# What Factors Influence Sustainable Growth Worldwide? The Role of Green Finance and Technological Development

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**Abstract**

This study examines the impact of green finance and technological development on sustainable growth in 86 countries, including 40 developed and 46 developing countries, from 2010 to 2024. The study utilizes pooled Ordinary Least Squares (OLS), Fixed Effects (FE), Random Effects (RE), and the Generalized Method of Moments (GMM) to address endogeneity and the dynamics of panel data. Analysis is conducted using two main models, respectively, to assess the direct impact of green finance and technological development on sustainable growth. The study uses control variables including trade openness, foreign direct investment, total natural resources rents, and domestic credit to the private sector. Results from the GMM models show that sustainable growth is highly resilient, as indicated by the Adjusted Net Savings index. Technological development has a positive impact on sustainable growth in both groups of countries, highlighting the crucial role of clean technology in improving resource efficiency. Meanwhile, green finance presents challenges regarding short-term structural transformation costs. Control variables, including trade openness, significantly support sustainable growth; over-reliance on natural resources; and undirected private credit reflect potential macroeconomic risks. These findings underscore the need for flexible policies to promote technological development and effectively manage capital flows toward global sustainable development goals.

**Keywords:** Green Finance, Technological Development, Sustainable Growth

## Introduction

Green finance and technological development are increasingly seen as drivers of sustainable growth through enhanced technological innovation and structural economic shifts towards green sectors (Li et al., 2025). The need for a green financial system is becoming increasingly important to sustain economic growth without depleting natural capital, especially in the context of transitioning to a green growth model (Deng et al., 2024). However, the interaction between green finance and technological development plays a crucial role in shaping the stability and sustainable growth trajectory of countries worldwide. In 2022, global investment in energy transition and green finance reached a record high of US\$1.1 trillion, reflecting a significant shift in global economic strategy. Although traditional financial instruments remain dominant in the global financial system, green financial instruments, particularly green bonds, have grown rapidly since 2020, both in terms of issuance volume and share of total sustainable debt (Climate Bonds Initiative, 2024).

Despite its global importance, this research problem has not been fully considered: How do the development of green finance and technological advancements asymmetrically affect sustainable growth in developed versus developing countries, and what explains the differing responses observed in the empirical literature? This topic goes beyond mere economic inquiry, representing a central theme in current social science discussions concerning "green growth," technological transition, ecological inequality, and the political economy of climate policies. Traditional economic theory often assumes a linear impact of capital investment; However, modern studies have refuted this view, discovering nonlinear effects and a threshold at which green finance truly exerts a positive impact (Lee & Lee, 2022; Desalegn et al., 2022). Particularly in developing economies, the lack of technological infrastructure and an incomplete financial regulatory framework makes analyzing this interaction more urgent than ever.

The need for this research is further strengthened by considering the latest empirical evidence. Sun et al. (2025) pointed out that institutional quality plays a fundamental role in transforming green capital into sustainable development outcomes, through ensuring transparency, efficient resource allocation, and a stable policy environment. Kafeel et al. (2024) shows that green innovation plays a crucial role in improving environmental quality in OECD countries, through intermediary channels such as renewable energy development and carbon tax mechanisms, emphasizing that environmental technological progress is a necessary condition for sustainable policies and financial instruments to be truly effective. Xiong and Dai (2023) point out that green finance has a positive impact on sustainable growth, and the role of technological development and renewable energy plays a crucial role in improving environmental efficiency, thereby promoting sustainable growth. In the context of emerging economies, both green finance and technological innovation are important factors in promoting sustainable economic growth (Ali et al., 2024). Conversely, Gul et al. (2025) indicates that the impact of green finance and green innovation on sustainable development is non-linear and dependent on the economic and technical conditions of each country. This result helps explain the inconsistencies in previous studies and emphasizes the need for dynamic analytical methods capable of addressing endogeneity in multinational studies. In particular, most current studies still have several major limitations. First, many studies consider green finance or technological innovation individually, without analyzing the interactive role between these two factors. Second, traditional measures of sustainable

growth do not fully reflect the accumulation of natural and human capital. Third, differences between groups of countries according to development level have not been systematically analyzed within a dynamic framework and appropriate endogeneity handling.

Therefore, stemming from the theoretical and empirical gaps that exist in the existing literature, this research directly addresses them. Firstly, the study constructs an integrated analytical framework that simultaneously examines green finance and technological development, rather than considering each element individually as most previous studies have done. Secondly, by utilizing the Adjusted Net Savings (ANS) index, the study overcomes the limitations of traditional measures in reflecting the multidimensionality of sustainable growth. Finally, the analysis on a multinational sample including both developed and developing economies allows for more generalized conclusions about the effectiveness of green finance and technological development in different development contexts. The objective of this study is to develop an integrated analytical framework for green finance and technological development in explaining sustainable growth, using the Adjusted Net Savings (ANS) index as a central measure. It aims to clearly identify the mechanisms by which green finance and technological development impact sustainable growth, thereby providing empirical evidence for designing strategies aligned with the Sustainable Development Goals (SDGs).

This study expands on existing literature by analyzing data from 86 countries, selected based on the availability of green bond issuance data, and categorized into 40 developed countries and 46 developed countries for the period from 2010 to 2024, using a dynamic panel model and the GMM system. This approach thoroughly addresses endogeneity issues, captures lagged effects, and distinguishes short-term versus long-term impacts. Integrating essential macroeconomic control variables such as trade openness, foreign direct investment, natural resource income, private sector credit, and human resources provides a comprehensive framework for understanding the interaction between green finance, technological development, and sustainable growth.

In this way, this study addresses a crucial empirical gap and enhances understanding of the mechanisms driving sustainable development in the global digital economy era. The research findings not only enrich the body of environmental economics theory but also provide evidence-based insights for countries to optimize the integration of finance and technology, moving towards a greener and more sustainable future.

## Literature Review

Currently, the nexus between green finance and sustainable growth is frequently discussed, especially as nations worldwide are actively promoting sustainable growth and global climate mitigation. For example, studies by Tufail et al. (2024) and Fu et al. (2023) both support the view that green finance promotes green growth in countries and emphasize the crucial role of substantial investments in green and low-carbon initiatives to effectively address climate change and promote sustainable economic growth. Despite its many benefits, green finance may also have negative impacts if it is not effectively regulated and managed. According to Nguyễn et al. (2024), the authors concluded that when the regulatory role of renewable energy and green manufacturing is ignored, green finance negatively impacts green growth. Nevertheless, some studies still suggest that the impact of green

finance on sustainable growth is not unidirectional. For example, Yin et al. (2022) pointed out that in China, the level of coordination between green finance and economic growth is low, and there is no effective link with structural transformation of industries and environmental protection. In synthesis, research findings show that the impact of green finance on sustainable growth is heterogeneous. Some studies affirm a positive outcome, while others point to risks, challenges, or ambiguities in the relationship between green finance and sustainable growth.

In recent years, the impact of technological development on sustainable growth has remained a widely discussed topic, with numerous research findings highlighting both positive and negative aspects. According to Omri (2020), it showed that technological development simultaneously contributes to the three pillars of sustainable growth in major developed countries. Although technological development is recognized as a driver of sustainable growth and profitability (Nguyen et al., 2019), risks from AI such as resource depletion and electronic waste remain significant challenges (Dauvergne, 2020). In particular, the effectiveness of technology is not uniform across economies (Omri, 2020). Consequently, experiments at different stages will yield different results, but most current studies show a positive outlook on technological development for sustainable growth. In this study, the research team will re-examine this impact to provide a more comprehensive analysis.

A preponderance of studies suggests that trade openness has a negative impact on sustainable growth. Zhou et al. (2024) used a two-step SYS-GMM method to analyze the impact of energy, trade openness, and institutions on environmental sustainability in 54 African countries (1996–2019). These analyses yielded six key findings, including that trade openness hinders environmental sustainability. Conversely, alternative empirical evidence has demonstrated that trade openness also has a positive impact on sustainable growth. The study by Ulhaq et al. (2023) analyzed the impact of trade openness on sustainability for G20 countries from 1990 to 2019, suggesting that in the long term, sustainable growth is significantly and positively influenced by trade openness. Overall, the relationship between trade openness and sustainable growth presents conflicting evidence, therefore further research and consideration with diverse data and methodologies is warranted to establish more conclusive evidence.

Extensive empirical evidence suggests that foreign direct investment (FDI) has a positive impact on sustainable growth. Aust et al. (2020) used multivariate analysis and an ordered probit model across 44 African countries to assess the role of FDI in the Sustainable Development Goals (SDGs). The results confirmed that FDI has a positive impact, creating a foundation for attracting investment to the region. Conversely, alternative evidence indicates that foreign direct investment has a negative impact on sustainable growth. Specifically, Arthur et al. (2024) used the GMM-PVAR model to examine the causal relationship between FDI and sustainable growth in 48 African economies (1990–2020). Using measures such as Adjusted Net Savings (ANS) and the Sustainable Economic Growth Index (SEG), the study indicated that FDI had a significant negative impact on sustainable development in the region. Collectively, these studies demonstrate that the impact of foreign direct investment on sustainable growth remains heterogeneous. Thus, further empirical investigation employing robust methodologies and comprehensive data sources is warranted to establish conclusive evidence.

Extensive research indicates that domestic credit to private sector has an inverse effect on sustainable growth. Byaro et al. (2024) examined the impact of domestic credit to the private sector on CO2 emissions in 34 African countries between 2000 and 2020. The study found that domestic credit to the private sector in African countries represents a cause of increased CO2 emissions across all percentiles (10-90%). Nwani et al. (2020) used the Dynamic ARDL technique to analyze the impact of bank credit on $CO_2$ emissions in Brazil (1971-2014). The results showed that private sector credit had a significant negative impact on total emissions and intensity in both the short and long term. This model was built on an analytical framework that combined population, economic growth, fossil fuel consumption, and globalization. Therefore, the relationship of domestic private sector credit on sustainable growth presents conflicting evidence, thus, further empirical investigation employing robust methodologies is warranted.

Extensive research suggests that total natural resources rents exert a beneficial impact on sustainable growth. Ullah et al. (2021) used the Panel Smooth Transition model to examine the nonlinear relationship between renewable energy consumption, resource leases, and ecological sustainability in 15 leading renewable energy countries (1996-2018). The results showed that resource leases positively impact the ecological footprint at both thresholds (low and high), although other empirical evidence suggests this impact is heterogeneous with respect to sustainable growth. Arslan et al. (2022) indicates that natural resources improve environmental sustainability but reduce economic growth. In contrast, there are also studies showing that total natural resources rents negatively impact sustainable growth. For example, Ulucak et al. (2020) analyzed the impact of the allocation of energy and natural resource consumption on environmental sustainability in OECD countries. It concluded that the exploitation of natural resources increases CO2 emissions, thereby undermining sustainable growth. Collectively, the results of these studies demonstrate that the impact of total natural resources rents on sustainable growth presents conflicting evidence. Therefore, further research, analysis, and more specific and objective impact assessments are warranted.

## Methodology
### Data Source and Measurement
This study uses panel data collected from 86 countries, including 40 developed countries and 46 developping countries comprising Australia, Austria, Belgium, Bermuda, Canada, Cayman Islands, Croatia, Rep. of, Cyprus, Czech Rep., China, P.R.: Hong Kong, China, P.R.: Macao, Denmark, Estonia, Rep. of, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Korea, Rep. of, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, The, New Zealand, Norway, Portugal, Singapore, Slovak Rep., Slovenia, Rep. of, Spain, Sweden, United Kingdom, United States, Argentina, Bangladesh, Belarus, Rep. of, Brazil, Colombia, Costa Rica, Côte d'Ivoire, Chile, China, P.R.: Mainland, Egypt, Arab Rep. of, Fiji, Rep. of, Georgia, Honduras, Hungary, India, Indonesia, Kazakhstan, Rep. of, Kenya, Lao People's Dem. Rep., Malaysia, Marshall Islands, Rep. of, Mauritius, Mexico, Mongolia, Morocco, Namibia, Nigeria, Pakistan, Panama, Peru, Poland, Rep. of, Philippines, Qatar, Romania, Russian Federation, Saudi Arabia, Serbia, Rep. of, Seychelles, South Africa, Turkey, Rep. of, Thailand, Ukraine, United Arab Emirates, Uzbekistan, Rep. of, Venezuela, Rep. Bolivarian de, Vietnam. The research dataset was collected from the World Bank Database and IMF Database for the period 2010-2024.

*Variable Description*

To assess the impact of green finance and technological innovation on the countries' sustainable development levels, the team incorporated the following variables:

Adjusted Net Savings (ANS): The Adjusted Net Savings index was introduced by the World Bank as an indicator to measure the level of sustainable development of an economy (Boos, 2015; Everett & Wilks, 1999; Jha et al., 2018). It is considered a proxy variable for sustainable growth. This index measures the actual savings in production, natural capital, and human capital after adjusting for the depletion of natural resources. Specifically, ANS subtracts fixed capital consumption (CFCs) and the depletion of natural resources (such as minerals, forests, energy) as well as losses due to carbon dioxide ($CO_2$) emissions from Gross National Income (GNI) (Chang, 2011; World Bank, 2011).

Green bonds (GB): Green bonds are fixed-income securities explicitly designed to support climate and environmental projects. The research group utilized GB as the primary indicator of green finance. with data sourced from the IMF Database. This is a fixed-income instrument, where the proceeds are dedicated to financing, refinancing, new and/or existing green projects. Empirical evidence demonstrates that GB serves as an independent variable, such as the study by Bhutta et al. (2022), which emphasizes green bonds as a financial instrument to finance these tasks, providing capital for green projects. Furthermore, the study also points out the characteristics of green bonds and their distinctive features and competitive advantages relative to alternative instruments of financial securities and suggests some directions for future research.

Research and development expenditure (RD): Gross domestic expenditures on research and development (R&D), expressed as a percentage of GDP. They include both capital and current expenditures in the four main sectors: Business enterprise, Government, Higher education, and Private non-profit. R&D covers basic research, applied research, and experimental development (World Bank, 2025). Data is sourced from Our World in Data (OWID). Several studies have also used RD as an independent variable, such as Fernández et al. (2018) when analyzing the impact of R&D spending on CO2 emissions in the European Union, the United States, and China during 1990-2013. The study employed a linear regression model with ordinary least squares methodology, and the model results supported the hypothesis that RD contributes positively to developed countries. The results showed that RD in China significantly enhances sustainable innovation, and this impact mediated pathways to R&D cooperation and investment networks.

Trade openness (TRADE): Trade is the sum of exports and imports of goods and services. This indicator is expressed as a percentage of Gross Domestic Product (GDP), which is the total income earned through the production of goods and services in an economic territory during an accounting period. Trade data for various countries is collected from Our World in Data (OWID). Trade has been extensively employed in empirical research and has demonstrated significant influence on sustainable development; however, these conclusions remain contradictory. Some scholars posit that trade exerts positive effects on sustainable development, such as the study by Sheihk et al. (2020). This study empirically examined the effects of trade liberalization on sustainable development in India since the liberalization policy of 1991. The empirical results contradicted conventional expectations, showing that

trade is inversely correlated with green GDP growth and positively correlated with the gap between traditional GDP and green GDP.

Domestic credit to private sector (DCPS): Domestic credit to the private sector refers to financial resources provided to the private sector by financial corporations, such as through loans, purchases of nonquity securities, trade credits and other accounts receivable, that establish a claim for repayment. For some countries, these debt claims include credit to state-owned enterprises. Data on domestic DCPS for various countries is collected from Our World in Data (OWID). Many studies worldwide also use the FD variable, such as those by Park et al., (2018) and Shahbaz et al., (2013).

Foreign direct investment (FDI): FDI data collected from Our World in Data measures the amount of foreign direct investment flowing into a country in a year. FDI promotes economic growth in any country by mobilizing capital, increasing labor productivity, promoting technological progress, etc. Izadi et al. (2023) studied the potential impact of FDI on Sustainable Development in Eurasian countries, considering a sample of 78 Eurasian countries, classified by income group. A fixed-effects regression model was used to investigate the relationship between FDI and the SDG index. The research results showed that FDI has a positive and significant impact on the SDG index. However, in the study by Ayamba et al. (2020) in China, it was found that FDI does not have a significant impact on sustainable development.

Total natural resources rents (RENT): Total natural resources rents constitute the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents (World Bank). RENT data is collected from Our World in Data. Krokmaz et al. (2022) studied the causal relationship between oil/coal/natural gas consumption, returns from coal/oil/natural gas, and economic growth in the context of the Russian Federation. The authors used data from 1992 to 2018 and the ARDL Bounds test. Empirical results showed a long-term relationship between all variables in the Russian Federation. The results indicate returns from oil have a positive impact on economic growth, while returns from natural gas and coal have a negative impact on economic growth.

*Model Specification*
This study uses two methods as follows:

Model 1: Studying the impact of green finance on sustainable growth:

$$ANS_{i,t} = \beta_0 + \beta_1 GB_{i,t} + \beta_2 TRADE_{i,t} + \beta_3 FDI_{i,t} + \beta_4 RENT_{i,t} + \beta_5 DCPS_{i,t} + \varepsilon_t$$

Model 2: Studying the impact of technological innovation on sustainable growth

$$ANS_{i,t} = \beta_0 + \beta_1 RD_{i,t} + \beta_2 TRADE_{i,t} + \beta_3 FDI_{i,t} + \beta_4 RENT_{i,t} + \beta_5 DCPS_{i,t} + \varepsilon_t$$

Where*:*

ANS represents the sustainable growth index of countries, acting as the dependent variable. GB represents green finance, and RD represents technological development; these are the two independent variables of the model. TRADE, FDI, RENT, and DCPS respectively represent trade openness, foreign direct investment, total natural resources rents, and domestic credit to private sector; these are the control variables in the model, which are factors affecting sustainable growth.

*Estimation Method*

To systematically assess the impact of green finance and technological development on sustainable growth, the study uses data regression. Given the nature of macroeconomic variables, which often exhibit lags and bidirectional causal relationships, the authors chose the Generalized Moment Estimation (GMM) method to test the relationship between green finance, development, and sustainable growth.

Furthermore, to test the stability and reliability of the GMM estimation results, the research team conducted robust tests using econometric models, including the Pooled Ordinary Least Squares method, which treats all observations as independent and ignores potential entity- or time-specific effects. To account for unobservable individual differences, we applied both random effects (assuming entity effects are uncorrelated with regression variables) and fixed effects (controlling for all unobservable variables that do not change over time by focusing on variability within the entity) and then compared the results with those from GMMs. The use of multiple models allows for testing consistency and reliability in assessing the impact of green finance and technological innovation on sustainable growth.

**Results and Discussion**

Firstly, regarding Model 1, the impact of green finance on sustainable growth:

Table 1

*Impact of green finance on sustainable growth*

| Variables | Developed countries | | | | Developing countries | | | |
|---|---|---|---|---|---|---|---|---|
| | Pool OLS | Random Effect | Fixed Effect | GMM | Pool OLS | Random Effect | Fixed Effect | GMM |
| L.ANS | | | | 0.2129*** (0.009) | | | | 0.7336*** (0.000) |
| GB | -13.8042 (0.168) | -0.0569 (0.992) | 0.7759 (0.889) | -23.6594** (0.020) | -11.1588 (0.718) | -72.3853** (0.042) | -64.9945* (0.071) | -25.906*** (0.001) |
| TRADE | 6.5976*** (0.000) | 2.6275*** (0.005) | 1.1756 (0.326) | 4.6928*** (0.000) | 5.2619*** (0.000) | 6.6557*** (0.000) | 6.7185*** (0.000) | 2.2249*** (0.003) |
| FDI | -0.5204* (0.055) | 0.1468 (0.301) | 0.1429 (0.312) | -0.3612*** (0.003) | -1.3707*** (0.006 ) | -0.3922 (0.173) | -0.3466 (0.232) | -0.5470*** (0.007) |
| RENT | 93.7124*** (0.000) | 12.9017 (0.559) | 1.3381 (0.954) | 61.0094 (0.126) | 17.9231*** (0.003) | 11.5633** (0.025) | 9.4434* (0.080) | 0.7269 (0.774) |
| DCPS | 2.9874*** (0.000) | -4.0783*** (0.000) | -4.9621*** (0.000) | 1.2412 (0.286) | 1.9526 (0.104) | -6.760*** (0.000) | -8.5868*** (0.000) | -0.3706 (0.445) |
| __cons | -0.0344 (0.978) | 11.7326*** (0.000) | 14.4654*** (0.000) | 1.5620 (0.406) | 4.6987*** (0.000) | 8.6196*** (0.000) | 9.3149*** (0.000) | 1.2241** (0.040) |
| N | 392 | 392 | 392 | 359 | 426 | 426 | 426 | 388 |
| R-squared | 0.3258 | 0.1521 | 0.1573 | | 0.0979 | 0.1409 | 0.1430 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **S test** | | | | 0.001 | | | 0.003 |
| **H test** | | | | 0.221 | | | 0.177 |
| **AR (1)** | | | | 0.023 | | | 0.001 |
| **AR (2)** | | | | 0.954 | | | 0.497 |

*Note: *, ** and *** depict 10%, 5% and 1% level of significance respectively.*

Table 1 examines the impact of green finance on sustainable growth, where the columns present the model results with the dependent variable ANS, using the Generalized Systematics (GMM) estimation method. This estimation method is based on available data from 86 countries, including 40 developed countries and 46 developing countries, from 2010 to 2024. The GMM method is suitable for our data because the number of countries exceeds the number of years (N > T). The results from model (1) show that the coefficient of the green finance variable (GB) is negative and statistically significant in both groups of countries. Specifically, in the group of developed countries, the GB coefficient is -23.6594 and is significant at the 5% level, while in the group of developing countries, this coefficient is -25.906 with a significance level of 1%. This suggests that in the short term, the increase in green finance may slow economic growth, and this impact is stronger in developing countries.

These results are consistent with the research of Sachs et al. (2019), which argues that initial green investments often come with high switching costs, including clean technology costs, environmental compliance costs, and production restructuring costs, increasing the short-term financial burden. For developed countries, although the green financial system and capital markets are relatively mature, the rapid expansion of green finance instruments can still put pressure on capital efficiency in the short term. Similarly, Taghizadeh-Hesary et al. (2020) also point out that in developing economies, the efficiency of green capital allocation is limited due to the immature financial markets and inconsistent policy frameworks.

The negative impacts of green finance become more apparent in developing countries due to structural limitations. According to Taghizadeh-Hesary et al. (2020), in developing economies, the green finance market is nascent and the capacity to absorb green technologies is limited. Therefore, green capital is at risk of being allocated inefficiently, or even used for "greenwashing" projects, undermining the overall efficiency of the economy. Furthermore, prioritizing green finance in the context of limited financial resources may reduce investment in traditional economic sectors, which still play a crucial role in job creation in these countries.

The regression results show that the coefficients of the lagged variable (L.Growth) are both positive and statistically significant at the 1% level in both groups of countries. Specifically, this coefficient is 0.2129 in the group of developed countries, while it is 0.7336 in the group of developing countries. This result reflects the sustained nature of economic growth over time, particularly evident in developing countries, where the current growth trajectory is strongly dependent on the results of previous periods.

The study suggests that the benefits of green finance for growth are typically only realized in the medium and long term through technological innovation and improved energy efficiency (Banga, 2019; Zhou et al., 2020). Therefore, the observed negative impact may reflect the early stages of the green transition, when adjustment costs outweigh the benefits

gained. The results indicate a higher sensitivity of growth to green finance in the group of developing countries, implying that these countries face greater adjustment pressure due to technological limitations and governance capacity constraints. This finding is consistent with the argument of Aghion et al. (2019), which states that the effectiveness of green policies strongly depends on the level of development of the financial market and innovation capacity.

The combined results show that the impact of green finance on sustainable growth is heterogeneous between the two groups of countries and reflects the characteristics of the initial transition phase, where adjustment costs may outweigh long-term benefits. This implies that for green finance to truly play a role in promoting sustainable growth, supporting conditions are needed regarding technological capacity, financial market quality, and efficient capital allocation, especially in developing countries.

Secondly, regarding model 2, the impact of green finance on sustainable growth. Table 2 presents the regression results, showing that the coefficient of the technological development (RD) variable is positive in both groups of countries, with values of 1.3460 for the developed group and 5.8535 for the developing group, respectively. These coefficients are statistically significant at the 5% level in developed countries and 10% in developing countries, confirming that increased investment in technological development plays a crucial role in promoting sustainable growth.

Table 2
*Impact of technological development on sustainable growth*

| Variables | Developed countries | | | | Developing countries | | | |
|---|---|---|---|---|---|---|---|---|
| | Pool OLS | Random Effect | Fixed Effect | GMM | Pool OLS | Random Effect | Fixed Effect | GMM |
| L.ANS | | | | 0.5072*** (0.000) | | | | 0.6488*** (0.000) |
| RD | 4.1431*** (0.000) | 1.3126*** (0.003) | -0.1115 (0.825) | 1.3460** (0.021) | -0.5740 (0.558) | 3.3141** (0.011) | 3.9787*** (0.005) | 5.8535* (0.075) |
| TRADE | 6.5976*** (0.000) | 7.3065*** (0.000) | 3.6772*** (0.000) | 3.2460*** (0.000) | 5.1407*** (0.000) | 6.3283** (0.000) | 6.3960*** (0.000) | 3.890** (0.014) |
| FDI | -0.5204* (0.055) | -0.0941 (0.648) | 0.1317 (0.366) | -0.1630 (0.287) | -1.3861*** (0.005) | -0.3339 (0.239) | -0.3061 (0.283) | -0.528 (0.511) |
| RENT | 93.7124*** (0.000) | 135.9417** (0.000) | 31.3882 (0.152) | 50.7745* (0.047) | 17.8541** (0.004 ) | 11.960** (0.074) | 9.5664* (0.074) | 11.575* (0.051) |
| DCPS | 2.9874*** (0.000) | 1.1608** (0.021) | -3.4731** (0.000) | 0.1904 (0.781) | 2.2852* (0.053) | -8.5214** (0.019) | -10.6457** (0.000) | -3.707* (0.093) |
| __cons | -0.0344 (0.978) | -8.46108*** (0.000) | 7.0341** (0.000) | -1.8344 (0.252) | 4.930*** (0.000) | 7.9243** (0.000) | 8.4311*** (0.000) | -1.130 (0.397) |
| N | 392 | 392 | 392 | 359 | 426 | 426 | 426 | 352 |

| R-squared | 0.3258 | 0.6162 | 0.1229 | | 0.0986 | 0.1512 | 0.1535 | |
|---|---|---|---|---|---|---|---|---|
| S test | | | | 0.029 | | | | 0.006 |
| H test | | | | 0.145 | | | | 0.347 |
| AR(1) | | | | 0.004 | | | | 0.001 |
| AR(2) | | | | 0.926 | | | | 0.484 |

Note: *, ** and *** depict 10%, 5% and 1% level of significance respectively.

Notably, the impact of technological development is significantly stronger in developing countries than in developed countries. This finding is consistent with the argument of Aghion et al. (2019), which argues that technological development is a key factor in improving productivity, optimizing resource use, and reducing emission intensity. In developing countries, technological development creates a "catch-up effect," helping these economies transition from resource-intensive to more efficient production models, thereby generating leaps in sustainable growth. Conversely, in developed countries, due to their highly mature technological infrastructure, the marginal impact of R&D investment tends to be lower.

This result is also consistent with classic studies by Grossman and Krueger (1995), which emphasize that technological development is a tool to address the trade-off between economic growth and environmental protection. Particularly in the context of developing countries facing the pressure of rapid growth coupled with environmental degradation, investment in clean technology and R&D help break the pollution cycle. However, the statistical significance of the R&D variable in the group of developing countries is only 10%, reflecting the reality that the effectiveness of technological development is still hampered by institutional limitations, the quality of human resources, and the ability to commercialize research results.

In short, the empirical results confirm that technological development is the central driver of sustainable growth. To maximize this benefit, the study suggests that developing countries need to simultaneously invest in R&D by improving the institutional environment and enhancing the market's capacity to absorb technology.

Regarding the control variables, trade openness (TRADE) shows a positive and statistically significant impact in both groups of countries, confirming its role in promoting growth through international integration. Conversely, foreign direct investment (FDI) has a negative coefficient, reflecting the challenges of this capital flow to sustainable development goals in the early stages of the transition process. Resource rent (RENT) has a positive impact, particularly significant in the technology development model, demonstrating the important contribution of natural resources to economies of scale. Finally, private sector credit (DCPS) is not statistically significant in developed countries but shows a negative impact in developing countries in the technology model, suggesting limitations in the efficiency of capital allocation within the financial system.

## Conclusion and Policy Implications

Against the backdrop of increasingly serious global challenges regarding environmental degradation, climate change, and pressure to shift growth models, the research finds Yield significant academic and policy implications. Firstly, the study emphasizes

that green finance and technological innovation constitute essential pillars of sustainable growth strategies, particularly in developing countries. Expanding green finance tools, combined with promoting investment in technological innovation, generate positive externalities and spillover effects, supporting economic growth while reducing pressure on the natural environment. Secondly, the differences in results between the two groups of countries suggest that they is not applicable to all nations. Developing countries must prioritize institutional strengthening institutional quality alongside expanding green finance, while developed countries should prioritize enhancing the effectiveness of technology innovation policies and reducing adjustment costs during the green transition.

Prioritizing investment in research, development, and transfer of green technologies is crucial to effectively leveraging the advantages of technological catch-up in developing countries. First, in the legal sphere: Developing countries must refine their legal frameworks and specific policies, such as tax incentives, corporate income tax exemptions and reductions, interest rate subsidies for green technology projects, credit guarantees, and ESG standards. Such measures are reduced for investors and create a transparent and favorable legal environment. Tax incentives for R&D and green technologies can mitigate fiscal constraints on businesses, encourage investment in innovative research, and increase the adoption of environmentally friendly solutions. In parallel, developing countries must prioritize investment in research and development of green technologies in developing countries – a critical imperative to overcome the technology trap and achieve sustainable modern industrialization. Furthermore, complementing domestic efforts, these nations should facilitate the transfer of green technologies from technological leaders houses through multilateral mechanisms. This is key to shortening the development path and technological convergence. Strategic partnerships with financial institutions and investment funds will strengthen access to green patent databases and validate technological innovations for businesses in developing countries. Financing strategies should encompass, including both through attracting indirect green FDI and through direct investment projects coupled with agreements to transfer technology to the recipient. Simultaneously, the application of financial instruments such as green bonds or concessional credit facilities will mobilize critical resources for domestic businesses to effectively acquire and deploy new technologies. The synergy between targeted R&D and coordinated technology dissemination establishes a comprehensive innovation ecosystem, helping developing countries achieve economic growth and the while preserving of natural capital for the future.

Developing specific green finance mechanisms linked to a flexible transition roadmap are designed to mitigate structural adjustment costs and liquidity risks in accessing green capital. Countries should prioritize building a flexible financial ecosystem to reduce liquidity pressures and transition costs. The focus of policy should be on establishing a phased transition roadmap, allowing businesses to gradually adapt to environmental standards instead of imposing abrupt regulatory tightening. In addition, the government needs to establish stabilization funds or specific credit guarantee mechanisms for green projects to support businesses during the initial investment phase in infrastructure, which has a long payback period. Financial institutions systematically deploy credit models linked to sustainable performance, where interest rates are gradually reduced based on the level of achievement of environmental targets. Simultaneously, policies are needed to support compliance costs, such as subsidies for green audit fees and international certification costs,

helping businesses reduce non-productive financial pressure, thereby creating a real incentive to achieve economic greening without weakening competitiveness. Implementing these recommendations requires synchronized and coordinated collaboration among state management agencies and the financial system, from the Central Bank, the Ministry of Finance, the Ministry of Planning and Investment, commercial banks, and credit institutions, to effectively track capital allocation and ensure that green capital flows truly contribute to long-term sustainable objectives goals.

Establishing a flexible policy framework for sustainable growth, focusing on enhancing capital absorption capacity in developing countries and optimizing the innovation ecosystem in developed countries. To achieve sustainable growth, the authors propose several policies adapted to the economic characteristics of each group of countries. For developed countries, it is necessary to reinforce and enhance stringent environmental standards through ESG standards. Governments need to strengthen green finance policies and establish binding requirements to ensure reductions derived from domestic emissions come from technological innovation and changes in the energy structure, rather than carbon leakage to developing nations. For developing countries, the focus is on improving governance capacity to optimize foreign capital flows. The authors propose two strategic solutions: First, governments need to make the green classification system more transparent. Specifically, the government needs to issue clear and specific criteria for what constitutes a green project based on international standards. This will help prevent foreign capital from being misused for polluting projects under the guise of sustainability. Second, it is necessary to improve the assessment and implementation capacity of officials. Public administration capacity needs to be enhanced at all levels, from central to local, by organizing in-depth training sessions for officials on sustainable project assessment skills and environmental risk management. This will help countries select projects and use capital effectively to achieve sustainable results. In both groups of countries, businesses must have long-term green transition roadmaps, transparently disclose information, and optimize their internal governance. Financial intermediaries such as banks also need to strengthen institutional capabilities by integrating ESG standards into their assessment processes and diversifying green financial products.

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