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# Structural and Investment Determinants of Green Growth in Transition Economies: Evidence from South East and Eastern Europe

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**ABSTRACT**

The main aim of this study is to investigate the structural and investment determinants of green growth in the transition economies of South East and Eastern Europe including Kosovo, Albania, Bosnia and Herzegovina, North Macedonia, Serbia, Montenegro, Moldova, Ukraine, Georgia, Armenia, and Azerbaijan with the data from the World Development Indicators (WDI) database for the period 2000-2024. This study employs pooled ordinary least squares (OLS), random effects (RE) GLS regression with cluster-robust standard errors adjusted for country clusters (id), fixed effects (FE) (within) regression estimates, FE regression with Driscoll-Kraay standard errors and the Hausman specification test that compares the FE and RE estimators and suggests the FE Driscoll-Kraay as appropriate model under study circumstances. Based on the econometric results obtained from the FE Driscoll-Kraay, the statistically significant variables are GDP per capita, gross capital formation, industrial value added and renewable energy consumption and have a positive effect on green growth as measured by Adjusted net savings, including particulate emission damage (% of gross national income (GNI)). In contrast, foreign direct investment has a negative effect on green growth. Otherwise, the coefficients of PM2.5 emissions, trade openness and unemployment remain statistically insignificant under the conditions of this study. The findings suggest that investment, industrial development and renewable energy transition have a significant impact on promoting green growth in all selected transition economies. This study provides important policy implications on the forms and structures useful for green growth in selected South East and Eastern Europe countries indicating that investment and structural determinants have an essential influence. This study highlights that the quality and composition of investments are more important than the volume itself, while emphasizing the need for policies that target green investments, renewable energy deployment and sustainable economic development.

## 1. INTRODUCTION

Literature on green growth points to its multidimensional nature, which includes environmental, economic, and social dimensions [1]. According to Komakech [2], it is crucial to understand the impact of circular economy approaches and green policy tools toward the promotion of green growth and sustainable development in emerging economies. In addition, Awosusi et al. [3] found that the renewable energy diversification and globalization are key aspects of fostering green growth and sustainable development in emerging economies.

The system of adjusted net savings has gained wide acceptance as a powerful tool that can comprehensively measure sustainable development by accounting for resources depletion and environmental degradation [4-6]. Empirical evidence presents mixed empirical findings regarding green growth determinants, where investment, income, and institutions play crucial roles; however, foreign direct investments (FDI) effects are controversial [7, 8].

The accelerating increase of global temperatures and its broad impact on human livelihoods have positioned sustainable development at the forefront of international discussions [9]. In response, governments continue to explore strategies to mitigate climate change [10]. Initiatives such as the Paris Agreement and the 2030 Agenda for Sustainable Development have strengthened global commitments to environmental improvements [11] and as highlighted by the Organisation for Economic Co-operation and Development [12], the 2030 Agenda now serves as a universal framework for both developed and developing economies. Nevertheless, counties vary in their progress toward environmentally sustainable economic growth.

Green growth involves transforming traditional economic practices to support a greener economic framework. A green economy, in turn, is one in which economic progress is aligned with the protection and protection of the environment. The Organisation for Economic Co-operation and Development (OECD) [13] similarly describe green growth as promoting economic expansion while preventing the natural resources and environmental ecosystem services that future generations depend on.

Rapid industrialization and economic growth continue to hinder climate goals, fostering the United Nations (UN) Sustainable Development Goals to emphasize climate action worldwide [14]. In this context, green growth has emerged as a framework that decouples economic expansion from environmental degradation through cleaner technologies, renewable energy, and ecosystem conservation [15-18].

Assessing sustainability requires robust indicators beyond simple measures such as $CO_2$ emissions. Recent literature employs multidimensional indices and convergence analysis to evaluate cross-country environmental performance and policy effectiveness [19, 20]. Environmental convergence examines whether countries with weaker performance catch up with environmental leaders, providing valuable insights for global policymaking [21, 22].

Evidence suggests that convergence patterns differ across income groups and regions, motivating the use of club convergence methods [23]. This approach supports international climate commitments, including the Kyoto Protocol and COP28, by identifying groups of countries facing similar sustainability challenges [24, 25]. Existing studies highlight trade openness, institutional quality, natural resources, green technology, and innovation as a key driver of green growth [26-29].

Given the complex and multidimensional nature of environmental challenges, and recognizing that no single policy approach can adequately address them in today's context of expanding economic activity, this study investigates the diverse factors that influence green growth. Green growth reflects the extent to which economic expansion becomes more environmentally friendly through the efficient use of natural resources. According to Muhammad et al. [11] achieving green growth means utilizing natural capital in a way that support economic development without undermining long-term ecological integrity, while aiming to foster an economy that enhances human well-being, reduces inequality over time, and protects future generation from environmental degradation.

Many nations are now seeing accelerated economic expansion that has helped lower poverty levels and raise overall living standards. According to Jamet and Corfee-Morlot [30] this increase in the economic activity contributes to the degradation of the natural environment which often comes at the cost of environmental degradation, including water and air contamination and other ecological issues. The accelerating economic processes placed on ecological systems create disruptions that, in turn, pose threats to continued economic progress and development. Thus, the rate of climate change adds an additional layer of complexity to how economic development interacts with environmental degradation [31]. According to the OECD [12], innovation policies play a vital role in advancing technologies that support environmental goals. Further, green technologies refer to the creation and use of tools, products, and systems designed to defend natural resources and the environment by reducing the environment consequences of human activities. Such technologies help protect ecosystems, limit environmental degradation, and promote economic outcomes through innovative solutions. The challenge, therefore, lies in determining how best to develop green technologies, which are essential for economies aiming to reduce carbon emissions.

The main aim of this study is to analyze the structural and investment determinants of green growth in the transition economies of South East and Eastern Europe including Kosovo, Albania, Bosnia and Herzegovina, North Macedonia, Serbia, Montenegro, Moldova, Ukraine, Georgia, Armenia, and Azerbaijan based on the concept of adjusted net savings as an indicator of capital accumulation.

Analyzing green growth dynamics in these countries can offer insights into how emerging nations can align their development strategies with green growth principles and support the broader global transition toward environmental sustainability.

By identifying the key determinants that influence green growth, this study provides policymakers with direction for guiding strategies that can facilitate the transition towards green growth. The result also indicates that nations at different development levels require context-specific solutions to meet these shared global targets. For example, developing countries need to be selective about the foreign investments and trade relationships, ensuring these engagements do not damage the environment. At the same time, both developed and emerging economies must evaluate how well their institutions and regulatory systems support progress toward greener pathways of economic development.

### 1.1 Research objectives

RO1: To assess the impact of gross capital formation, GDP per capita, FDI, trade openness, industrial structure, unemployment, pollution, and renewable energy consumption on adjusted net savings by employing panel data models.

RO2: To identify the appropriate econometric model form that could be either a pooled ordinary least squares (OLS) model, a fixed effect (FE) model, or a random effects (RE) model via diagnostic testing including the Hausman test.

RO3: To test the robustness of the findings using cluster robust and Driscoll-Kraay standard errors and to ascertain the most robust determinants of green growth in transition economies.

### 1.2 Research questions

RQ1: What are the principal macro-economic and structural factors affecting green growth in transition economies?

RQ2: How does investment intensity, FDI, and industrial composition influence the country-level trends in adjusted net savings?

RQ3: Do environmental and energy-related dimensions like pollution and renewable energies significantly shape green economic performance?

The study is organized as follows: Section 1 present the main aim of the study, research objective and research question and further develop the main hypothesis. Section 2 summarizes the existing literature on what drives green growth, focusing on elements like economic conditions, foreign investment, industry, and the use of renewable energy. Section 3 details the methodological approach, describing the data used, the variables examined, and the econometric techniques applied. Section 4 reports and discusses the empirical results. Section 5 concludes the paper and highlights the main policy implications.

Table 1 presents the study hypothesis, the expected signed and the theoretical rationale. It is worth noted that the higher investment intensity enhances productive capacity and sustainable capital accumulation and further the economic growth may improve technological progress, institutional capacity, and environmental management.

**Table 1.** Research hypothesis

| Hypothesis | Statement | Expected Sign | Theoretical Rationale |
|---|---|---|---|
| H1 | Gross capital formation positively affects green growth performance. | + | Higher investment intensity enhances productive capacity and sustainable capital accumulation. |
| H2 | GDP per capita positively influences adjusted net savings. | + | Economic growth improves technological progress, institutional capacity, and environmental management. |
| H3 | Foreign direct investment significantly affects green growth performance. | ± (expected − based on findings) | FDI may promote technology transfer, but in transition economies it may also support pollution-intensive sectors (pollution haven effect). |
| H4 | Industrial value added positively influences green growth. | + | Structural transformation toward industry strengthens capital deepening and long-term wealth creation. |
| H5 | Renewable energy consumption positively affects green growth performance. | + | Energy transition reduces environmental damage and supports sustainable development. |
| H6 | PM2.5 exposure negatively affects adjusted net savings. | − | Higher pollution increases environmental damage and reduces sustainable capital accumulation. |

Source: Authors' compilation

## 2. LITERATURE REVIEW

Recent evidence suggests that institutional quality, foreign direct investment, trade openness, and capital formation significantly shape environmental sustainability and green growth dynamics in emerging economies. Girgis and Yousri [32] demonstrated that the relationship between investment, trade openness, governance, and environmental sustainability is highly interrelated, emphasizing that institutional and structural conditions play a critical role in determining sustainable development outcomes.

Further, it should be noted that recent works underline the significance of structural and investment factors in the processes of green growth and sustainable economic transformation in developing and transitional economies. Ogunsola and Zwane [33] highlighted the necessity of paying attention to green finance and institutions to support sustainable economic growth and transition to renewable energy. In this line Voronova et al. [34] emphasized the role of investments in renewable energy for green transition, technological development, and environmental sustainability.

Ülger Danacı [35] identified the development of capital formation and shifts in the structure of energy as crucial factors in facilitating sustainable development and green transition initiatives in the case of Kazakhstan, additionally noted that the development of renewable energy and structural changes become crucial for lowering environmental vulnerabilities. In addition, Gachino [36] found that foreign direct investment, energy use, and trade openness are key determinants of sustainable economic growth in developing countries. Applying dynamic panel data analysis on the BRICS+ nations, the study discovers substantial long-term associations between investment flows, trade openness, energy development, and sustainable growth dynamics.

From the summary of empirical research provided in Table 2, it is evident that structural, investment-driven, institutional, and environmental drivers have become increasingly significant determinants of green growth and sustainable economic development among emerging and transition economies. From the analysis of the reviewed literature, it has been demonstrated that foreign direct investment, renewable energy sources, trade openness, institutional quality, industry composition, and investments focused on sustainability have played a significant role in determining environmental outcomes and economic transformation in developing nations. In addition, the literature shows that the processes towards green transition and sustainable economic development are related to institutional quality, innovation, and sustainable policies.

**Table 2.** Summary of recent empirical research on structural, investment, and sustainability drivers of green growth

| Source | Variables/Focus | Methodology | Main Findings and Relevance |
|---|---|---|---|
| Ogunsola and Zwane [33] | Green finance, regulatory quality, technological advancement, renewable energy investment, sustainable growth | GLM applied to 40 emerging market economies | Green finance and renewable energy investments positively affect ecological sustainability and productive capacity, while regulatory quality supports sustainable development. The study supports the inclusion of institutional quality and investment-related variables in green growth analysis. |
| Danga and Nguyen [37] | FDI, institutional quality, green technology innovation, green growth | System GMM, ASEAN-5 countries (2002-2021) | Institutional quality moderates the impact of FDI on green technology innovation and sustainable development. Supports the inclusion of FDI and governance indicators. |
| Houfi and Farhat [38] | Financial development, banking sustainability, renewable energy investments | ARDL, 16 emerging economies (1990-2021) | Renewable energy investments and sustainable banking practices contribute positively to environmental sustainability. Supports investment-related and sustainability variables. |
| Pachiyappan et al. [39] | Green finance, low-carbon technology trade, $CO_2$ emissions | Panel ARDL, BRICS countries | Green finance and low-carbon technology trade significantly influence sustainable economic growth. Supports trade and environmental indicators. |
| Liu et al. [40] | Financial development, renewable energy transition, | IPAT model with FE and robust LS | Renewable energy transition reduces environmental degradation, while industrial structure and growth increase |

| | | | |
|---|---|---|---|
| | industrial structure | | emissions. Supports renewable energy and structural variables. |
| Li and Shahzad [41] | Public investment, digitalization, innovation | DK standard errors and System GMM | Public investment and digital innovation enhance sustainable economic growth. Supports investment and digitalization variables. |
| Ghazalat [42] | Corporate governance, transparency, investment opportunities | Random-effects GLS | Governance and transparency encourage investment opportunities and sustainable development. Supports institutional quality indicators. |
| Kautish et al. [43] | FDI, industrialization, economic growth, $CO_2$ emissions | ARDL bounds testing | FDI and industrialization influence environmental sustainability dynamics. Supports inclusion of FDI and industrial structure variables. |
| Pata et al. [44] | Renewable energy, globalization, technological innovation | Nonparametric causality-in-quantiles | Renewable energy, trade globalization, and innovation affect carbon emissions and sustainability. Supports renewable energy and trade openness indicators. |
| Afshan et al. [45] | Sustainable investments, environmental taxation, green technologies | MMQR, emerging economies | Green investments and renewable energy positively affect green growth across development stages. Supports investment and renewable energy variables. |

Source: Author's contribution

Note: GMM = Generalized Method of Moments, ARDL = Autoregressive Distributed Lag, IPAT = Impact = Population × Affluence × Technology, LS = Least Squares, DK= = Driscoll-Kraay, MMQR = Method of Moments Quantile Regression

From the time of industrial evolution, the world has experienced robust economic growth, thus leading policymakers and researchers to study how economic development affects environmental sustainability [46].

In addition, several studies show that human activities directly contribute to environmental degradation [23]. Organizations such as the Intergovernmental Panel on Climate Change (IPCC) [9] and the United Nation states that economic activities are major causes of environmental degradation [47]. International bodies, institutions, specialists and practitioners increasingly emphasize the key role of green growth within the broader agenda of sustainable development. Green growth extends far beyond environmental concerns as it focuses on reshaping how economies expand. As nations rethink their development models, the durability and long-term resilience of their economies have become central issue [48].

Sustainable green growth requires clear conceptual foundations and consistent measurement systems. In response to this fragmentation, international bodies collaborated to establish shared knowledge platforms and indices to track progress. Since then, many countries particularly in the emerging economies have integrated green growth into national development strategies, with receiving recognition and supporting economic planning with environmental sustainability and social inclusion [49]. In addition, Sadorsky [50] found that the excessive use of natural resources as a result of economic expansion can harm the environment, increase production, the energy consumption and transport. Therefore, global organizations and researchers are placing greater emphasis on promoting environmentally sustainable economic activities [51]. However, it is worth noted that many countries continue to face difficulties in balancing economic growth with environmental protection and the sustainable use of natural resources [49, 52]. As a result, the idea of green growth has developed to promote economic growth while improving environmental quality [53].

Green growth aims to support steady economic progress while lowering the use of natural resources and decreasing carbon emissions. In addition, there is also the need for resilient economic, industrial, and financial systems. In this regard the environmentally friendly technologies play a key role in the process, encouraging green businesses and innovation. However, investing in green technologies involve high uncertainty, thus specialized financial tools and risk management strategies are needed to support such investments. As new technologies change how goods are produced and how markets operate, they can drive broader economic transformation. For this reason, the green growth approach considers both economic and financial factors [54].

Moreover, green growth offers integrated solutions to climate and development challenges, supports economic diversification, accelerates technological progress and promotes sustainable growth across sectors [55].

Since the Rio Summit, the global economy has struggled to balance continued economic expansion with growing environmental degradation. Green growth emerged as a framework to reconcile this competing pressure by promoting economic development while preserving natural resources essential for human well-being [10]. In addition, economic growth can reduce emissions through improved efficiency and cleaner technologies [56, 57] while others show that growth initially increases pollution until a certain threshold is reached [58]. Additional research highlights the role of education, trade openness, investment and regional differences in shaping environmental performance alongside growth [59]. According to Talebzadehhosseini and Garibay [60], green products promote green growth across 61 countries, while technological innovation itself shows no significant effect. In contrast, Mensah et al. [61] reported that sector-specific technological progress support green growth, particularly in transport in Ocean countries, manufacturing in Asia, and energy technologies in Europe. Further studies indicate the human capital closely linked to green technologies and regulation. In this regard the education is shown crucial factor towards enhancing the green growth and the green transition [28] and human capital plays a significant role in G7 countries [62]. While Lee and Kim [63] highlighted that this effect depends on the size and environmental awareness of the urban population.

Beyond these areas, fewer studies examine green growth's link with industrial and labor outcomes [64], environmental regulation [65, 66], and political economy [67].

In addition, recent studies on finance-sustainability have traditionally focused on energy use and carbon emissions, but recent works increasingly emphasize green growth, which integrated economic expansion with environmental sustainability [68]. Furthermore, green growth-oriented studies draw on growth theory to assess whether sustainable growth is feasible in both theory and practice [15]. In addition, income levels, research and development spending, fiscal and monetary policies, and foreign direct investment are shown to play an important role in promoting green growth across different country groups [69, 70]. Macroeconomic stability also supports green growth, as evidenced in the EU, India and BRICS-T economies [47]. Evidence on financial development is mixed, because while it can foster green growth through innovation spillovers and regional effects, it may also delay local green growth when financial expansion is unbalanced [71, 72].

Moreover, to expand their economies, countries increasingly rely on FDI and trade, which can enhance technology transfer, human capital and productive efficiency. However, their environmental effects remain contested. The pollution haven hypothesis argues that trade and FDI shift pollution-intensive activities to host countries, worsening environmental quality [73], a view supported by evidence linking FDI to higher emissions [74, 75] though long-run effects may be insignificant [76]. Trade effects also differ, with exports increasing emissions and imports reducing them in some cases [77].

In contrast, the pollution hypothesis suggests that internationalization improves environmental performance through technology transfer and better practices, showing that trade and FDI can narrow technology gaps and enhance environmental quality under appropriate conditions [78]. Nonetheless, outcomes depend on policy and institutional quality, as effective regulation and innovation are needed to direct FDI toward greener activities [79].

Furthermore, green investment, credit and institutional quality improve environmental and economic outcomes across regions [59, 80]. Overall, the literature highlights the central role of financial development, innovation and human resources in green transition, though existing studies remain concentrated on single countries such as China, leaving cross - country evidence in emerging economies relatively limited [81].

## 3. RESEARCH METHODOLOGY AND ECONOMETRIC MODELING

This study employs pooled OLS Regression, RE GLS regression, RE GLS regression with cluster-robust standard errors adjusted for country clusters (id), FE (within) regression estimates and FE regression with Driscoll-Kraay standard errors. The Hausman specification test was conducted to determine whether the FE or RE estimator is appropriate. In order to investigate the structural and investment determinants of green growth in eleven transition economies from South East and Eastern Europe including Kosovo, Albania, Bosnia and Herzegovina, North Macedonia, Serbia, Montenegro, Moldova, Ukraine, Georgia, Armenia, and Azerbaijan, the data from World Development Indicators (WDI) database for period (2000-2024) was used.

These countries were selected based on the similarities in their economic reforms, structural transition processes, and development paths in the context of the broader regional structural transformation. Furthermore, the selected countries reflect economies at different stages of structural transformation, institutional dynamics, and levels of market integration, emphasizing their relevance to investigating the causes of difference in green growth outcomes in transitional economies.

While the initial panel dataset contained eleven countries, it is worth noted that in the absence of data for a large number of explanatory variables included in the econometric models, the panel consists of only eight countries since Kosovo, Bosnia and Herzegovina, and Montenegro were excluded because of missing observations. In the process of econometric investigation and the models' estimations, all the observations that had high missing value rates across several variables, mainly environmental and governance variables, were automatically excluded from the regression.

In addition, it is worth noted that the variables used in this study are obtained from WDI [82] assessed on January 28, 2026. These indicators furnish a wide selection of internationally consistent, comparable, and reliable macroeconomic, structural, environmental, and energy-related indicators.

The dependent variable is adjusted net savings (NETs) (including particulate emission damage), which is employed as an indicator of capital-based green growth and sustainability as cited previously [4].

The explanatory variables employed in the model are:
GDP per capita (GDPpercap),
Gross capital formation (GCF),
Foreign Direct Investment (FDI),
Trade openness (TR),
Industry (including construction), value added (Industry),
Unemployment total (Unempl),
Control of corruption (Corr),
PM2.5 air pollution, mean annual exposure, and
Renewable energy consumption (RenEnergy).

**Table 3.** Definition, indicator, and variables source

| Series Name | Indicator | Source |
|---|---|---|
| Adjusted net savings, including particulate emission damage (% of GNI) | NETs | WDI |
| PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) | PM2 | WDI |
| GDP per capita (constant 2015 US$) | GDPpercap | WDI |
| Gross capital formation (% of GDP) | GCF | WDI |
| Foreign direct investment, net inflows (% of GDP) | FDI | WDI |
| Trade (% of GDP) | TR | WDI |
| Industry (including construction), value added (% of GDP) | Industry | WDI |
| Unemployment, total (% of total labor force) (modeled ILO estimate) | Unempl | WDI |
| Control of Corruption: Estimate | Corr | WDI |
| Renewable energy consumption (% of total final energy consumption) | RenEnergy | WDI |

Source: World Bank (2026)

The explanatory variables are categorized into macroeconomic, institutional, structural, environmental, and labor. The selection of the explanatory variables is based on the body of theory and evidence from the literature on green growth, capital accumulation in transition economies, and structural transformation. The variable GDP per capita is included as a proxy variable of economic development and income levels. Theory suggests that higher income levels may contribute to greater awareness regarding the environmental sustainability, high-quality institutions, and the overall technology that may drive better levels of sustainability. Regarding the Green Growth perspective, economic development is a driving force in capital accumulation. GCF is added to capture investment intensity and capital deepening. Foreign direct investment is used to examine the impact of capital inflows from other economies. In the case of transition economies, FDI may be used to transfer better technology and improve productivity; on the contrary, if FDI invests in resource-intensive industries, it may generate environmental degradation. In this way, the FDI allows investigation into whether international capital contributes positively or negatively towards green growth outcomes. Industrial value added (industry) is used to account for the effects of structural transformations. Structural composition plays an important role in the process of industrialization, a phenomenon that is essential in the process of economic development. Trade openness (TR) is added as a proxy of integrating with the world economy. Trade may drive technical progress and productivity increases but could also accelerate environmental degradation via scale effects. The coefficient of trade openness allows for evaluation of its impact on promoting or hindering sustainable capital formation. And the variable PM2.5 air pollution, mean annual exposure PM2.5, is used as an indication of environmental degradation and the intensity of environmental pollution.

Table 3 presents the Definition, Indicator, and Variables source.

In order to estimate further the impact of the selected variables, the following panel data equations are as follows:

General panel equation:

$$yit = \alpha + \beta Xit + ui + \varepsilon it \tag{1}$$

Pooled OLS equation:

$$yit = \alpha + \beta Xit + \varepsilon it \tag{2}$$

FE equation:

$$yit - y^{-}i = \beta(Xit - X^{-}i) + (\varepsilon it - \varepsilon^{-}i) \tag{3}$$

RE equation:

$$yit = \alpha + \beta Xit + ui + \varepsilon it \tag{4}$$

To examine the determinants of green growth, the following baseline panel regression model is estimated:

$$\begin{gathered} NETsit = \alpha + \beta 1PM2it + \beta 2GDPit + \beta 3GCFit \\ +\beta 4FDIit + \beta 5TRit + \beta 6INDit + \beta 7UNEMPLit \\ +\beta 8RENit + ui + \varepsilon it \end{gathered} \tag{5}$$

where, *i* denotes country, *t* denotes time and *ui* represents the country-specific effects that are not captured by the model, whereas *εit* refers to the individual-specific error term. The panel data estimation in its first step begins with the pooled OLS regression while adding robust standard errors. Nonetheless, due to the chances of heterogeneity, both FE and RE regressions are estimated [83]. FE models are applied for cases where the effects are correlated with the regressors, as mentioned by Wooldridge [84].

### 3.1 Model selection and diagnostic tests

To choose between the FE or the RE the Hausman specification test is employed. Under the null hypothesis of the test, it is assumed that there is no difference between the FE estimator and the RE estimator. Failure to reject the null hypothesis implies that the FE estimator is consistent.

$$\begin{gathered} H0: E(ui \mid Xit) = 0(RE\ consistent) \\ H1: Cov(ui, Xit) different from\ 0 \\ = 0(REno - consistent) \end{gathered} \tag{6}$$

$$\begin{gathered} yH = (\beta^{FE} - \beta^{RE})'[Var(\beta^{FE}) - Var(\beta^{RE})] \\ -1(\beta^{FE} - \beta^{RE}) \\ H \sim \chi k2 \end{gathered} \tag{7}$$

To assess the presence of of multicollinearity in the model, the Variance Inflation Factor (VIF) is estimated according to standard procedures. For serial correlation with panel data, the Wooldridge test is used in order to estimate the presence of autocorrelation. Due to the presence of serial correlation as well as potential cross-sectional dependence, robust standard errors clustered at the country level is employed. Furthermore, for robust standard errors that correct for heteroscedasticity, autocorrelation, as well as any potential cross-sectional dependence in the data, the model is re-estimated by employing Driscoll-Kraay standard errors.

### 3.2 Estimation strategy

Estimation strategy followed in this study is divided into four steps. First, the pooled OLS model with robust standard errors as a first benchmark is estimated. Second, FE and RE models to control for unobserved heterogeneity at the country level are estimated. In addition, as a third step, this study employs the Hausman specification test to check the consistency of RE model in relation to FE model. Fourth, robustness check using cluster robust standard errors and the Driscoll-Kraay standard errors are carried out to account for possible heteroscedasticity, serial correlation, as well as cross-section dependence. All results from the various model specifications are reported in the next section to enable a comprehensive comparison across estimators. Although the Hausman test points to FE as providing the most consistent estimates, pooled OLS, RE, and robust estimations are also reported in order to check for stability and sensitivity of the findings.

## 4. RESULTS

This section presents the results obtained from econometric models and diagnostic tests. Table A in the Appendix provides the pooled OLS regression results that assess the impact of the explanatory variables on NETs. The results indicate positive and statistically significant effect of GCF ($\beta = 0.823$, $p < 0.001$). This implies that higher levels of investments positively may impact the sustainable economic growth or wealth creation after accounting for environmental costs measured with NETs. Additionally, the GDP per capita is found to have a positive and significant impact on NETs ($\beta = 0.00129$, $p = 0.001$). Moreover, industrial value added is also positively and significantly related to NETs ($\beta = 0.403$, $p < 0.001$).

In contrast, Foreign Direct Investment (FDI) has a negatively and significantly strong relationship ($\beta = -0.735$, $p < 0.001$), which indicates that FDI flows can possibly be unrelated to the positive contribution towards sustainable growth in the selected countries. On the other hand, unemployment has a significant and negative impact on NETs ($\beta = -0.282$, $p = 0.004$). Renewable energy consumption has a positive impact with marginal significance ($\beta = 0.136$, $p = 0.054$). This implies that renewable energy consumption may have a positive impact on sustainable development. Otherwise, exposure to PM2.5 emissions ($\beta = 0.178$, $p = 0.169$) and trade openness ($\beta = 0.048$, $p = 0.164$) do not show statistical significance under the study circumstances. Table A presents the Pooled OLS regression results.

Table B in the Appendix provides the results of the RE estimation of the determinants of adjusted net savings (NETs). It should be noted that the estimated coefficients are still very stable with respect to the values that were estimated using the pooled OLS model, which indicates that the direction and significance of relations are rather consistent and robust under different estimators used. Specifically, such explanatory variables as gross capital formation ($\beta = 0.823$, $p < 0.001$), GDP per capita ($\beta = 0.00129$, $p = 0.001$), and industrial value added ($\beta = 0.403$, $p < 0.001$) still have a positive and statistically significant impact on NETs, while foreign direct investments ($\beta = -0.735$, $p < 0.001$) and unemployment ($\beta = -0.282$, $p = 0.003$) have a negative and statistically significant impact.

Renewable energy consumption is still positively related to NETs ($\beta = 0.136$, $p = 0.052$), although the statistical significance is marginal under the RE model. On the other hand, PM2.5 exposure ($\beta = 0.178$, $p = 0.167$) and trade openness ($\beta = 0.048$, $p = 0.162$) are not significant. High consistency between the two models is explained by the minimal between-group variance estimate (rho = 0) in the RE model. To address issues of potential within-country correlation and heteroskedasticity, the RE model has been re-estimate with cluster-robust standard errors clustered at the country-level (8 clusters) presented under Table C.

Table C presents RE estimates using cluster-robust standard errors. It is seen that gross capital formation ($\beta = 0.823$, $p < 0.001$) and industrial value added ($\beta = 0.403$, $p = 0.001$) are still positive and statistically significant factors for the NETs, whereas the relationship between foreign direct investment and NETs is still negative and highly significant ($\beta = -0.735$, $p < 0.001$). GDP per capita is found to have a positive impact on NETs, marginally significant ($\beta = 0.00129$, $p = 0.070$). On the other hand, PM2.5 ($\beta = 0.178$, $p = 0.597$), trade openness ($\beta = 0.048$, $p = 0.432$), unemployment rate ($\beta = -0.282$, $p = 0.149$), and renewable energy ($\beta = 0.136$, $p = 0.429$) have no statistically significant effect on NETs in the context of clustered robustness test correction. The interpretation of the insignificant relationship between PM2.5 exposure and NETs needs further examination due to possible lags in environment impacts, measurement issues, and adjustments for sustainable NETs.

In order to find out which panel specification to use, a Hausman test was carried out to differentiate between the RE and FE models. The null hypothesis is that the difference between the parameters is random, i.e., the RE model provides consistent and efficient results. The alternative hypothesis indicates that RE results are inconsistent because of correlation between individual effects and regressing variables. The results reject the null hypothesis because $\chi^2(8)$ is greater than 38.58 and p-value $< 0.001$. This shows that the differences between FE and RE models are statistically significant. This suggests that the model assumption that unobserved country effects are uncorrelated with regressing variables is violated.

The results make sense in view of the large correlation established in the previous results between the individual effects and the regressors, i.e., (corr(u_i, Xb) = -0.7792). Therefore, the results from the FE estimator are consistent and preferred. The size of the differences in the coefficients also adds credence to the above finding. Notable differences arise for the coefficients of GDP pc, industry share, FDI, and unemployment levels, warranting the notion that country-specific factors are systematically related to these variables. Also, the reversal in the signs of the coefficients of the unemployment levels and trade openness between the FE and RE regression results points towards the presence of significant differences across the countries. Although the Hausman test results summary indicates that the variance difference matrix ($V\_b - V\_B$) is not positive definite—which is common in a finite sample case—the chi-square results are very significant in favor of the fixed-effects model.

From the Hausman test results, the FE is suggested over the RE, this is because the RE estimator appears inconsistent due to correlation of unobserved country-specific factors with the regressors. In addition, Table D presents FE results, and Table E shows Hausman test results

### 4.1 Model selection and reliability assessment

The result of rejecting the null hypothesis verifies our line of argument that conventional FE or RE standard errors are not fully reliable under the study circumstances. Accordingly, using cluster robust standard errors is more appropriate for consistent results. To address issues of heteroskedasticity, serial correlation, and cross-sectional dependence, the FE model is further estimated using standard errors following the Driscoll-Kraay approach with a slight modification of the maximal lag equal to two (Table F). This is especially appropriate in a macro panel data environment featuring a lower number of cross-section units, i.e., N = 8. The results continue to highlight that the Fixed Effect Driscoll-Kraay is statistically significant overall ($F(8,20) = 320.49$; $p < 0.001$), with the $R^2$ remaining unchanged (=0.6317).

It is worth emphasize that based on the econometric results obtained from the Fixed Effect Driscoll-Kraay, chosen between pooled OLS and RE, as appropriate model under the study circumstances, the statistically significant variables are GDP per capita, gross capital formation, industrial value added and renewable energy consumption and have a positive effect on green growth as measured by Adjusted net savings, including particulate emission damage (% of GNI). In contrast, foreign direct investment has a negative effect on green growth. Otherwise, the coefficients of PM2.5 emissions, trade openness and unemployment remain statistically insignificant under the conditions of this study presented in Appendix Table F. FE regression with Driscoll-Kraay standard errors.

To determine the existence of multicollinearity among the independent variables, the results of VIF test were obtained as presented in Table 4. The results have shown that the values of VIF for the independent variables are very low, far below the critical value of 10, and even below the rather conservative critical value of 5 as proposed in the field of panel econometrics. The maximum value of VIF is found in the variable of renewable energy consumption (VIF = 4.87) and exposure to PM2.5 (VIF = 4.13). Although the values of VIF hint towards moderate correlations with other regressors for these two variables, the values are nevertheless within acceptable limits and do not hint at severe multicollinearity. The other variables have even lower VIF values: Unemployment (3.49); Industry share (2.98); Gross capital formation (2.38); Trade openness (2.18); FDI (2.15); GDP per capita (1.52). The average VIF value is 2.96. This is well within tolerance levels. Hence, we can conclude that the levels of correlation between the explanatory variables are not high. Also, we conclude that multicollinearity will not impact the estimates of the regression coefficient. Overall, the diagnostic evidence clearly verifies that multicollinearity is not an essential problem that the model faces, hence boosting the credibility of the results obtained by the model.

**Table 4.** Variance inflation factors for the explanatory variables

| Variable | VIF | 1/VIF |
|---|---|---|
| renenergy | 4.87 | 0.205129 |
| pm2 | 4.13 | 0.242132 |
| unempl | 3.49 | 0.286622 |
| industry | 2.98 | 0.33584 |
| gcf | 2.38 | 0.420554 |
| tr | 2.18 | 0.458946 |
| fdi | 2.15 | 0.464494 |
| gdppercap | 1.52 | 0.658345 |
| Mean VIF | 2.96 | |

Source: Authors' estimations

**Table 5.** Wooldridge test for autocorrelation in panel data

| Test | Statistic | Value |
|---|---|---|
| Null Hypothesis | No first-order autocorrelation | — |
| F-statistic | F(1, 7) | 22.440 |
| Prob > F | p-value | 0.0021 |
| Decision | Reject $H_0$ | Yes |

Source: Authors' estimations

Table 5 presents the results obtained from Wooldridge test for autocorrelation in panel data. The results suggest to reject the null hypothesis ($F(1,7) = 22.440$, $p = 0.0021$), and indicate the presence of serial correlation in the panel data under the study circumstances thus justifying the use of robust estimation techniques.

Table 6 presents the OLS Robust, FE, and RE estimations for the factors determining NETs. The coefficients in the three estimators for the variable's gross capital formation and industrial value added have remained positive, whereas that for the GDP per capita has been found to be positive and significant in all three estimations. On the other hand, the coefficient for FDI reveals negative signs on sustainability indicators, which indicates a mixed effect of FDI in transition economies.

The coefficients of the two variables PM2.5 and trade openness are not found to be statistically significant in the three estimations. Nevertheless, it cannot be inferred from this that pollution does not affect sustainable development, considering that the variable itself represents the sustainability-adjusted index, and environmental issues might take time to influence such an economic indicator.

The same reasoning may also apply to renewable energy consumption, as it is not found to be statistically significant in some cases.

**Table 6.** Pooled ordinary least squares (OLS) with robust standard errors, fixed effect (FE), and random effects (RE) results

| | (1) | (2) | (3) |
|---|---|---|---|
| | OLS robust | FE | RE |
| VARIABLES | nets | nets | nets |
| pm2 | .177734 | 0.0248 | 0.178 |
| | (.3363549) | (0.189) | (0.129) |
| gdppercap | .001293*** | 0.00333*** | 0.00129*** |
| | (0007128) | (0.000649) | (0.000389) |
| gcf | .8232251 *** | 0.918*** | 0.823*** |
| | (.1453161) | (0.119) | (0.0993) |
| fdi | .7351703 *** | -0.563*** | -0.735*** |
| | (.1423843) | (0.0973) | (0.0880) |
| tr | .0479619 | -0.0422 | 0.0480 |
| | (.061066) | (0.0411) | (0.0343) |
| industry | .4030222*** | 0.769*** | 0.403*** |
| | (.1250832) | (0.131) | (0.0677) |
| unempl | -.2824829*** | 0.00620 | -0.282*** |
| | (.1956992) | (0.203) | (0.0959) |
| renenergy | .1361753* | 0.189 | 0.136* |
| | (.1722923) | (0.115) | (0.0702) |
| Constant | -35.41157 *** | -49.77*** | -35.41*** |
| | (15.8798) | (9.673) | (5.590) |
| Observations | 141 | 141 | 141 |
| R-squared | 0.620 | 0.632 | |
| Number of id | | 8 | 8 |

Source: Authors' estimations

**Table 7.** Summary of hypothesis testing results

| Hypothesis | Variable | Expected Sign | Fixed Effect Coefficient | p-Value (FE) | Robustness (DK) | Decision |
|---|---|---|---|---|---|---|
| H1 | Gross Capital Formation (GCF) | + | 0.9181 | 0.000 | Significant | Accepted |
| H2 | GDP per capita | + | 0.00333 | 0.000 | Significant | Accepted |
| H3 | Foreign Direct Investment (FDI) | − | −0.5634 | 0.000 | Significant | Accepted (Negative effect confirmed) |
| H4 | Industrial Value Added | + | 0.7687 | 0.000 | Significant | Accepted |
| H5 | Renewable Energy Consumption | + | 0.1886 | 0.104 | Significant under DK (p=0.032) | Partially Accepted |
| H6 | PM2.5 Exposure | − | 0.0248 | 0.896 | Not significant | Rejected |

Source: Authors' estimations

Table 7 presents the summary of the hypothesis testing and results. Most of the hypotheses raised in this study find strong support by the empirical findings. Gross capital formation is the most influential determinant of green growth performance, confirming that investment intensity plays a binding role in sustaining adjusted net savings.

Similarly, GDP per capita exerts a positive and statistically significant within-country effect, which supports income growth as enhancing sustainable capital accumulation over time. Industrial value added follows with a strong and quite consistent positive contribution, suggesting that structural transformation is an important factor shaping green growth dynamics in transition economies.

The results from the estimation of the FDIs relationship with adjusted net savings reveal a statistically significant but with negative impact, which supports the hypothesis of the association of FDIs with ecologically intensive types of economic activity within the economies under investigation.

Renewable energy consumption presents a positive effect, which reveals statistical significance when using robust estimation of the Driscoll-Kraay estimation. The results offer partial verification of the support of such an economic factor in the promotion of green growth. The effect of exposure to PM2.5 fails to reveal statistical significance; thus, the associated hypothesis is rejected.

The results support the dominant explanation of green growth in transition economies, highlighting the investment processes and economic factors alongside with renewable energy, as key drivers within this economic development model.

## 5. DISCUSSION

The results suggest that the performance of green growth, represented by adjusted net savings, is primarily influenced by investment intensity, the dynamics of economic growth, and industrial structure, rather than pollution itself or trade openness. Gross Capital Formation (GCF) appears as a highly robust and significant determinant regardless of the specification. The positive and significant coefficient of GCF suggests that increasement of the investment levels contribute significantly to sustainable capital formation. The above conclusion is consistent with the capital accumulation perspective of green growth, which emphasizes that lasting sustainability requires sustained and rising stocks of productive capitals. GDP per capita has a positive and significant within-country effect, indicating that economic growth contributes to higher adjusted net savings and supports long-term economic sustainability. This is consistent with the hypothesis that higher levels of income support better institutional performance, technological progress, and fiscal ability to address environmental degradation. Industrial value added exhibits a strong positive association with green growth performance. More importantly, however, the results reveal that the influence of industrial value added becomes more pronounced when we apply the fixed-effect estimation, whereby structural change towards industrial activities may actually improve efficiency and capital intensity as opposed to increasing environmental pressures**.**

In contrast, FDI exhibits a robust negative coefficient in both FE and Driscoll-Kraay estimations. This indicates that FDI inflows in transition economies may be concentrated in resource-intensive and environmentally degradation activities, thereby lowering adjusted net savings. This result is consistent with the pollution haven hypothesis, in which transition economies with lax environmental regulations may attract environmentally damaging investments. The variables for environmental factors and openness show less significance. In the case of exposure to PM2.5, statistical insignificance shows that the level of pollution is not a determinant for sustainable savings, ignoring other structural factors. Trade openness is also not statistically significant, which points to the fact that being open does not guarantee a greener economy. Renewable energy consumption, however, becomes statistically significant after employing the Driscoll-Kraay correction procedure, which implies that the shift to sustainable energy is beneficent after controlling for cross-section dependence.

The findings indicate that green growth in transition economies seems to be investment- and structure-driven, with the quality of institutions and regulations likely mediating the sustainability of capital accumulation.

As consistent with our study, Lyulyov et al. [6] used adjusted net savings as a measure for economic growth under a green economy in Europe. Similar findings were reported recently, Sarkodie [1] integrated measures of socio-environmental metrics on green economic growth patterns globally. Consistent with this study, Khan et al. [62] reviewed studies on the impact of renewable resources and innovations in forming determinants of green economic growth performance. Further, empirical panel data provide useful insights into the determinants of green growth and adjusted net savings. For example, regarding transition economies in Central and Eastern Europe, investment, structural, and external effects are found to shape adjusted net savings in a sustained manner, whereas Din et al. [7] related adjusted net savings to sustainable development performance, while Mai et al. [8] focused on macroeconomic and financial determinants of green growth. In addition, Ziberi et al. [85] found that in the case of the Western Balkan countries the GDP per capita growth increased carbon intensity and contributes to environmental degradation in the case of Western Balkan countries. Furthermore, Batrancea et al. [5] discussed green economy challenges and transition to a green economy as well as investment quality in order to address how governance and external capital inflows, FDI have a mixed or adverse effect on sustainability. The findings, justifies the current investigation into macroeconomic, structural, and environmental determinants of adjusted net savings in South East and Eastern Europe.

### 5.1 Policy implications

The empirical findings carry an important policy implication for transition economies in South East and Eastern Europe. The first reason behind is that the gross capital formation is significant and robust, implies that green growth outcomes is driven by investment. Therefore, policymakers should prioritize strengthening domestic investment capacity while seeking to ensure that capital allocation supports environmentally sustainable infrastructure, innovation, and green technologies. Environmental screening mechanisms and long-term sustainability criteria should be integrated into public investment strategies, with a view to making capital accumulation contribute not only to output expansion in the short term but also to durable wealth creation and environmental resilience. The second reason for the relevance of FDI to an environmental perspective on sustainable development relates to the negative and statistically significant effect of FDI on adjusted net savings. This significant correlation points toward a qualitative shift in FDI promotion strategies. Transition economies would need to surpass the efforts applied until now in investment promotion based primarily on volumes toward more differentiated qualitative approaches toward FDI. In investment contracts, environmental conditionality would be a necessary prerequisite, along with more severe regulation and incentives for high-tech and renewable energies.

The positive role played by the industrial structure and the developing role played by renewable energy underscore the need for structural change to be consistent with environmental concerns. The policy aimed for industrial development should focus on the development of value-added manufacturing, energy efficiency technologies, technology upgrades, and the ongoing but gradual decarbonization of the production process. At the same time, developing renewable energy infrastructure and encouraging private sector investment in green technologies are crucial for achieving long-term green growth objectives. The green promotion is crucial [86] thus the transition should be accompanied by robust institutional and regulatory arrangements to ensure that structural change is reflected in meaningful and sustainable green growth.

### 5.2 Future research

Future research might extend the present analysis by testing non-linear and dynamic interactions between economic growth and sustainability towards green growth. In particular, testing threshold effects or Environmental Kuznets Curve-type dynamics would determine whether income-induced improvements in adjusted net savings are linear or non-linear in transition economies. Besides, dynamic panel estimators would capture persistence effects and better control for potential endogeneity between investment, FDI, and sustainability outcomes. Further investigation is also needed regarding the composition and quality of capital flows and the processes of structural transformation. Disaggregating foreign direct investment into sectors could help identify whether pollution intensity or comparative specialization patterns in economies are driving its negative sign. Moreover, institutional quality indicators and alternative measures of green growth, such as carbon intensity and green total factor productivity, would add robustness and greater external validity to the findings. The sample size can also be expanded into a larger set of emerging economies, so comparative insights could be gathered on how governance and structural conditions shape sustainable economic performance.

## 6. CONCLUSION

The determinants of green growth in the selected transition economies of South East and Eastern Europe including Kosovo, Albania, Bosnia and Herzegovina, North Macedonia, Serbia, Montenegro, Moldova, Ukraine, Georgia, Armenia, and Azerbaijan with the data from WDI database for period (2000-2024) have been examined in the current study by the use of the panel data methods. The econometric results indicate that green growth, represented by the adjusted net savings, is driven by the investment intensity, income growth, and industrial composition, whereas the controls of trade, pollution, as well as labor, do not offer robust results. The FE model, which is verified by the Hausman test, indicates that gross capital formation has the strongest and most consistent impact on the determinants of green growth. Higher rates of investment are observed to strengthen the rates of adjusted net savings in countries over time, thereby emphasizing the importance of capital accumulation and the need to sustain economic wealth in the long run. The within-country estimates are appreciably positive and statistically significant when measuring the effects of GDP per capita on sustainable savings performance. In addition, the positive and consistent effects of industrial value added can be attributed to the potential positive impacts of structural change towards the industrial sector to capital deepening, rather than negatively affecting sustainability. In contrast, the results for foreign direct investment reveal a negative sign, which is significant for both the FE and robust estimations. It can therefore be implied that the inflows of FDI, as far as the transition countries included in the study are concerned, may be connected with environmentally intensive activities, contributing to decreased net savings. PM2.5 exposure and trade openness do not present any directly significant effects, while the impact of renewable energy consumption is positive, although it is significant after the application of the correction suggested by Driscoll and Kraay. Overall, what these findings suggest is that green growth in transition economies is largely driven by investment composition and structural economics, rather than openness or external investment. The sustainable development strategy in transition economies should place greater emphasis on enhancing productive investment and the environmental quality of investment, as well as promoting structural change in transition economies, especially in industrial efficiency.

The findings of this study indicate that green growth in transition economies depends on the quality and composition of economic transformation, highlighting that domestic capital formation, industrial development and renewable energy developments contribute positively to regulated net savings, while foreign direct investment exhibits a negative relationship. Among other things, it is worth noting that not all forms of investment equally support sustainable wealth creation. Therefore, it is important to guide economic transformation towards productive, environmentally responsible and long-term activities. Green growth should be seen not only as a consequence of economic growth, but as the result of a development model that aligns investment decisions, industrial modernization and energy transition with sustainability objectives.

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## APPENDIX

**Table A.** Pooled ordinary least squares (OLS) regression results

| Variables | Coefficient | Std. Error | t-Statistic | p-Value |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.178 | 0.129 | 1.38 | 0.169 |
| GDP per capita | 0.001*** | 0.0004 | 3.33 | 0.001 |
| Gross Capital Formation (gcf) | 0.823*** | 0.099 | 8.29 | 0.000 |
| Foreign Direct Investment (fdi) | -0.735*** | 0.088 | -8.35 | 0.000 |
| Trade Openness (tr) | 0.048 | 0.034 | 1.40 | 0.164 |
| Industrial Value Added (industry) | 0.403*** | 0.068 | 5.95 | 0.000 |
| Unemployment (unempl) | -0.282*** | 0.096 | -2.95 | 0.004 |
| Renewable Energy (renenergy) | 0.136* | 0.070 | 1.94 | 0.054 |
| Constant | -35.412*** | 5.590 | -6.33 | 0.000 |
| **Model Statistics** | | **Value** | | |
| Observations | | 141 | | |
| R-squared | | 0.620 | | |
| Adjusted R-squared | | 0.597 | | |
| F-statistic | | 26.97 | | |
| Prob > F | | 0.000 | | |

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

**Table B.** Random effects GLS regression

| Variables | Coefficient | Std. Error | z-Statistic | p-Value |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.178 | 0.129 | 1.38 | 0.167 |
| GDP per capita | 0.001*** | 0.0004 | 3.33 | 0.001 |
| Gross Capital Formation (gcf) | 0.823*** | 0.099 | 8.29 | 0.000 |
| Foreign Direct Investment (fdi) | -0.735*** | 0.088 | -8.35 | 0.000 |
| Trade Openness (tr) | 0.048 | 0.034 | 1.40 | 0.162 |
| Industrial Value Added (industry) | 0.403*** | 0.068 | 5.95 | 0.000 |
| Unemployment (unempl) | -0.282*** | 0.096 | -2.95 | 0.003 |
| Renewable Energy (renenergy) | 0.136* | 0.070 | 1.94 | 0.052 |
| Constant | -35.412*** | 5.590 | -6.33 | 0.000 |
| Model Statistics | | | Value | |
| Observations | | | 141 | |
| Number of Groups | | | 8 | |
| R-squared (within) | | | 0.558 | |
| R-squared (between) | | | 0.903 | |
| R-squared (overall) | | | 0.620 | |
| Wald Chi-square | | | 215.75 | |
| Prob > Chi-square | | | 0.000 | |
| Sigma_u | | | 0.000 | |
| Sigma_e | | | 4.890 | |
| Rho | | | 0.000 | |

Notes: Random Effects GLS regression estimates. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

**Table C.** Random Effects GLS regression with cluster-robust standard errors adjusted for country clusters (id)

| Variables | Coefficient | Robust Std. Error | z-Statistic | p-Value |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.178 | 0.336 | 0.53 | 0.597 |
| GDP per capita | 0.001* | 0.0007 | 1.81 | 0.070 |
| Gross Capital Formation (gcf) | 0.823*** | 0.145 | 5.67 | 0.000 |
| Foreign Direct Investment (fdi) | -0.735*** | 0.142 | -5.16 | 0.000 |
| Trade Openness (tr) | 0.048 | 0.061 | 0.79 | 0.432 |
| Industrial Value Added (industry) | 0.403*** | 0.125 | 3.22 | 0.001 |
| Unemployment (unempl) | -0.282 | 0.196 | -1.44 | 0.149 |
| Renewable Energy (renenergy) | 0.136 | 0.172 | 0.79 | 0.429 |
| Constant | -35.412** | 15.880 | -2.23 | 0.026 |
| **Model Statistics** | | **Value** | | |
| Observations | | 141 | | |
| Number of Groups | | 8 | | |

| | |
|---|---|
| R-squared (within) | 0.558 |
| R-squared (between) | 0.903 |
| R-squared (overall) | 0.620 |
| Sigma_u | 0.000 |
| Sigma_e | 4.890 |
| Rho | 0.000 |

Notes: Random Effects GLS regression with cluster-robust standard errors adjusted for country clusters (id). *** p<0.01, ** p<0.05, * p<0.10.

**Table D.** Fixed effect results

| Variables | Coefficient | Std. Error | t-Statistic | p-Value |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.025 | 0.189 | 0.13 | 0.896 |
| GDP per capita | 0.003*** | 0.0006 | 5.13 | 0.000 |
| Gross Capital Formation (gcf) | 0.918*** | 0.119 | 7.73 | 0.000 |
| Foreign Direct Investment (fdi) | -0.563*** | 0.097 | -5.79 | 0.000 |
| Trade Openness (tr) | -0.042 | 0.041 | -1.03 | 0.307 |
| Industrial Value Added (industry) | 0.769*** | 0.131 | 5.88 | 0.000 |
| Unemployment (unempl) | 0.006 | 0.203 | 0.03 | 0.976 |
| Renewable Energy (renenergy) | 0.189 | 0.115 | 1.64 | 0.104 |
| Constant | -49.767*** | 9.673 | -5.14 | 0.000 |
| **Model Statistics** | | **Value** | | |
| Observations | | 141 | | |
| Number of Groups | | 8 | | |
| R-squared (within) | | 0.632 | | |
| R-squared (between) | | 0.541 | | |
| R-squared (overall) | | 0.437 | | |
| F-statistic | | 26.80 | | |
| Prob > F | | 0.000 | | |
| Sigma_u | | 7.206 | | |
| Sigma_e | | 4.890 | | |
| Rho | | 0.685 | | |
| FE Test | | Value | | |
| F test that all u_i = 0 | | 4.75 | | |
| Prob > F | | 0.0001 | | |

Notes: FE (within) regression estimates. *** p<0.01, ** p<0.05, * p<0.10.

**Table E.** Hausman test results

| Variables | FE Coefficient (b) | RE Coefficient (B) | Difference (b−B) | Std. Error |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.025 | 0.178 | -0.153 | 0.139 |
| GDP per capita | 0.003 | 0.001 | 0.002 | 0.001 |
| Gross Capital Formation (gcf) | 0.918 | 0.823 | 0.095 | 0.065 |
| Foreign Direct Investment (fdi) | -0.563 | -0.735 | 0.172 | 0.041 |
| Trade Openness (tr) | -0.042 | 0.048 | -0.090 | 0.023 |
| Industrial Value Added (industry) | 0.769 | 0.403 | 0.366 | 0.112 |
| Unemployment (unempl) | 0.006 | -0.282 | 0.289 | 0.179 |
| Renewable Energy (renenergy) | 0.189 | 0.136 | 0.052 | 0.091 |
| **Hausman Test Statistics** | | | **Value** | |
| Chi-square statistic | | | 38.58 | |
| Degrees of freedom | | | 8 | |
| Prob > Chi-square | | | 0.000 | |

Notes: The Hausman specification test compares the FE (FE) and Random Effects (RE) estimators. The null hypothesis assumes that differences in coefficients are not systematic and that the Random Effects estimator is consistent and efficient. The statistically significant test result (p < 0.01) indicates that the FE estimator is preferred over the Random Effects specification.

**Table F.** FE regression with Driscoll-Kraay standard errors

| Variables | Coefficient | Driscoll-Kraay Std. Error | t-Statistic | p-Value |
|---|---|---|---|---|
| PM2.5 Exposure (pm2) | 0.025 | 0.175 | 0.14 | 0.889 |
| GDP per capita | 0.003** | 0.001 | 2.80 | 0.011 |
| Gross Capital Formation (gcf) | 0.918*** | 0.115 | 7.98 | 0.000 |
| Foreign Direct Investment (fdi) | -0.563*** | 0.127 | -4.44 | 0.000 |
| Trade Openness (tr) | -0.042 | 0.065 | -0.65 | 0.524 |
| Industrial Value Added (industry) | 0.769*** | 0.092 | 8.35 | 0.000 |
| Unemployment (unempl) | 0.006 | 0.114 | 0.05 | 0.957 |
| Renewable Energy (renenergy) | 0.189** | 0.082 | 2.31 | 0.032 |
| Constant | -49.767*** | 6.881 | -7.23 | 0.000 |

| Model Statistics | Value |
|---|---|
| Observations | 141 |
| Number of Groups | 8 |
| F-statistic | 320.49 |
| Prob > F | 0.000 |
| Within R-squared | 0.632 |
| Maximum Lag | 2 |

Notes: FE regression with Driscoll-Kraay standard errors correcting for heteroskedasticity, autocorrelation, and cross-sectional dependence. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.