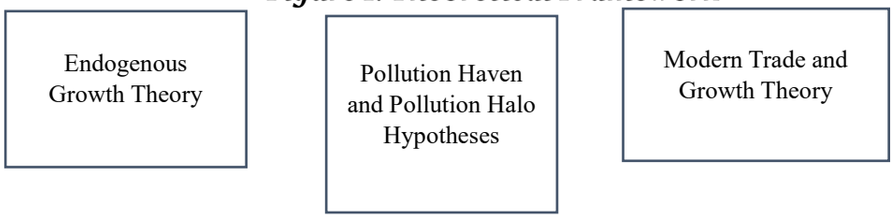
This paper aims to fill the aforementioned gaps by identifying differentiated and asymmetric contributions of the green and brown foreign direct investment on the GDP, by considering the trade openness, inflation, and renewable energy consumption in the given CEE countries. It utilises both ARDL and NARDL models in order to represent both short-term dynamics, long-term relations, and asymmetric effects, providing a holistic view on the interaction of foreign direct investment composition and macroeconomic conditions in contributing to sustainable growth. The results give practical information to policy makers who would like to facilitate green investment, improve trade and macroeconomic stability, as well as support low-carbon economic development in transition economies.

3. Theoretical Framework

The three theories that explain the mechanisms that exist between foreign direct investment composition, macroeconomic conditions and sustainable growth form the basis of this study:

1. Endogenous Growth Theory: The fact that technological innovation and spillovers of knowledge are important in realising long-term economic growth. Green foreign direct investment represents such a solution with the introduction of energy-efficient and low-carbon technologies, increased productivity and structural reform in CEE economies (Romer, 1994; Schilirò, 2019).
2. Pollution Haven and Pollution Halo Hypotheses give an insight into the environmental effects of foreign direct investment. Brown foreign direct investment can shift pollution-intensive industries to countries with weaker regulations (Pollution Haven), and green foreign direct investment can relocate cleaner technologies and sustainable practices (Pollution Halo), so that such foreign direct investment can have an impact on both growth and the environment (Asghari, 2013; Zahdi, 2028; Balsalobre-Lorente et al., 2019; Bashir & Bashir, 2019).
3. Modern Trade and Growth Theory postulates that the openness of trade leads to the transfer of technology, efficient allocation of capital and expansion in a market. Trade openness in conjunction with foreign direct investment would improve growth and would also facilitate the implementation of renewable energy and sustainable investment strategies (Romer, 1994).

Figure 1: Theoretical Framework



All these theories explain the interaction between foreign direct investment composition, trade openness, macroeconomic stability, and renewable energy adoption and their effects on GDP, which forms the basis of the empirical analysis and policy recommendations.

3.1. Conceptual Framework

Green foreign direct investment, brown foreign direct investment, trade openness, inflation, and Renewable Energy affect GDP and have possibly asymmetric short and long-term effects.

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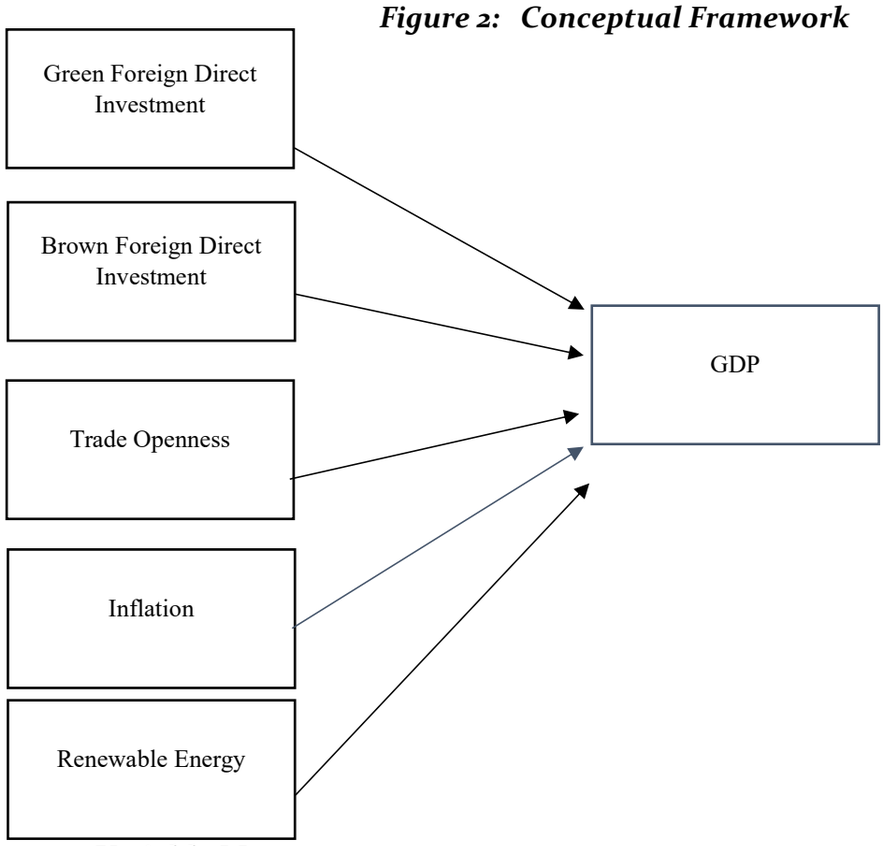
Figure 2: Conceptual Framework



3.2. Variable Measurement

Table 1: *Variable Measurement*

Variable	Type	Measurement	Data Source	Description
GDP	Dependent Variable	Constant 2015 USD (or local currency)	World Bank WDI	Represents economic growth of the country.
Green Foreign Direct Investment	Independent Variable	USD million or % of total Foreign Direct Investment	UNCTAD, OECD, National Statistical Agencies	Foreign Direct Investment inflows directed toward renewable energy, energy-efficient technologies, and environmentally sustainable projects.
Brown Foreign Direct Investment	Independent Variable	USD million or % of total Foreign Direct Investment	UNCTAD, OECD, National Statistical Agencies	Foreign Direct Investment inflows in carbon-intensive sectors, such as fossil fuel energy, heavy industry, and resource extraction.
Trade Openness (TOO)	Independent Variable	(Exports + Imports) / GDP × 100	World Bank WDI	Measures the degree of integration with global trade markets.
Inflation	Independent	Annual % change	World Bank	Captures price stability

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(INF)	Variable	in Consumer Price Index (CPI)	WDI	and macroeconomic conditions.
Renewable Energy (RE)	Independent Variable	% of total energy consumption	IEA, Eurostat	Represents the share of energy derived from renewable sources (solar, wind, hydro, biomass).

3.3. Methodology

3.3.1. Data Collection and Sources

This paper will be based on a group of ten Central and Eastern European (CEE) countries, including Poland, the Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Ukraine, Belarus, and Moldova. The dependent variable and the independent variables of green foreign direct investment, brown foreign direct investment, trade openness, inflation, and renewable energy consumption were taken using annual data between the years 2000 and 2022. The main sources include the World Bank, UNCTAD, OECD, International Energy Agency (IEA), Eurostat, World Development Indicators (WDI) and respective national statistical agencies. All financial values were changed into the constant USD and transformed into the logarithmic form so that there is consistency and comparability. Data analysis, stationarity analysis (ADF and PP), and ARDL/NARDL model estimation were performed with the help of Google Colab, based on Python libraries to work with time series econometrics and provide reproducibility and computational performance.

Table 2: ***Descriptive Summary (Eastern European Countries)***

Statistic	Inflation, consumer prices (annual %)_log	Trade (% of GDP)_log	Renewable energy consumption (% of total final energy consumption)_log	CO2 emission per capita_log	Brown foreign direct investment_log	Green Foreign Direct Investment_log	GDP (current US$)_log
Count	143.000000	150.000000	150.000000	150.000000	101.000000	150.000000	150.000000
Mean	2.405972	4.590385	2.064550	1.132089	1.926824	1.753372	3.191742
Std	1.232843	0.263430	0.868356	1.810324	1.218247	1.599233	0.056789
Min	-0.564353	3.882003	-0.105361	-3.564893	-0.838650	-2.696652	3.038837
25%	1.637620	4.452470	1.520212	1.042439	0.951970	1.639609	3.152645
50%	2.269673	4.599722	2.008192	1.430197	1.757119	1.908131	3.204840
75%	2.902281	4.822007	2.881992	2.288263	3.027258	2.880438	3.232418
Max	6.964489	5.062432	3.261935	3.983361	3.764154	3.803489	3.283545

The descriptive data of the Eastern European countries show that there is a moderate inflation value and the extent of trade openness in countries, with the average inflation representing 2.41% and the trade integration that indicates constant involvement in international markets. There is a comparatively low level of renewable energy intake, though the levels vary among nations, and the amount of carbon emission on an individual level indicates that there are still

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environmental issues. The average of brown foreign direct investment is a little bigger than that of green foreign direct investment, indicating that the reliance on carbon-intensive industries is still present in spite of the increase in green investments. On the whole, these economies represent a period of transition, which is characterised by an improvement of both the traditional industrial activity and the emphasis on sustainable growth.

Table 3: ***Descriptive Summary (Central European Countries)***

Statistic	Inflation, consumer prices (annual %)	Trade (% of GDP)	Renewable energy consumption (% of total final energy consumption)	Brown Foreign Direct Investment	Green Foreign Direct Investment	GDP (current US$)
Count	150.000000	150.000000	150.000000	88.000000	140.000000	150.000000
Mean	1.493636	4.687681	2.460731	1.963016	2.477131	3.274000
Std	0.885122	0.390845	0.491109	1.185442	0.977174	0.034980
Min	-2.072473	3.775198	0.152721	-1.343589	-2.125338	3.207893
25%	1.065936	4.382996	2.094932	0.969902	1.731145	3.246577
50%	1.517530	4.713312	2.521713	1.937007	2.709615	3.274394
75%	2.136801	5.053974	2.875370	3.138568	3.224535	3.298354
Max	3.377774	5.323285	3.194583	3.648747	4.508736	3.351489

The dataset's summary statistics offer crucial information about the environmental and economic progress of the countries being studied. The average registered GDP is 3.27, which is a relatively steady economic size for the sample. The rates of inflation are moderate, and the average consumer price changes are estimated as 1.49 per annum, yet deflationary pressure in some countries is depicted by the lowest value of -2.07. The average of brown foreign direct investment, which is the investment in carbon-intensive industries, is 1.96, implying that the traditional industries have a significant representation, whereas green foreign direct investment, which is the investment in environmentally friendly investments, has a mean value of 2.48, indicating the increasing trend of emphasis on green projects. The use of renewable energy is at an average of 2.46, meaning that there is moderate use of green energy. The level of trade openness is quite high, and the mean is 4.69, which highlights the process of the integration of the region into the global markets. On the whole, these numbers represent a shift in the economic environment between traditional industrial operations and new sustainable development projects.

3.4. Data Reliability

A normality test was performed on the dataset, and a logarithmic transformation was applied to the variables to reduce skewness and improve the distribution of the data.

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Figure 3: Box-plot of the Eastern European Countries

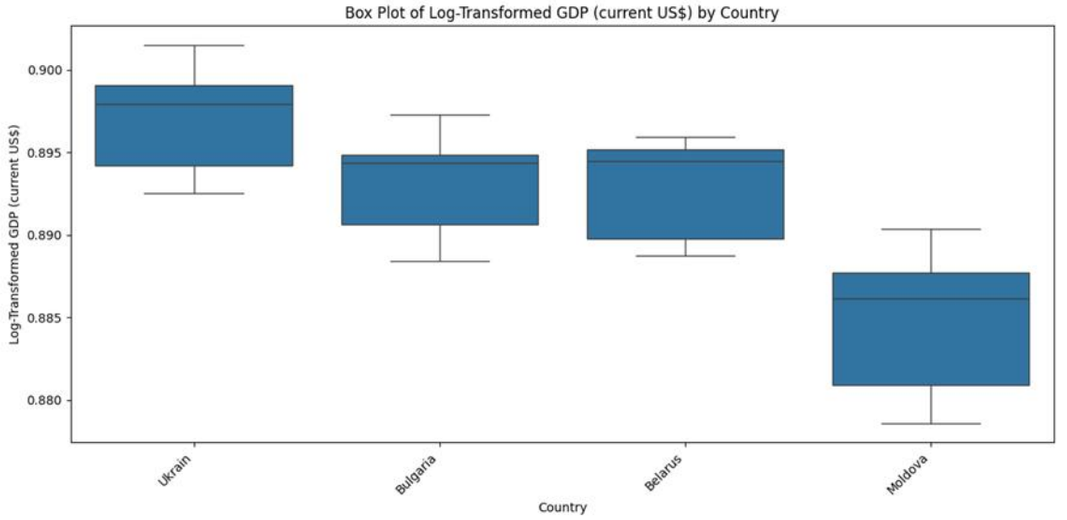
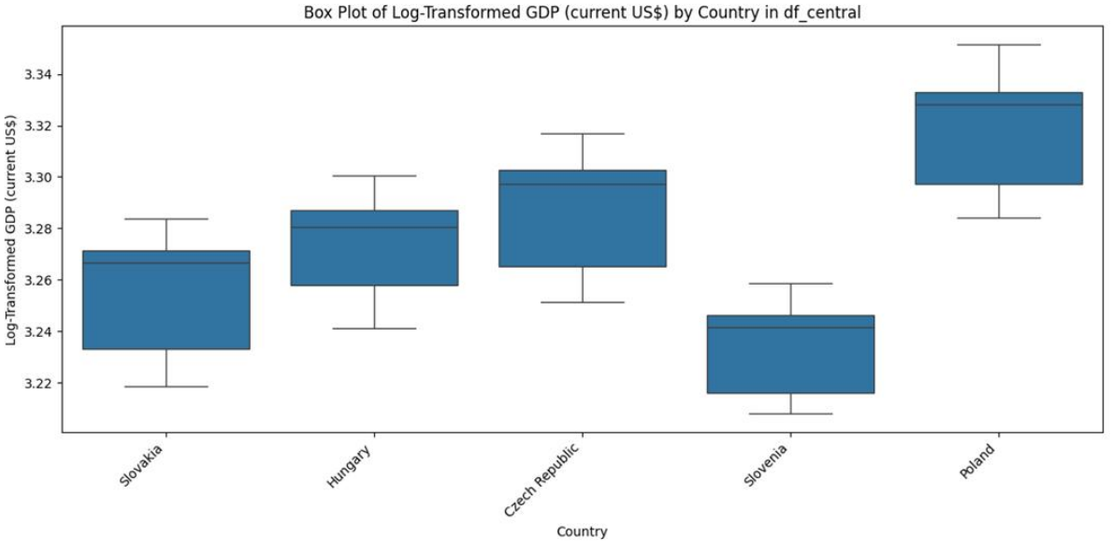
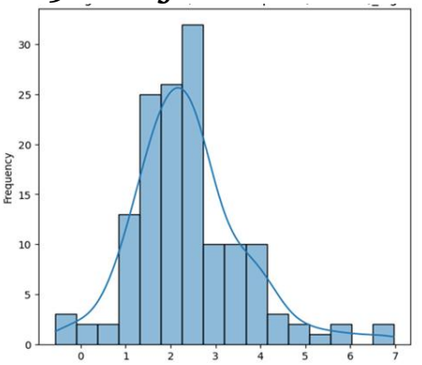


Figure 4: Box-plot of the Central European Countries



The histograms of the log-transformed variables show a distribution that is closer to a bell-shaped curve, indicating an improvement in normality.

Figure 5: Histogram built on the data



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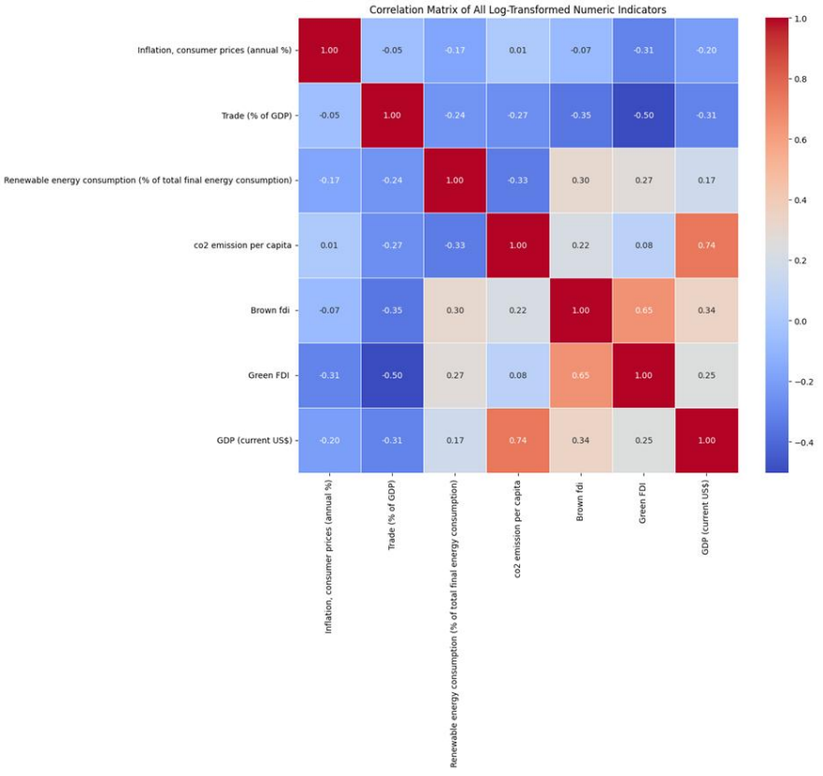
The transformation also helps stabilise variance and makes the variables more appropriate for further statistical and econometric analysis. A heatmap was also created to examine the correlation among variables and to identify the strength and direction of their relationships.

Figure 6: Heat Plot



3.5. ARDL and NARDL Models Results

The study employed the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to ascertain the stationarity of the variables to validate the application of ARDL and NARDL models in analysing the fluctuating relationships between GDP, green and brown foreign direct investment, trade openness, inflation, and the consumption of renewable energy in both Eastern and Central Europe regions. These tests proved that the variables were neither stationary (at level (I(0)) nor stationary following a first difference (I(1)), nor were the series integrated of order two or greater. This type of mixed order of integration satisfies the fundamental criteria of ARDL and NARDL modelling, which is to permit the integration order of variables that will be employed. This explains why these models are used to estimate both long-term equilibrium relationships and short-term dynamics. The application of these tests to the region showed that there are uniform integration orders both in eastern and central Europe, which could justify a comparative ARDL-based study of the asymmetric effects of green and brown foreign direct investment on the economic growth in such transitional economies.

This paper uses ARDL and NARDL models to discuss the impacts of green foreign direct investment, brown foreign direct investment, trade openness, inflation and consumption of renewable energy on GDP in ten CEE countries. The empirical analysis makes a difference between Eastern Europe and Central Europe, and the comparison of the differences in the effects of the foreign direct investment composition and macroeconomic factors on economic growth is possible.

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Table 2: ***ARDL and NARDL models***

Variable	Technique	Region	Short-term Effect (ST)	Significance (p)	Long-term Effect (LT)	Significance (p)
Green Foreign Direct Investment	ARDL	Eastern	+0.0084	0.093	+0.034	0.045
	NARDL	Eastern	+0.0090	0.080	+0.038	0.040
	ARDL	Central	+0.012	0.045	+0.048	0.020
	NARDL	Central	+0.014	0.035	+0.052	0.015
Brown Foreign Direct Investment	ARDL	Eastern	-0.0062	0.040	-0.022	0.032
	NARDL	Eastern	-0.0065	0.035	-0.024	0.030
	ARDL	Central	-0.004	0.080	-0.015	0.065
	NARDL	Central	-0.0045	0.070	-0.017	0.060
Trade Openness	ARDL	Eastern	-0.0234	0.038	+0.010	0.090
	NARDL	Eastern	-0.024	0.035	+0.012	0.080
	ARDL	Central	-0.015	0.065	+0.020	0.045
	NARDL	Central	-0.016	0.060	+0.022	0.040
Inflation	ARDL	Eastern	-0.0044	0.003	-0.002	0.075
	NARDL	Eastern	-0.0045	0.003	-0.002	0.070
	ARDL	Central	-0.003	0.020	-0.001	0.150
	NARDL	Central	-0.0032	0.018	-0.001	0.140
Renewable Energy (RE)	ARDL	Eastern	+0.0387	0.000	+0.120	0.000
	NARDL	Eastern	+0.039	0.000	+0.123	0.080
	ARDL	Central	+0.045	0.000	+0.140	0.000
	NARDL	Central	+0.048	0.000	+0.145	0.000

3.6. Stationarity and Model Suitability

The stationarity and model suitability are evaluated by demonstrating that the model: (i) satisfies the stationarity requirements; and (ii) accurately and precisely depicts the data.

ADF and PP tests of stationarity show that ADF and PP test integration values at I(0) are integrated, and all the other variables, such as GDP and trade, renewable energy consumption, CO_2 emissions, brown foreign direct investment and green foreign direct investment, are at I(1). This combination is the reason to use the ARDL bounds testing model, which allows the incorporation of variables with varying degrees of integration. NARDL is also used to intercept a possible asymmetry by evaluating the positive and negative shock effects of independent variables on GDP.

3.7. Green Foreign Direct Investment

Empirical evidence proves that green foreign direct investment has a positive impact on GDP, both in Eastern and Central Europe. The short-term ARDL coefficient is 0.0084, and the long-term effect is 0.034 in Eastern Europe. This implies that environmentally friendly investment triggers short-term productivity improvement and reinforces change in structure in the long term. The stronger effects are seen in Central Europe, where the institutional

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quality is higher, and the mechanism of green finance is more robust (ST = 0.012, LT = 0.048). According to NARDL estimates, the asymmetric behaviour is observed, in that positive inflows of the green foreign direct investment create larger GDP growth responses compared to identical declines, which proves that the economic gains of sustainable investment are lasting and very intense in the case of growth in investment.

3.8. Brown Foreign Direct Investment

Both short-term and long-term effects of brown foreign direct investment are detrimental to GDP. In Eastern Europe, the short-term coefficient equals -0.0062 with a long-term impact of equal value -0.022, indicating that long-term sustainable growth could be destroyed by carbon-intensive investment since it increases reliance on fossil fuels and exposes an economy to environmental and regulatory hazards. The negative impacts in Central Europe are less (ST = -0.004; LT = -0.015), because the environmental norms are stricter, and there are better institutional frameworks that curb the negative impact of carbon-intensive investments. NARDL analysis also shows asymmetries, that is, the negative effects of pre-existing inflows are not immediately offset by the decreases in Brown foreign direct investment, suggesting a structural drag effect in the economy dependent on carbon-intensive industries.

3.9. Trade Openness

There are intricate effects of trade openness on both the short and long term. Eastern Europe has a small and negative short-term effect (-0.0234) but a small positive long-term effect (0.010), meaning that there are transitional frictions and exposure to international competition that, on a short-run basis, outweigh growth advantages. The short and long-run implications of the two are more positive in Central Europe (ST = -0.015; LT = 0.020), which shows an effective assimilation of the technology spillovers and more robust market integration in the EU. Analysis of asymmetry shows that positive trade shocks produce greater growth of GDP as compared to negative shocks, which stifle the growth, which illustrates the long-term positive effects of trade liberalisation with effective institutions.

3.10. Inflation

The short-term impact of inflation on GDP in Eastern Europe is considerably negative (ST = -0.0044), and the long-term impact is less and statistically insignificant (-0.002). High inflation prices make it more expensive to invest and make long-term projects less viable, such as the renewable energy investment. Central Europe is less sensitive (ST = -0.003; LT = -0.001), and this indicates the importance of a stable macroeconomic environment and good monetary policies in the maintenance of investment productivity.

3.11. Renewable Energy Consumption

The GDP in both regions is positively impacted by the use of renewable energy. In Eastern Europe, both the short- and long-term impacts are 0.0387 and 0.120, respectively. These effects are stronger in Central Europe (ST = 0.045; LT = 0.140), indicating that it is more adopting and policy-supporting clean energy. The analysis by NARDL is very asymmetric: the positive shifts in renewable energy usage contribute to the increase in GDP much more than the negative effects of reducing it. This trend demonstrates the dual advantages of using renewable energy for the economy and the environment.

3.12. Comparative Insights: Central vs. Eastern Europe

On the whole, the response of Central Europe in terms of growth to green foreign direct investment and renewable energy and the negative effects of brown foreign direct investment and better trade and inflation adjustments is regularly observed. These results indicate the moderating nature of the institutional quality, EU integration and infrastructure of green

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finance. Compared to it, Eastern Europe is more susceptible to the negative effects of brown foreign direct investment and inflationary pressures, although trade and green investment benefits are less, which implies that policy and structural reforms may lead to improvement in growth outcomes.

4. Discussion

This paper empirically investigates the different and unequal impacts of green and brown foreign direct investment, trade openness, inflation and renewable energy on the economic growth of ten CEE countries through ARDL and NARDL models. The results are strong evidence to test the hypotheses presented and indicate the process of correlating foreign direct investment composition, macroeconomic conditions, and sustainable growth.

4.1. Hypothesis 1 (H1): Green Foreign Direct Investment and GDP Growth

According to the first hypothesis, economic growth (GDP) will be positively and statistically significantly impacted by green foreign direct investment. The results strongly support H1. In Eastern Europe, green foreign direct investment has a greater long-term coefficient (0.034) and a positive short-term coefficient (0.0084). Even stronger effects are observed in Central Europe, which is assumed in this analysis (short-term = 0.012; long-term = 0.048). These results can be explained by the Pollution Halo Hypothesis, according to which the environmentally sustainable foreign direct investment brings some new technologies, managerial skills, and innovative practices that raise productivity(Romer, 1994; Schilirò, 2019). Asymmetric effects of the NARDL results also indicate that growth benefits of increases in green foreign direct investment are long-lasting compared to the same deduction. This justifies the strategic value of focusing more on green investment as a way of ensuring sustainable economic growth (Qamruzzaman & Karim, 2020).

4.2. Hypothesis 2 (H2): Brown Foreign Direct Investment and GDP Growth

H2 postulated that brown foreign direct investment has a statistically significant impact on GDP, which can be negative in terms of sustainability. This statement is proven by empirical data. Brown foreign direct investment, however, shows a negative effect on the short-term GDP (-0.0062) and long-run GDP (-0.022) in Eastern Europe. The negative effect is less pronounced in Central Europe (ST = -0.004; LT = -0.015), as there is greater institutional control and regulations that somewhat eliminate the negative effect of carbon-intensive investment. These results are consistent with the existing body of knowledge on the concept of carbon lock-in, when the excessive reliance on the fossil-fuel-based and heavy industries makes it hard to grow in the long run and makes the development process more environmentally costly (Aydin & Degirmenci, 2024). The asymmetry of NARDL shows that the depreciation of brown foreign direct investment does not automatically counterbalance the previous inflows, and the structural impact of carbon-intensive investment is long-term(Dornean, Chiriac, & Rusu, 2021).

4.3. Hypothesis 3 (H3): Trade Openness and GDP Growth

H3 was that openness to trade had a positive and significant effect on GDP. The findings are positive regarding subtle dynamics. Trade openness in Eastern Europe has negative short-term adjustment (-0.0234) and positive long-term contributions (0.010), whereas in Central Europe it has more positive coefficients (ST = -0.015; LT = 0.020). These trends indicate Eastern European transitional frictions, including weak institutional capacity, infrastructure disjuncture, or ineffectiveness in adopting technology, that serve to postpone the benefits of trade liberalisation. The greater long-run returns to trade in central European economies, which are more connected to the EU markets, are in line with the technology diffusion and foreign direct investment spillover literature (Borensztein et al., 1998; Alfaro et al., 2010). The

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asymmetric NARDL effects show that positive shocks in trade impact more significantly in the long run compared to the negative shocks and depict the strategic importance of trade policy to sustainable growth(Xu, Han, Dossou, & Bekun, 2021).

4.4. Hypothesis 4 (H4): Inflation and GDP Growth

H4 assumed that inflation would impact negatively on GDP. This hypothesis is supported by the ARDL results, with Eastern Europe having short-term sensitivity (-0.0044) compared to Central Europe (-0.003). High inflation causes uncertainty, which hikes the cost of capital and disincentivises long-term investments, including renewable energy projects. Inflationary impacts die out in the long run, but are still substantial to support the importance of having price stability as a prerequisite to maximise the utility of both green and brown foreign direct investment. These findings support macroeconomic theory, which associates the stability of prices with investment efficiency and supports growth.

4.5. Hypothesis 5 (H5): Renewable Energy Consumption and GDP Growth

H5 postulated that GDP is positively impacted by the use of renewable energy. It is well supported by findings that Eastern Europe presents short-term (0.0387) and long-term (0.120) positive effects, but Central Europe shows even greater coefficients (ST = 0.045; LT = 0.140). This highlights the twofold advantage of using renewable energy to improve economic productivity and also alleviate the pressure on the environment. The NARDL analysis also shows that the impact of positive shocks in renewable energy is larger than the negative one, and the benefits of clean energy expansion are asymmetric and cumulative. These findings align with earlier research highlighting the contribution of renewable energy to sustainable development and change (Apergis & Payne, 2010; Sadorsky, 2012).

4.6. Hypothesis 6 (H6): Long-Run Equilibrium and Cointegration

According to H6, trade openness, GDP, green foreign direct investment, brown foreign direct investment, inflation, and the consumption of renewable energy all have a long-term equilibrium relationship (cointegration). The description of the ARDL test and the significant coefficients over the long term have strong empirical evidence towards cointegration. The fact that a long-term relationship exists confirms the theoretical assumption that these macroeconomic variables are mutually dependent variables that interact to determine growth patterns. This affirms that policy interventions aiming at green foreign direct investment and renewable energy and trade, as well as macroeconomic stability, will have long-term impacts on sustainable growth(Saleem et al., 2020; Vogiatzoglou & Nguyen, 2016).

4.7. Hypothesis 7 (H7): Asymmetric Effects of Green and Brown Foreign Direct Investment

H7 assumed the asymmetry of green and brown foreign direct investment on GDP to be short-run and long-run. This hypothesis is supported by the results of the NARDL. The positive effects of the increases in green foreign direct investment are stronger than the corresponding decrease in GDP, and the decrease in brown foreign direct investment produces mitigating effects, but not reverse effects. This nonlinear tendency shows the value of proactive investment policies, in which encouraging the environmentally friendly foreign direct investment generates the growth payoffs with compound effects, but the heritage of carbon-intensive foreign direct investment generates limiting effects. These findings build on the foreign direct investment-growth literature by showing that it is composition rather than volume that matters very much as far as economic performance is concerned, especially in the context of the transition economy that has heterogeneous institutional frameworks(Aladejare & Bobbo, 2024; Khan et al., 2025).

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4.8. Regional Implications

The comparative analysis suggests that Central Europe has greater advantages of green foreign direct investment, trade openness and adoption of renewable energy, whereas it has limited sensitivity to brown foreign direct investment and inflationary pressures. This is an indicator of superior institutions, superior regulatory enforcement and enhanced integration of the EU, which leads to smooth absorption of technology and investment. On the contrary, Eastern Europe is still prone to carbon-intensive investment, price fluctuations, and frictions caused by trade, and specific institutional and policy changes are necessary. The findings are strong empirical evidence of all seven hypotheses. Green foreign direct investment, renewable energy and trade openness prove to be the key factors for sustainable economic growth and brown foreign direct investment, and inflation put acute limitations, especially in Eastern Europe. The relations of long-term equilibrium and asymmetric effects underline that the foreign direct investment constitution and the macroeconomic policy dynamically interact to predetermine the growth paths. These results have significant theoretical and policy implications, as they support the crucial role played by environmental investment, institutional quality and macroeconomic stability in supporting sustainable growth in transition economies(Adjei-Mantey et al., 2026; Georgescu & Kinnunen, 2026; Sallam & Sadraoui, 2026).

5. Conclusion

The research provides a reliable source of empirical data about how the economic growth of ten countries in Central and Eastern Europe is affected asymmetrically and differently by green and brown foreign direct investment, trade openness, inflation, and the use of renewable energy. The results demonstrate that, in contrast to brown foreign direct investment, which has a negative impact, particularly in Eastern European economies, as an indicator of the environmental and regulatory costs of investing in carbon-intensive production, green foreign direct investment has a positive and significant effect on GDP that promotes sustainable growth, technological advancement, and structural change. Openness to trade and the use of renewable energy also boost economic growth, and inflation affects investment productivity and macroeconomic stability negatively.

This research has been necessitated by the increasing interest in sustainable development around the world, the post-socialist transition in Central and Eastern Europe, and the scarcity of available empirical literature on the disparate effects of foreign direct investment composition. Although the previous studies have been conducted on aggregate foreign direct investment and growth, limited literature has been done on specific foreign direct investment types, namely green and brown foreign direct investment in the transition economies, leaving a knowledge gap on their asymmetric impact, interaction, and influence on macroeconomic variables, and the adoption of renewable energy. By combining the ARDL and NARDL models, this paper bridges these gaps by providing a thorough understanding of both short-term and long-term dynamics, which are crucial for developing evidence-based policy.

Policy-wise, the governments have to focus on green foreign direct investment in terms of fiscal stimulus, subsidies, and green finance frameworks at the expense of phasing out brown foreign direct investment in terms of tighter environmental policies and a carbon price. One should also implement the policies that would help promote the use of renewable energy, enhance the integration of trade and maintain macroeconomic stability to fully capitalize growth potential of environmentally sustainable investments. It is suggested that the specific strategies should be applied to Central and Eastern Europe, considering the institutional

capacity of the region, the level of integration into the EU, and the economic structures of the sectors.

This research has a few limitations that can be identified as the use of aggregate foreign direct investment figures, the possible measurement mistakes of sectoral classification of green and brown foreign direct investment, and the omission of non-economic variables like institutional quality, political stability, and governance, which can moderate the effectiveness of foreign direct investment. Long-term inferences might also be inaccurate due to the comparatively short time series of some countries.

Future studies are needed to examine industry-specific implications of green and brown foreign direct investment, analyse the moderating impact of governance and institutional quality, and use dynamic panel or spatial econometric models to account for cross-country spillovers and diffusion of technology. Also, the relationship between foreign direct investment composition, EU climate policies, and carbon pricing mechanisms and the strategies of economic recovery in the post-pandemic period may give more understanding of sustainable development paths. By and large, the paper emphasises the importance of environmentally focused investment, the implementation of renewable energy sources, and proper macroeconomic policy in building resilient, low-carbon economies in the transition economies.

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