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Exploring the role of Green Innovation in Green Development around the world: Implications for Economic Growth

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ABSTRACT

The aim of this research was to conduct an in-depth analysis of green innovation's influence on green development by examining how these effects may change based on factors like a country's gross capital formation, digital transformation, and education levels. Subsequently, green innovation was tested for its role in strengthening the previously established positive relationship between green development and economic growth, according to past studies. Country-level data from 161 nations, including 20 developed countries and 141 developing countries, spanning 1975 to 2022 was collected from sources namely the World Bank National Accounts Data and OECD Data, resulting in over 3,089 unique data observations. Results from multiple linear regression models showed that advances in green innovation correlate with increased green development. Further analysis indicates these impacts are more pronounced for countries with higher gross capital formation, greater digital transformation, or higher education levels. Finally, the study found that the positive link between green development and economic growth appears to be strengthened by high levels of green innovation.

Keywords: Green Innovation, Eco-innovation, Green Development, Economic Growth.

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List of Abbreviations

AGR	Agriculture, forestry and fishing rate
AI	Artificial Intelligence
AR(2)	Arellano-Bond test order 2
BRICS	BRICS countries (Brazil, Russia, India, China, South Africa,…)
CO2	Carbon Dioxide
CPC	Consumer Price Inflation
DI	Digital Inclusion
DTF	Digital Transformation
Eco-friendly	Environmentally friendly
EcoII	Eco-innovation Index
EDSII	European Digital Social Innovation Index
EII	European Innovation Index
EU	European Union
GCF	Gross Capital Formation
GD	Green Development
GDP	Gross Domestic Product
GI	Green Innovation
GLS	Generalized Least Squares
GMM	Generalized Method of Moments
HRM	Human Resource Management
ICT	Information and Communication Technology
IDU	Industrialization rate
IMF	International Monetary Fund
INF	Inflation rate
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ln(POP) or l_POP	The natural logarithm of Population
max	maximum
min	minimum
MLR	Multiple Linear Regression
OECD	Organization of Economic Co-operation and Development
OER	Official exchange rate
R&D	Research and Development
SDGs	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Program
UPOP	Urbanization rate

VIF	Variance Inflation Factor
WTO	World Trade Organization
β	Beta (the coefficient)

1. INTRODUCTION

1.1. Research problem

Environmental sustainability has become essential to reaching the Sustainable Development Goals (SDGs) due to the growing environmental difficulties brought about by economic growth (Janowski, 2016; Ufua et al., 2021). In order to satisfy the demands of social and economic growth while protecting natural surroundings, this emphasis entails finding a balance between the economy, society, and environment (Ma and Zhu, 2022; Ni et al., 2022). Recent years have seen a number of environmental and climate change-related issues throughout the world due to industrial expansion and technology developments. Globally speaking, a large portion of innovation falls well short of environmental care. Green innovation was created to adopt questions for minimizing the detrimental effects of renewal on the environment in order to ensure the best possible answer to these challenges. There is a dearth of thorough knowledge on how green innovation and green development interact and support environmental sustainability on a global scale, despite the rising interest in these ideas.

As green innovation may create goods, processes, services, and technology to achieve both economic and environmental advantages, it has been acknowledged as the key to reaching the objective of environmental sustainability (J. Zhang et al., 2020; S. Yin and Yu, 2022; Luo et al., 2023). Scholars now disagree on how well governments could implement governance measures to support green innovation in local communities for environmental sustainability. Government policies, particularly in developing nations, are a major factor in motivating SMEs to switch to ecologically friendly industrial practices (Wasiq et al., 2023). The SMEs in South Korea and Malaysia changed from conventional to contemporary technology in their manufacturing processes as a result of the government's engagement in policy formulation (Arfi et al., 2018). Therefore, in order to convince SMEs to embrace GI practices and technology, government intervention policies are now required. Furthermore, and this is a critical component, encouraging green innovation in SMEs calls for outside collaboration and engagement. Firm capabilities are considered important market resources, and inter-firm cooperation has become more significant as a way to arrange and use marketing resources for improved competitive advantage and information exchange between internal and external parties (Wang et al., 2021; Alraja et al., 2022). Furthermore, there are currently more green customers, and there is a growing awareness of the creation of green products (Alfonso et al., 2018). One strategy to incentivize SMEs to invest in green infrastructure (GI) is to leverage consumer demand for eco-friendly, innovative products (Arsawan et al., 2021). Clients are also the ultimate users of the merchandise. As a result, their desires could influence manufacturers to adopt GI more than other considerations. According to a number of studies, businesses that depend on green infrastructure (GI) are more successful and thriving than their rivals because they employ their pool of green resources to quickly meet client needs (Del Giudice et a.l, 2018). A company's adoption of green purchasing is influenced by a number of internal variables, such as management pledges, supplier partnerships, and pressure from customers and regulations. As a result, managerial commitment and the implementation of green technology are directly correlated (Yin et al., 2021). Adoption of green technologies and management philosophy have a strong correlation. Conversely, human resource management (HRM) has a good impact on GI and products, and HRM practices that promote a commitment culture have a favorable and substantial impact on businesses' creative orientation (Jun et al., 2019; Wang et al., 2020). Moreover, this study discovers that in companies with progressive cultures and flat organizational structures, strategic HRM has a beneficial influence on product innovation. The fundamental distinction between developing and developed nations lies at the core of the GI problem; certain research indicates that poorer nations may find it more challenging to seize chances presented by green innovation. To be more precise, these nations might not have the technological, financial, or human resources required to create and implement green technology. Developed nations may have greater resources than less developed nations, making it easier for them to get and use green technology. However, in order to encourage green innovation and sustainable growth, both sets of nations must put in place the necessary legislative measures (Wasiq et al., 2023).

China, as the world's largest developing nation, stands to gain from investigating a workable model of green development, as well as from offering China's answer to other nations looking to reduce their green emissions (Tang & Zhang, 2023). As a result, China is aggressively implementing a number of initiatives to assume its share of the necessary carbon emission reduction responsibilities. China's 2015 Opinions on Accelerating the Construction of Ecological Civilization made it apparent that it will pursue "green development" for the first time. The idea of "people-oriented, resource conservation, and environmental protection" was presented as the cornerstone of green growth in the same year by the Third Plenary Session of the 18th CPC Central Committee. Since then, low-carbon and green development have become the dominant trends in China's economic development. China's 20th National Congress report from 2022 reiterated that "promoting green development and promoting harmonious coexistence between man and nature" is the development aim. Thus, it is especially crucial to investigate workable avenues for achieving green growth.

The purpose of this study is to examine the relationship between green innovation and green development at the global scale. The empirical findings of this study, which show how shifts in green innovation affect green development, corroborate the fundamental conclusion. We used the GMM approach to investigate the connection between green innovation and development in order to gain more insight. Additionally, we investigate whether these connections vary among nations by employing factors of differentiation that separate country groupings, such as digital transformation (DTF), education (EDU), and gross capital formation (GCF). Lastly, we look at how green innovation affects the connection between green development and economic growth—a topic that has been the subject of several previous studies (Tawiah et al., 2021).

1.2. Research aims and questions

This study’s objective is to determine the impact of green innovation on green development. In addition, we also study the relationship between green innovation and economic growth. This research aims at answering the below questions:

Question 1: How does green innovation affect green development?

Question 2: Do green innovation's influences on green development differ when considering a country's GCF, EDU and DTF?

Question 3: How do green innovation affect the relationship between green development and economic growth?

Our research sources information and statistical data from OECD Data as well as the World Bank Data Indicator. Through sorting and compiling, our database of 3,089 observations from 161 countries from 1975 to 2022 is used to calculate the baseline results and interaction terms, which we then compare to our hypotheses.

1.3. Research Contribution

Regression analysis with the GMM approach applied to correct for any endogeneity yielded the following results: a positive correlation between rising green innovation and rising green development. Additionally, it is discovered that the aforementioned associations are more prominent for established and emerging nations with high GCF, EDU, and DTF. Finally, we can validate the premise that a high level of green innovation strengthens the positive impact of green development on economic growth. We provide policymakers with implications from these findings as well as suggestions for further research on related subjects.

Our research makes two contributions to the body of literature. First, we contribute to the body of knowledge already available on the effects of green innovation on different factors. This allows future researchers, particularly those focusing on the topic of green development (such as the IPCC, 2014; Irandoust, 2016; Geissdoerfer et al., 2017; Lin & Zhu, 2019; Yu & Du, 2019; Ulucak, 2020) to compare our findings with those of earlier studies. The second contribution is that, although the relationship between green development and economic growth is frequently examined, there is little to no literature that highlights the importance of green innovation, gross capital formation, or even the effects of education or digital transformation when those factors are taken into consideration as well.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1. Green Development

Green development, otherwise referred to as sustainable development, is a concept attracting global attention. It encompasses a comprehensive strategy aiming to harmonize economic progress with environmental conservation and social welfare (OECD, 2011; Indrawati, 2015).

A landmark report issued by the Brundtland Commission, previously known as the World Commission on Environment and Development, has wielded considerable influence on green development research. The commission's "Our Common Future" report established the notion of sustainable development and underscored that present generations must meet their needs while ensuring future generations can fulfill their own (Brundtland, 1987). The paper helped establish the foundation for worldwide discussions emphasizing the interrelations between economy, environment, and social issues.

Moreover, the United Nations Sustainable Development Goals (SDGs) formulated in 2015 have developed into a pivotal framework guiding cross-national green development initiatives. The UN General Assembly established these 17 goals and 169 objectives to assist nations in accomplishing the SDGs, which address an array of concerns such as poverty reduction, renewable resources, sustainable cities, climate action, and biodiversity protection. The SDGs have sparked extensive empirical and policy investigations at national and international scales surrounding approaches for attaining said targets (UN, 2015). Both the Brundtland report and SDGs have noticeably influenced inquiries into balanced socioeconomic progress benefiting present and future populations.

The literature on green development of Fay (2012), Volz (2018), Taghizadeh-Hesary & Yoshino (2019), Dogaru (2021) showcase the positive impacts of green development on various aspects. Green development is a long-term plan for diminishing the effects of climate change, protecting the environment, and increasing the efficient use of natural resources. It entails the use of green technology, green finance, and green policy frameworks to help countries achieve the SDGs.

2.2. Green Innovation

Green innovation, known also as eco-innovation involves developing and applying new technologies aiming to lower environmental effects while strengthening sustainability. It involves systematically integrating environmentally practices and approaches throughout all organizational operations and societal endeavors. Green innovation spans various industries such as energy, transportation, agriculture, waste management, and construction (Schiederig, Tietze & Herstatt, 2012). It plays a pivotal part in transitioning sectors and societies toward a more sustainable future state.

The UN Environment Programme (UNEP) has promoted green innovation via studies and works. UNEP's "Green Economy Report" highlighted green innovation's potential to drive sustained financial development. The report underscores the necessity of green technologies and clean energy sources in fostering the transition toward a green economic model (UNEP, 2011). It underscores investing in green innovation as paramount for accomplishing the UN's SDGs. Both documents highlight how nurturing green innovation can smooth pathways to integrated socioeconomic advancement and environmental protection.

Furthermore, research has investigated the influence of green innovation on many sustainability outcomes. The introduction of electric vehicles and alternative fuel technologies has the capacity to minimize air pollution and reduce reliance on traditional gasoline-powered vehicles (Zeng, Xie & Tam, 2010). Furthermore, green innovation can help to promote sustainable agricultural practices, waste management, and construction. Precision agriculture techniques, sustainable farming methods, and organic farming practices can improve resource efficiency while using fewer pesticides and fertilizers (Hockerts & Wüstenhagen, 2010). Innovative recycling and waste-to-energy technologies can lower waste disposal's environmental impacts while boosting circular economy (Bocken et al., 2014). Green innovation in construction involves developing eco-friendly building materials, energy-efficient designs, and smart technologies that optimize resource utilization and diminish $CO2$ emissions.The effects of green innovation extend beyond solely environmental benefits. It can also boost economic growth and open new commercial opportunities. Studies have demonstrated organizations investing in green innovation tend to experience higher market competitiveness, operational efficiency and financial performance (Schiederig et al., 2012). Furthermore, green innovation is able to help generate jobs and stimulate local economies, particularly in renewable energy and energy-efficient technology sectors (Zeng et al., 2010). Green innovation possesses the potential to mitigate environmental challenges, advance sustainability and drive economic expansion simultaneously. By addressing ecological issues through innovative solutions, opportunities arise to strengthen business performance, foster employment and stimulate broader economic activity—thereby merging environmental protection and socioeconomic development objectives.

2.3. The relationship between green innovation and green development

The correlation between green innovation and green development is a significant topic of research that investigates how innovative practices and technology contribute to SDGs. Innovation has an important role in the realm of green development. It includes both scientific and non-technological breakthroughs that lead to significant changes in the environment through the creation and use of novel devices. The objective of green innovation and expansion is to increase productivity via the efficient utilization of natural resources, reduction of wasted resources and energy consumption, identification of novel opportunities for value creation, and optimization of the distribution of resources (OECD, n.d.).

Several studies have been conducted in the past few decades to investigate how renewable energy technology affects green development throughout the globe. The significance of green innovation in tackling environmental concerns and propelling sustainability is broadly recognized. The Intergovernmental Panel on Climate Change (IPCC, 2014) stresses green innovation's role in battling global warming and accelerating the change to a carbon-neutral economy.

A study by Ulucak (2020) investigates the significance of environmental technology in green development for BRICS nations. The findings show that environmentally friendly technologies have a statistically significant influence on diminishing both overall CO_2 emissions and production-based CO_2 emissions, hence contributing to green development. Overall, green innovations help decrease greenhouse gas emissions and promote environmental sustainability.

A study by Geissdoerfer et al. (2017) examined the idea of the circular economy and its importance for how green innovation relates to green development. The scholars explored how fostering innovative green solutions can help transition to an economic system focused on reducing resource use, waste production, and negative environmental effects. The work underscores the necessity of new solutions and corporate practices for achieving the circular economy' goal to promote both environmental protection and advancement through prudent resource management. By highlighting the importance of new approaches and strategic business decisions, the study emphasizes that achieving the circular economy's goals as well as encouraging green development will rely on fresh thinking from all relevant actors.

Many studies also have shown that green innovation plays an important role in promoting green development by reducing CO_2 emissions, increasing labor productivity, creating new economic opportunities, and improving the quality of life, which all contribute to green development (Irandoust, 2016; Lin & Zhu, 2019; Yu & Du, 2019).

Overall, these research papers showcase various fields in which green innovation influences green development. They demonstrate the advantageous relationship between green innovation and green development in a wide range of areas at various levels: firm, regional, national, etc. Green innovation is critical to promoting green development and reaching a more sustainable future given that it encourages the development and implementation of sustainable technologies, processes, and practices. In our study, we extend this scope to a global scale and develop hypothesis:

→ Hypothesis 1: Green innovation has a positive and significant impact on Green development.

Due to variations in socioeconomic situations, technical capabilities, and legislative frameworks, the effects of green innovation on green development might differ across developed and developing countries.

Green innovation can have a big impact on sustainable development in nations that are developing. These nations frequently deal with serious environmental issues including pollution, dwindling resources, and the effects of climate change. By developing environmentally friendly behaviors, encouraging resource efficiency, and introducing sustainable technology, green innovation may aid in addressing these issues. Green innovation has the potential to improve environmental outcomes, lower greenhouse gas emissions, improve energy availability, and boost climate change resilience in poor nations, according to research (UNEP, 2016). By encouraging the growth of green businesses and sectors, these technologies may also aid in the eradication of poverty, the creation of jobs, and economic expansion (World Bank, 2017). The scope and speed of green innovation as well as its subsequent influence on green development may be impacted by poor countries' inadequate institutional frameworks, technological capabilities, and financial resources (Anholon et al., 2020).

Rich nations, on the other hand, frequently have more financial resources, more sophisticated technology, and well-established legislative frameworks to encourage green innovation and green growth. In industrialized nations, green innovation can result in less ecological footprint, increased resource efficiency, and better environmental performance. Studies have indicated that green innovation in industrialized nations has led to the adoption of energy-efficient practices, sustainable transportation systems, renewable energy technology, and circular economy concepts (Popp, 2019). These developments have helped to separate economic expansion from environmental deterioration, which has produced favorable results including lower carbon emissions and better air and water quality. Furthermore, green innovation has boosted economic diversification and competitiveness in developed nations, as well as job creation and export potential in the green sector (OECD, 2011).

Moreover, wealthy nations frequently contribute significantly to green innovation and growth in underdeveloped countries employing technology transfer, funding, and capacity-building programs. By facilitating the adoption and spread of environmentally friendly practices and technology, these partnerships help hasten the transition of poor nations to sustainable development (UNEP, 2011).

In conclusion, while developing and developed countries may have different effects of green innovation on green development, both provide possibilities and difficulties. Green innovation may help developing countries with environmental issues, spur economic expansion, and lower poverty rates. They could, however, be constrained by capacity and resource limitations. On the other hand, green innovation may lead to increased competitiveness, economic diversification, and environmental gains in industrialized nations with strong technology capabilities and appropriate governmental frameworks. They also play a significant role in promoting technology transfer and capacity-building programs that promote green development in underdeveloped countries.

→ Hypothesis 1.a: The impacts of green innovation on green development can vary between developing nations and developed countries due to differences in socio-economic conditions, technological capabilities, and policy frameworks.

2.4. The impact of gross capital formation on the relationship between Green Innovation and Green Development

Adequate allocation of resources towards tangible assets is vital to maintain the advancement and integration of environmentally-friendly technology and infrastructure, in addition to fostering sustainable practices and economic expansion. Studies have indicated that green innovation and development are positively impacted by gross capital creation. For instance, a study by Rahman & Ahmad (2019) looked at the connection between carbon emissions and gross capital creation in emerging nations. The results showed a correlation between reduced carbon emissions and higher levels of investment in physical assets, indicating that capital expenditure might support the uptake and use of green practices and technology.

Studies have further indicated the contribution of gross capital creation to the development of sustainable infrastructure. Song et al. (2020) carried out an analysis of the effect of expenditure on infrastructure on long-term development in emerging countries. Reducing resource consumption, raising living standards, and improving the environment may all result from increased investment in green infrastructure, which includes energy-efficiency initiatives, public transit networks, and landfills.

Additionally, efforts to conduct research and produce green innovation can also be aided by gross capital formation. The association between environmental innovation in businesses and gross capital creation was investigated by Yin & Wang (2018). According to the study, companies' investments in environmental R&D, which promotes the creation and uptake of green technologies and practices, were positively connected with greater levels of investment in physical assets.

On top of that, the development of jobs and economic expansion in the green sector can be facilitated by gross capital formation. The impact of green investments on employment and economic growth was examined by Lilliestam, Patt & Bersalli (2022). The paper suggests that investing in green sectors, such as clean energy and energy-efficient gadgets, might promote economic growth, assist in environmentally friendly growth, and result in the creation of employment.

The relationship between innovative thinking and ecological growth depends heavily on gross capital production in both developed and developing countries. Properly allocating resources to physical assets, such as green infrastructure and research and development projects, encourages the adoption and implementation of green technologies, speeds up economic growth, reduces adverse ecological consequences, and fosters ethical conduct. Hence, we put up the following hypothesis:

→ **Hypothesis 2: Gross capital formation has a significant impact on the relationship between Green Innovation and Green Development.**

2.5. The impact of education on the relationship between Green Innovation and Green Development

Education is a key factor in the link between green innovation and development in both developing and wealthy nations. It gives people the understanding, abilities, and information needed to promote and put into practice sustainable behaviors and technology.

Analysis indicates that education has a beneficial impact on promoting green innovation and green development. For example, an article published in 2019 by Leal Filho et al. emphasized the importance of education in both conventional and informal methods for advancing green innovation, which is a component of equitable growth. The study found that education can raise the public's comprehension of environmental challenges and sense of obligation towards the ecosystem, as well as provide them with the information and skills necessary to develop and execute environmentally friendly alternatives.

More studies has proved the substantial role that education plays in encouraging innovative green and ethical procedures in a variety of businesses. Koster (2017), for instance, carried out an investigation of the impact educational institutions have on entrepreneurial sustainability. The study found that a higher probability of utilizing sustainable business strategies and environmentally friendly technologies in business ventures was associated with a greater degree of education.

Education may also stimulate the demand for environmentally friendly goods and services and impact consumer behavior. Education and pro-environmental behavior were investigated in a study conducted in 2012 by Videras et al. According to the survey, those with greater levels of education had a larger propensity to support green projects and buy ecologically friendly goods. As a result, it appears that education could contribute to generating consumer demand for sustainable development and green innovation.

Education likewise possesses the power to influence governmental decisions and foster the conditions necessary for green development and innovation. Lang et al. (2012) emphasized the value of education in creating governance frameworks and policies with a focus on sustainability. The research highlighted the potential for knowledge to empower individuals to advocate for ethical behavior and participate in deciding across all domains, ranging from neighborhood organizations to global and national platforms. By equipping individuals with the necessary information, competencies, and consciousness, educational institutions may impact purchasing habits, promote green innovation, sustainably managed activities, and advance the development of policies toward a more ecologically conscious and equitable future. Thus, we proposed a hypothesis:

→ Hypothesis 3: Education has a positive impact on the relationship between Green Innovation and Green Development.

2.6. The impact of digital transformation on the relationship between Green Innovation and Green Development

Digital transformation entails a significant alteration impacting all aspects of society, organizations and industries through the implementation of advanced digital technologies (Hsu, Tsaih & Yen, 2018). It encompasses advanced information and communication technologies such as artificial intelligence (AI), big data analytics, the Internet of Things (IoT), blockchain, and other technologies (Truong, 2022). This transformation is not only applying digital technologies but also includes envisioning totally new approaches of arranging and interacting using digital technologies as an enabler (Cunningham, 2022).

The digital transformation plays a major role in the efficient use and production of energy, thus, it has many good effects on environmental sustainability. Digital transformations are sparking hopes of enhancing our environment. It increases the availability of environmental information and permits innovative solutions (Truong, 2022). For example, digital technologies protect the environment in three key aspects: waste management, pollution prevention and sustainable resource management. With regards to pollution prevention, digitalization and networking contribute to decreasing greenhouse gases (Truong, 2022).

Information and communications technology (ICT) services, one of the assessment indicators for digital transformation, play a crucial role in digital transformation (Rath & Hermawan, 2019; Kristyanto & Jamil, 2023). ICT services are classified as a subset of the ICT sector that includes software publication, telecommunications, computer programming, web portals, data processing, consulting and related activities, hosting and related activities, and computer and communication equipment maintenance (UNCTAD, 2015a). The rapid advancements of ICT have led to the emergence of various new services which can be exported globally without physical transportation. These services include big data and software as well as cloud computing services (UNCTAD, 2015b; WTO, 2023). A major factor in promoting green innovation is these services.

ICT services are critical to promoting green development through green innovation. ICT services can improve energy efficiency, reduce greenhouse gas emissions, and develop innovative environmental solutions. Simultaneously, it encourages green innovation by creating new services that help businesses and society shift to a green economy. ICT services improve the environment through substitution and optimization. Substitution refers to the replacement of physical items with digital services, which reduces the environmental impact. Research shows that ICT services have the ability to substitute conventional activities that have a greater negative environmental impact. Virtual meetings, for example, can be used instead of actual travel, resulting in lower carbon emissions (Hischier & Hilty, 2002; Coroamă, Hilty & Birtel, 2012, Coroamă et al., 2020, Lange, Pohl & Santarius, 2020).). Optimization is the use of ICT services to optimize current procedures to make them more efficient, lowering their environmental effect, such as different management services (Malmodin et al., 2014, Coroamă et al., 2020).

These studies demonstrate the moderating role of digital transformation, particularly ICT services in green innovation and green development, acting as a catalyst for environmental sustainability. Hence, we propose the following hypothesis:

→ Hypothesis 4: The positive impact of Green Innovation on Green Development is more pronounced for high digital transformation levels countries.

2.7. Implication for GDP: The relationship between green innovation and economic growth is strengthened by green development.

As per (Tawiah et al, 2021), the aforementioned study delves into the complex interplay between green development programs and economic growth in 123 countries, comprising both emerging and established nations. The study examines this important junction using data from the OECD database, covering the years 2000–

2017. The study's primary finding is that there is a positive and statistically significant correlation between green development and economic growth as measured by GDP per capita. Basically, nations with more financial resources at their disposal have a tendency to prioritize ecologically friendly policies more strongly. The results also lend credence to the idea that green development programs might act as accelerators for long-term economic expansion. Investing proactively in eco-friendly practices can help nations boost GDP growth by encouraging more economic activity and innovation. This two-way link points to a mutually reinforcing dynamic in which ongoing economic growth is made possible by increased investment in green development, which is made possible by economic success.

The long-term correlation between economic development and innovation was confirmed by several scholars. Numerous research studies have found a strong and positive relationship between economic growth and eco-innovation (Wang et al., 2020). Furthermore, a further study finds that exceptional financial success is frequently linked to more wise investments, which encourages eco-innovation (Temesgen Hordofa et al., 2023). Tu et al. (2023) report that a recent study in Saudi Arabia revealed a strong correlation between eco-innovation centered on sustainability and economic growth. Therefore, eco-innovation has the potential to be the cornerstone of success for African countries; nevertheless, its capacity to boost competitiveness, create jobs, and usher in long-term prosperity will determine how successful it remains. Eco-innovation is therefore a crucial force behind economic expansion.

Moreover, according to Baneliene & Strazdas (2023),three indicators were selected for the model: the European Innovation Index (EII), the Eco-innovation Index (EcoII), and the recently developed European digital social innovation Index (EDSII), as well as its sub indicators, digital inclusion (DI), access to employees with software engineering/development skills, and individual giving. The main idea of this paper is to evaluate and find a relationship among innovativeness, the green economy, and digitalization. Through investigation on the EU area specifically on 25 countries, they found that green innovation has a positive impact on GDP growth. Specifically, an increase in the EcoII point can create 146 € GDP per capita per year. In addition, the proposed hypotheses were supported by supplementary estimation including GDP growth indicators for 2020 and 2021 as independent variables. And as a result, green innovation growth not only increased by 146 € GDP per capita but also increased by 194 € GDP per capita. Furthermore, Ha et al (2023) also confirmed their argument through their paper that green innovation has a strongly positive relationship with financial performance especially in GDP growth. This study investigated the relationship between green innovation and external environmental conditions as well as how green innovation affected the financial and environmental performance of 400 manufacturing SMEs in Vietnam's key industrial units.

The study's findings highlight how crucial it is to understand how closely related environmental sustainability and economic growth are. They offer actual data to back up the claim that encouraging green development may be a tactic for boosting resilience and long-term economic growth in addition to improving environmental well-being. Therefore in this analysis, we proposed the following hypothesis:

→ Hypothesis 5: The relationship between green innovation and economic growth is strengthened by green development.

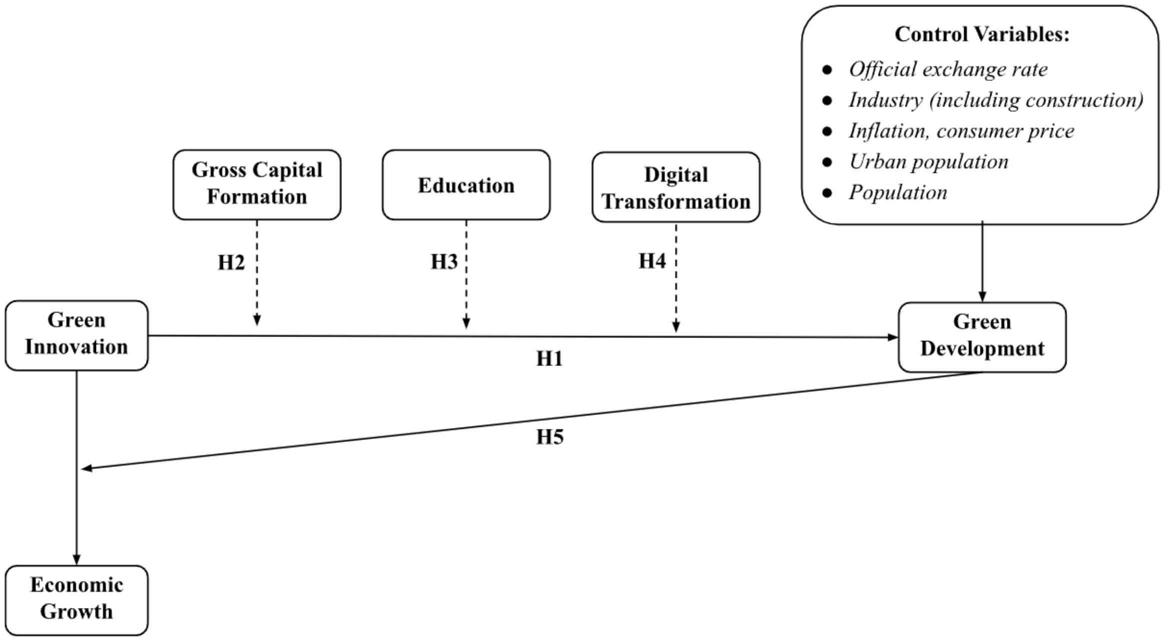

Figure 1: Conceptual Framework

3. METHODOLOGY

3.1. Data collection

This study examines the relationships between Green Innovation and Green Development using data between 1975 and 2022 across 161 countries. We first collect our country-level data including Official Exchange Rate, Industrialization rate, Inflation rate, Gross capital rate, Population growth, Urbanization rate, Agriculture, forestry, and fishing rate, from the World Bank Data, and then combine and store them as panel data. The Green Innovation is retrieved from OECD Data. The data for Green Development is collected from the World Bank.

In conclusion, it should be highlighted that all the data variables utilized in this study have been sourced from a variety of reliable references, which will be systematically organized in **Table 1**.

3.2. Dependent variable: GD

In our study, we primarily measure Green Development through the consumption of renewable energy. The underlying premise is that an increase in renewable energy consumption is indicative of enhanced green development (Nawaz et al., 2021; Mngumi et al., 2022; Lee, Wang & Thinh, 2023). The metric for renewable energy consumption is determined by the percentage of renewable energy sources to the total energy consumed within a given year.

This study will employ data on international renewable energy consumption, spanning globally and scaled from 0 to 100, as a measure of renewable energy consumption. We infer that a nation's energy consumption serves as a proxy for the decrease in CO_2 emissions from production, achieved through the implementation of green technologies and other initiatives (Lee, Wang & Thinh, 2023).

3.3. Independent variable

Green innovation is quantified through the number of patents granted for environmental technologies, which are viewed as crucial and positive elements of environmental quality (Yu et al., 2021; Ali et al., 2022). These green patents are awarded to technologies that pose no harm to the environment. This index reflects the profound understanding and concerns of various nations and their governments regarding the drawbacks of technological progress that does not adhere to green development principles. It implies a commitment to enhancing environmental standards (Wen et al., 2021).

Following (Ali et al., 2022), the approach to quantifying green innovation involves considering the total count of green patents, which are patents related to environmental technologies. The OECD website (www.oecd.org) provides data on patent applications from 161 countries from 1975 to 2022. This patent data encompasses information and fluctuations in new patents across these countries. Green innovation is represented by patents aimed at addressing global environmental concerns.

3.4. Control variable

In our study, we gather a comprehensive set of factors at the country level that could potentially influence Green Development. We consider variables such as the Official Exchange Rate (OER) and Consumer Price Inflation (INF), which could affect the funding and investment from governmengts and other entities in these countries towards environmental initiatives. The percentage of industry to total GDP (IDU) is also taken into account as it signifies the level of industrialization, which could potentially impact green development and pose environmental risks as countries expand their factories and manufacturing units. The Gross Capital Formation as a percentage of total GDP (GCF) provides insights into the financial landscape of these countries, indicating how resources are allocated between environmental and manufacturing activities. The Urban Population as a percentage of the total population (UPOP) is considered as a measure of urbanization, which could have implications for green development and the environment. Additionally, we take into account the total population (l_POP) and the proportion of the population engaged in agriculture, forestry, and fishing (AGR) in these countries. Those variables are gathered and compiled in **Table 1**.

	Acronym	Definition	Source
Green Development	GD	The percentage of renewable energy sources to the total energy	World Bank Data
Green Innovation	GI	The number of patents granted for environmental technologies	OECD website
Official exchange rate	OER	The exchange rate determined by national authorities or to the rate determined in the legally sanctioned exchange market	World Bank Data
Industrialization rate	IDU	The percentage of industry to total GDP	World Bank Data
Inflation rate	INF	The rate of increase in prices over a given year.	World Bank Data
Gross capital rate	GCF	Annual growth rate of gross capital formation based on constant local currency.	World Bank Data
Population growth	l_POP	The logarithm of the population of the country in a given year.	World Bank Data
Urbanization rate	UPOP	The percentage of people living in urban areas to total population.	World Bank Data
Agriculture, forestry, fishing rate	AGR	The percentage of agriculture, forestry, fishing to total GDP	World Bank Data
High gross capital rate	high_gcf	Dummy variable that equals 1 if the level of gross capital rate is higher than median and 0 otherwise.	World Bank Data
High education	high_edu	Dummy variable that equals 1 if the annual growth rate of gross capital formation based on constant local currency is higher than median and 0 otherwise.	World Bank Data

High digital transformation	high_dtf	Dummy variable that equals 1 if the level of digital transformation is higher than median and 0 otherwise.	World Bank Data
Economic growth	l_GDP	The logarithm of GDP of a country in a given year.	World Bank Data

Table 1: Variables definition

3.5. Model

The influence of Green Innovation on Green Development is thoroughly examined using the Multiple Linear Regression (MLR) for model estimation:

$$GD_{i,j} = \beta_0 + \beta_1 GI_{i,j} + \alpha' Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \quad (1)$$

In this study, we denote the country and the year by sub-indexes i and j, respectively. We define the ratio of renewable energy sources to the total energy of a country in a given year (j) as Green Development (GD), which serves as the dependent variable in **Equation (1)**.

The independent variable, Green Innovation (GI), is quantified by the number of patents granted for environmental technologies in country i during year j. In this context, β_0 represents the intercept, and β_1 signifies the slope parameter of the explanatory variables.

Our model incorporates a broad spectrum of control variables for country i in year j, which could potentially influence the relationship between Green Innovation (GI) and Green Development (GD). These control variables include Official Exchange Rate, Industry rate, Inflation rate, Gross capital rate, Population growth, Urbanization rate, and Agriculture, forestry, and fishing rate. Detailed definitions and sources of these variables are provided in **Table 1**.

To account for country and time-invariant unobservable factors that may affect the relationship between Green Development and Green Innovation, we include year and country fixed effects in our model.

Our primary hypothesis (**Hypothesis 1**) posits that Green Innovation exerts a positive and significant impact on Green Development. We test this hypothesis using a Fixed-effects Generalized Least Square (GLS) Regression Approach, anticipating a positive and statistically significant β_1.

In order to examine the influence of Gross Capital Formation, Education Level, and Digital Transformation Level on the Green Development in these countries, we formulated and estimated the subsequent model:

The equation for the impact of the Gross Capital Formation high-level on the relationship between Green Innovation and Green Development:

$$GD_{i,j} = \beta_0 + \beta_1 GI_{i,j} + \beta_2 high\_gcf_{i,j} + \beta_3 GI_{i,j} \times high\_gcf_{i,j}$$

$$+ \alpha_1 Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \ (2)$$

The equation for the impact of the Education high-level on the relationship between Green Innovation and Green Development:

$$GD_{i,j} = \beta_{0'} + \beta_{1'} GI_{i,j} + \beta_{2'} high\_edu_{i,j} + \beta_{3'} GI_{i,j} \times high\_edu_{i,j}$$

$$+ \alpha_2 Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \ (3)$$

The equation for the impact of the Digital Transformation high-level on the relationship between Green Innovation and Green Development:

$$GD_{i,j} = \beta_{0''} + \beta_{1''} GI_{i,j} + \beta_{2''} high\_dtf_{i,j} + \beta_{3''} GI_{i,j} \times high\_dtf_{i,j}$$

$$+ \alpha_3 Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \ (4)$$

In this study, we denote the country and year as i and j, respectively. The variables are clearly defined in **Equation (1)**. We introduce three indicator variables: $high\_gcf_{i,j}$ equals 1 for countries with an annual growth rate of gross capital formation (based on constant local currency) above the yearly sample median, and 0 otherwise. Similarly, $high_edu_{i,j}$equals 1 for countries where the education level of individuals aged 25 or over, who have attained a Master's level, exceeds the yearly sample median, and 0 otherwise. Finally, $high\_dtf_{i,j}$ equals 1 for countries where the percentage of Information and Communication Technology (ICT) service exports surpasses the yearly sample median, and 0 otherwise.

The coefficients of the interaction terms $GI_{i,j} \times high\_gcf_{i,j}$ (β_3), $GI_{i,j} \times high\_edu_{i,j}(\beta_{3\prime})$, and $GI_{i,j} \times high\_dtf_{i,j}(\beta_{3\prime\prime})$ will elucidate the relationship between Green Innovation and the levels of Gross Capital Formation, Education, and Digital Transformation. Hypotheses (2), (3), and (4) provide a detailed review of the positive effects of β_3, $\beta_{3\prime}$, and $\beta_{3\prime\prime}$ on the relationship between Green Innovation and Green Development. In essence, enhancing the levels of Gross Capital Formation, Education, and Digital Transformation in these countries amplifies the impact of Green Innovation on Green Development. Consequently, we anticipate the coefficients of the interaction terms β_3, $\beta_{3\prime}$, and $\beta_{3\prime\prime}$ to be significant and positive.

To determine the moderating effect of Green Development on the correlation between Green Innovation and Economic Growth, we introduce high_gdi,j as a binary variable. This variable is set to 1 if the proportion of renewable energy sources to total energy surpasses the annual sample median, and 0 otherwise. We then interact this variable with Green Innovation (GI) to create the interaction term $GI_{i,j} \times high\_gd_{i,j}(\beta_3)$. Subsequently, we estimate the ensuing model:

$$log\ (GDP) = \beta_0 + \beta_1 GI_{i,j} + \beta_2 high\_gd_{i,j} + \beta_3 GI_{i,j} \times high\_gd_{i,j} + \alpha' Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \ (5)$$

In which, the sub-indices i and t denote the country and year, respectively. The interaction term $GI_{i,j} \times high_gd_{i,j}$is designed to uncover the influence of Green Innovation in conjunction with rapidly advancing Green Development in these countries. Our attention is particularly drawn to the coefficient β_3, which is central to **Hypothesis 5**. This hypothesis posits that Green Development strengthens the relationship between Green Innovation and Economic Growth. Consequently, we anticipate that the coefficient of this interaction term will be both positive and statistically significant.

4. EMPIRICAL RESULTS:

4.1. Descriptive

	N	Mean	Std. Dev.	Min	Median	p75	Max
GD	6676	30.788	30.556	0	19.57	53.28	98.34
GI	4324	23.69	24.895	.42	13.585	28.5	349.65
OER	5439	52.488	49.128	2.857	40.215	64.918	647.638
IDU	5718	27.554	11.933	3.15	26.177	33.382	86.67
INF	5515	24.986	369.731	-16.86	3.835	8.332	23773.13
GCF	6667	21.975	12.655	-15.917	21.651	26.64	324.168
UPOP	6676	56.962	24.291	5.416	56.508	76.718	100
l POP	6676	15.124	2.391	9.125	15.513	16.798	21.067
AGR	5908	12.892	12.565	.013	8.503	19.993	79.042
l GDP13	3742	1.401	0.432	-2.062	1.446	1.684	3.792

Table 2: Descriptive statistics of variables for the full sample

Notes: This table provides variable descriptive statistics as well as a summary of all variables. It contains 3,089 observations from 161 countries spanning the years 1975 to 2022. The definitions of the variables are provided in Table 1.

Table 2 depicts the descriptive statistics for all variables in our model over the period from 1975 to 2022. Based on data collected from a sample of 3,089 observations from 20 developed and 141 developing countries, we are able to calculate the mean, standard deviation, and extreme values for each variable. The main independent variable GI has a mean of 23.69 and a standard deviation of 24.895, with the minimum, median, and maximum values being 0.42, 13.585, and 349.65, respectively. The potential-interaction-terms Gross Capital Formation variable (GCF) shows a mean of 21.975 with a standard deviation of 12.655, its 75th percentile value is 26.64 while the max value is 324.168 .

Panel A - Developed Countries

	GD	GI	OER	IDU	INF	GCF	UPOP	l POP	AGR
Australia	8.467	10.379	86.913	12.246	2.549	25.637	85.128	16.847	2.790
Belgium	4.671	8.462	16.100	7.204	2.000	23.289	97.367	16.182	0.924
Canada	22.015	10.444	86.278	27.749	2.166	21.992	79.850	17.303	1.982
Czechia	9.484	11.969	67.903	31.607	4.429	28.806	73.950	16.156	2.599
Denmark	18.909	14.942	58.273	33.345	1.771	21.146	86.194	15.513	1.759
France	11.408	9.998	37.514	23.973	1.540	22.331	77.369	17.960	1.913
Greece	10.858	12.013	19.791	40.471	4.781	20.581	74.888	16.194	4.318
Iceland	67.441	6.184	61.089	62.277	4.482	21.471	92.805	12.618	5.931
Italy	9.855	8.349	83.237	19.473	2.429	19.916	68.211	17.881	2.344
Japan	7.366	10.138	216.009	42.114	0.436	27.354	85.149	18.657	1.243
Netherlands	3.689	8.626	15.156	29.984	2.052	21.477	82.003	16.605	2.232
New Zealand	27.740	8.842	84.546	14.069	2.167	22.518	86.045	15.238	6.025
Norway	58.801	10.981	58.024	11.347	2.224	24.797	77.692	15.371	1.801
Portugal	24.753	12.118	20.920	45.934	3.146	22.199	57.659	16.148	2.561
Slovak Republic	8.096	11.824	25.568	41.071	5.363	25.982	55.301	15.500	2.013
Slovenia	17.212	6.592	33.391	32.885	32.455	23.035	52.131	14.521	2.438
Spain	11.886	9.718	25.883	34.943	2.717	23.484	77.702	17.585	3.030
Sweden	41.334	9.799	54.507	35.321	1.916	23.131	84.903	16.037	1.972
Switzerland	20.115	7.483	129.627	34.447	1.033	27.293	73.642	15.842	0.988
United States	6.828	8.888	78.882	23.688	2.481	21.295	79.698	19.500	1.082

Panel B - Developing Countries

	GD	GI	OER	IDU	INF	GCF	UPOP	l POP	AGR
Afghanistan	27.042	44.597	25.608	20.375	6.125	6.675	23.194	16.967	26.960
Algeria	40.698	20.852	62.041	13.145	8.559	35.602	63.839	17.330	8.619
Angola	62.641	15.510	28.062	26.646	369.464	22.377	54.196	16.795	7.249
Antigua and Barbuda	6.026	53.000	81.093	25.981	1.757	14.690	29.279	11.281	1.674
Armenia	8.870	10.407	29.671	27.098	131.067	26.644	64.398	14.941	10.173
Azerbaijan	2.248	28.195	26.282	25.143	111.325	25.111	53.317	15.965	13.111
Bahamas, The	0.958	13.600	54.151	14.641	2.205	27.908	82.011	12.752	1.389
Bahrain	0.000	33.899	69.793	35.440	1.312	24.588	88.620	13.719	0.464
Bangladesh	48.774	8.027	44.433	21.966	6.095	25.044	28.025	18.745	19.664
Barbados	6.648	15.412	88.506	18.897	3.406	15.996	33.223	12.507	2.019
Belarus	5.556	12.108	26.736	16.660	185.006	30.319	72.479	16.094	10.980
Belize	34.904	7.420	50.201	36.797	1.701	18.592	45.786	12.534	9.903
Benin	64.511	57.188	23.971	27.458	4.056	17.993	41.261	15.925	28.634
Bhutan	90.528	43.900	55.354	41.742	6.823	48.269	30.325	13.380	20.572
Botswana	35.123	88.347	38.646	63.022	7.900	29.238	57.948	14.460	2.717
Brazil	45.702	9.583	66.648	25.567	267.848	18.603	82.170	19.035	5.200
Brunei Darussalam	0.046	31.100	72.284	15.237	0.914	26.047	72.797	12.786	1.000
Bulgaria	10.257	13.510	63.721	19.854	63.593	21.156	70.780	15.862	8.170
Burkina Faso	82.048	39.600	26.080	23.741	2.768	19.890	21.785	16.462	25.823
Burundi	92.304	94.299	24.723	26.892	10.362	11.369	9.732	15.877	39.454
Cambodia	70.460	38.418	46.212	7.769	4.364	19.724	20.386	16.438	32.105
Cameroon	81.940	21.172	16.172	22.656	3.278	18.078	48.867	16.684	18.149

Central African Republic	91.952	91.428	20.207	44.131	3.896	14.390	38.738	15.226	33.435
Chad	82.089	99.205	13.066	11.445	3.593	23.786	21.998	16.126	30.492
Chile	30.400	16.962	66.856	53.585	5.888	25.094	86.253	16.601	4.841
China	20.890	8.946	151.944	23.658	3.924	40.682	43.633	20.981	13.080
Colombia	30.822	12.184	36.899	18.397	10.237	21.082	76.006	17.548	9.334
Comoros	66.159	45.124	18.436	22.536	3.192	16.729	28.298	13.304	30.437
Congo, Dem. Rep.	96.468	65.180	9.906	22.379	1285.30	13.470	37.725	17.864	28.197
Congo, Rep.	66.881	65.180	19.329	15.343	4.135	36.180	60.996	15.126	7.259
Costa Rica	36.614	18.083	42.171	16.964	9.735	19.924	66.082	15.259	8.321
Cote d'Ivoire	70.692	57.671	22.699	33.489	3.396	16.466	45.531	16.747	19.308
Croatia	28.837	9.719	441.638	21.571	94.188	19.871	54.270	15.288	4.017
Djibouti	31.237	40.298	71.167	25.465	2.779	23.276	76.886	13.620	1.057
Dominica	11.525	18.232	77.612	66.911	1.648	22.586	67.126	11.146	12.887
Dominican Republic	19.235	23.063	31.458	18.557	10.324	24.100	68.425	16.026	7.406
Ecuador	17.035	14.297	28.757	18.358	19.159	23.645	60.903	16.433	13.303
Egypt, Arab Rep.	7.078	9.145	83.520	27.308	10.018	18.776	42.920	18.185	13.934
El Salvador	37.719	29.499	51.891	19.812	4.897	17.692	62.189	15.606	7.937
Equatorial Guinea	31.488	81.025	10.628	10.854	4.926	23.165	56.829	13.692	2.152
Eswatini	65.275	25.148	23.412	21.621	7.729	16.100	22.565	13.869	10.076
Ethiopia	93.978	22.893	30.490	27.804	10.774	11.559	16.366	18.156	44.088
Fiji	41.672	44.750	58.614	23.512	3.292	20.244	50.177	13.668	13.108
French Polynesia	7.588	38.640	22.157	25.953	3.695	87.758	58.788	12.483	2.951
Gabon	80.170	34.273	18.195	27.756	2.591	25.257	81.577	14.214	5.837
Gambia, The	56.975	100.000	26.400	7.790	6.108	14.553	51.810	14.339	23.798

Georgia	35.220	16.353	26.242	26.009	12.695	23.894	55.220	15.214	15.852
Ghana	60.964	22.045	25.845	27.936	19.396	20.749	47.508	16.938	30.530
Grenada	9.913	24.836	81.322	30.822	2.024	33.037	35.500	11.619	5.621
Guatemala	65.860	28.191	38.516	20.878	8.304	16.397	47.030	16.368	15.696
Guinea	80.504	109.036	17.289	23.617	15.292	22.485	32.466	16.051	19.879
Guinea-Bissau	88.254	65.115	29.219	21.428	13.251	15.739	38.360	14.162	45.331
Guyana	29.926	42.572	61.572	29.978	4.504	31.183	27.794	13.539	29.860
Haiti	81.431	40.844	28.518	24.146	14.163	17.291	42.887	16.021	20.941
Honduras	54.608	53.873	46.000	10.559	10.444	26.305	49.229	15.827	14.818
Hungary	9.372	9.382	53.708	34.389	9.905	24.203	67.599	16.125	4.283
India	42.100	8.425	64.347	32.395	7.201	31.625	29.766	20.856	20.141
Indonesia	39.693	10.676	44.516	10.926	8.781	29.616	45.464	19.246	15.336
Iran, Islamic Rep.	0.978	13.605	47.792	60.471	20.042	36.401	66.961	18.069	9.278
Iraq	0.909	29.231	32.192	40.978	50.680	24.302	69.290	17.156	8.062
Jamaica	10.080	26.342	49.212	20.217	14.437	24.018	52.899	14.793	6.430
Jordan	3.397	17.402	116.607	10.549	3.674	28.129	82.786	15.644	3.734
Kazakhstan	1.735	18.960	27.753	19.964	82.359	25.858	56.614	16.606	7.785
Kenya	77.221	15.433	37.545	23.461	11.426	19.277	22.113	17.398	23.198
Kiribati	52.003	31.186	28.780	12.680	1.896	31.173	44.913	11.499	24.421
Korea, Rep.	1.502	9.878	98.692	23.490	3.399	33.380	80.071	17.689	3.364
Kuwait	0.039	31.926	84.898	6.377	3.095	18.707	99.401	14.717	0.398
Kyrgyz Republic	25.411	53.573	25.263	21.326	9.991	23.250	35.897	15.468	26.723
Lao PDR	71.014	39.466	17.797	13.972	15.320	20.621	26.247	15.580	29.121
Lesotho	49.306	103.226	33.242	16.311	6.689	20.008	22.215	14.518	6.360

Liberia	89.878	52.756	15.723	21.072	10.554	12.297	48.415	15.017	52.530
Libya	2.738	39.602	70.529	22.754	5.348	15.652	77.614	15.534	3.013
Madagascar	84.593	46.537	20.294	54.986	11.316	20.903	30.308	16.754	28.973
Malaysia	4.416	7.770	123.181	11.117	2.539	27.662	65.400	17.043	10.300
Maldives	2.109	10.509	40.933	22.257	4.546	15.537	32.851	12.712	5.673
Mali	80.060	75.876	23.895	34.064	2.561	20.243	32.971	16.424	35.189
Mauritania	37.362	43.449	21.079	33.235	5.289	27.540	44.451	14.939	22.235
Mauritius	21.348	39.343	91.374	29.514	5.415	24.100	42.157	13.998	5.587
Mexico	10.965	10.073	28.571	21.406	9.528	22.462	76.410	18.467	3.703
Micronesia, Fed. Sts.	1.263	7.870	49.527	47.241	2.464	18.946	23.186	11.601	24.349
Moldova	11.306	15.419	38.564	22.170	114.273	23.752	43.925	14.869	16.026
Mongolia	3.889	19.624	38.097	12.056	22.169	32.860	62.708	14.782	19.318
Montenegro	43.186	20.494	51.763	54.107	2.377	26.129	65.142	13.337	7.575
Morocco	15.124	17.674	83.307	23.484	2.441	28.609	55.846	17.228	12.555
Mozambique	88.266	23.424	30.245	28.549	7.774	9.355	30.871	16.840	25.993
Myanmar	78.808	17.436	32.552	24.810	18.070	17.956	28.111	17.673	36.417
Namibia	32.851	24.375	47.007	16.379	5.330	21.071	38.693	14.489	8.649
Nepal	87.245	21.167	63.312	8.246	7.333	27.583	15.089	17.049	33.181
New Caledonia	6.269	15.000	25.063	29.163	1.131	30.496	64.941	12.341	2.257
Niger	85.983	29.216	12.926	27.177	2.732	20.451	16.125	16.474	35.351
Nigeria	84.823	16.270	17.946	49.250	18.061	10.552	40.150	18.775	24.301
North Macedonia	17.287	16.947	40.607	28.509	6.886	23.715	58.087	14.528	9.895
Oman	0.003	24.166	34.847	18.376	2.104	24.535	74.884	14.842	2.007
Pakistan	49.223	18.317	44.411	26.249	8.485	16.823	34.056	18.957	22.741

Palau	0.479	2.778	22.392	25.220	2.671	7.554	73.763	9.808	3.621
Panama	27.509	16.862	57.747	30.968	1.852	32.734	62.973	15.013	4.971
Papua New Guinea	61.172	43.320	32.892	21.426	7.021	16.317	13.447	15.680	25.818
Paraguay	66.711	61.734	30.841	37.012	9.216	20.947	56.936	15.502	13.209
Peru	34.136	18.309	35.022	16.417	254.363	21.098	74.522	17.141	7.407
Philippines	34.260	15.933	57.958	20.107	5.479	20.751	46.272	18.267	14.102
Poland	8.629	11.645	48.834	16.032	28.179	19.919	61.043	17.458	3.123
Qatar	0.085	23.642	63.847	13.672	3.075	32.007	97.021	13.870	0.187
Romania	17.278	13.041	36.332	10.516	43.993	25.075	53.637	16.866	10.375
Russian Federation	3.544	11.217	46.727	21.377	63.107	23.248	73.666	18.794	5.363
Rwanda	86.558	99.479	16.527	30.263	6.838	18.112	14.543	16.046	31.021
Samoa	48.378	51.703	39.682	49.446	3.911	23.781	20.436	12.154	12.205
Sao Tome and Principe	47.563	35.686	34.979	20.109	14.589	12.539	59.739	12.008	11.669
Saudi Arabia	0.016	19.399	51.408	24.225	1.932	24.176	80.892	17.026	3.944
Senegal	45.426	27.112	25.547	25.439	2.522	23.034	42.660	16.233	15.783
Serbia	19.152	14.311	34.407	9.617	21.665	17.158	53.827	15.811	9.548
Seychelles	1.660	5.400	72.971	46.774	4.759	35.095	52.499	11.340	2.912
Sierra Leone	85.109	25.578	17.804	34.295	10.001	12.403	37.652	15.559	51.043
Solomon Islands	50.581	43.272	31.204	27.171	7.242	11.700	18.542	13.093	37.440
South Africa	12.368	10.947	58.473	45.931	6.646	16.860	59.870	17.716	2.660
South Sudan	31.157	36.586	28.155	32.564	87.870	6.894	19.278	16.196	7.057
Sri Lanka	60.630	18.487	39.739	42.591	8.895	26.423	18.387	16.797	14.892
Sudan	70.733	42.549	17.680	22.850	55.014	15.293	32.892	17.226	33.181
Suriname	19.618	25.904	53.418	23.997	20.096	29.994	66.337	13.212	8.777

Syrian Arab Republic	1.733	41.791	63.606	25.106	7.675	1.677	52.504	16.686	27.343
Tajikistan	52.522	26.105	18.040	24.799	11.187	25.306	27.497	15.777	24.070
Tanzania	90.258	44.800	20.568	25.054	11.812	28.489	26.075	17.512	30.236
Thailand	23.189	16.240	109.401	37.336	2.824	28.544	38.976	17.991	9.603
Timor-Leste	17.777	16.961	32.564	29.509	4.844	28.294	26.202	13.810	22.625
Togo	77.591	48.376	30.806	27.432	3.809	19.160	35.608	15.570	28.033
Tonga	1.716	9.916	42.593	29.363	4.982	23.296	23.096	11.551	19.830
Trinidad and Tobago	0.694	33.167	50.435	26.756	5.584	10.380	54.449	14.136	1.485
Tunisia	13.746	12.841	57.495	34.273	4.338	23.703	64.932	16.157	10.307
Turkiye	16.842	8.178	42.177	25.103	35.830	25.883	67.820	18.038	10.091
Tuvalu	1.570	27.814	38.876	37.568	0.501	10.304	51.585	9.224	21.442
Uganda	94.193	9.148	16.715	37.696	6.101	21.460	17.605	17.159	31.214
Ukraine	2.823	12.040	37.616	34.509	220.752	21.960	68.008	17.679	11.915
United Arab Emirates	0.152	15.980	55.740	20.741	2.030	19.267	82.292	15.367	1.313
Uruguay	46.512	11.315	44.474	15.953	21.438	17.239	92.927	15.011	7.613
Uzbekistan	1.288	27.075	28.503	23.165	12.240	27.211	47.706	17.102	27.794
Vanuatu	41.316	30.728	93.719	31.865	2.739	26.731	22.821	12.301	20.498
Venezuela, RB	14.554	16.762	30.615	41.611	72.740	18.625	87.360	17.071	4.757
Viet Nam	46.510	14.536	72.375	26.728	5.873	29.817	28.136	18.233	21.321
West Bank and Gaza	17.250	71.953	70.413	27.874	2.959	26.304	72.963	15.009	9.157
Yemen, Rep.	1.480	67.471	37.117	27.874	17.496	11.103	29.449	16.889	18.706
Zambia	86.240	85.943	19.537	35.855	33.127	22.703	38.970	16.299	12.030
Zimbabwe	75.218	26.046	31.398	27.885	77.520	12.975	32.634	16.343	12.980

Panel C - Differences in mean between developing and developed countries

	GD	GI	OER	IDU	INF	GCF	UPOP	l POP	AGR
Developed Countries	19.546	9.887	62.981	30.207	4.107	23.387	77.384	16.383	2.497
Developing Countries	37.790	31.603	46.524	26.334	32.499	22.487	49.160	15.557	15.539
Difference	-18.24	-21.71	16.457	3.874	-28.392	0.899	28.224	0.826	- 13.041
	***	***	***	***	***	***	***	***	***

Table 3: Descriptive statistics by country

Panel A and B show the summary statistics of the country-level performance variables including GD, GI and control variables by countries for the year 1975-2022 for developed and developing countries, respectively. Panel C demonstrates the difference in means between the two subsamples. The definitions of the variables are offered in Table 1.

Table 3 illustrates the summary statistics of the Green Development and Green Innovation overall score and the control variables of our models by the country for developing and developed countries in Panels A and B, respectively. Panel C of the table reports clearly the significant gap of all tested variables between the two samples. The Green Development and Green Innovation scores differences between our two subsamples are highly significant, where the statistics for developed countries are surpassed by the developing ones by 18.2 units for GD and by 21.7 units for GI. The Urbanization rate (i.e UPOP) shows a clearly opposite pattern, with the difference of 28.2 units greater for the developed nations as compared to the developing ones. The top 3 countries with highest scores in Green Innovation for developed countries are Denmark, Greece, Portugal with the overall score being 14.942, 12.013, and 12.118, respectively. Notably, the top 3 countries with highest scores in Green Innovation for developing countries are Gambia, Guinea, Lesotho with the overall score being 100, 109, and 103.2, respectively.

4.2. Correlation Matrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	VIF
(1) GI	1.000								2.079
(2) OER	-0.217***	1.000							1.938
(3) IDU	0.028***	0.027**	1.000						1.290
(4) INF	-0.022*	-0.033**	-0.016**	1.000					1.131
(5) GCF	-0.056***	0.091***	0.006*	-0.030**	1.000				1.066
(6) UPOP	-0.372***	0.279***	-0.041***	-0.016*	0.070***	1.000			1.041
(7) l_POP	-0.125***	0.016**	-0.140***	0.038***	0.053***	-0.127***	1.000		1.008
(8) AGR	0.412***	-0.331***	0.004	0.060***	-0.175***	-0.665***	0.142***	1.000	1.006
Mean VIF									1.320

Table 4: Correlation coefficient matrix.

This table provides the correlation coefficient matrix of the independent variables for our main model. The sample includes 3,089 observations in 161 countries, for the period from 1975 to 2022. The definitions of the variables are provided in Table 1

The pairwise correlations between the independent variables in our main regression are reported in **Table 4** using the entire sample. The main independent variable GI is apparently significantly correlated with all of the control variables since the correlations between them as shown in the table are statistically significant at 1%. The association between Green Innovation overall score and the Industrial Index is positive, while the data implies a negative relationship between the GI and UPOP variables. Such correlations suggest that industries facing stricter environmental regulations or resource scarcity might have a stronger economic incentive to invest in green technologies. Additionally, knowledge spillovers within industrial clusters could accelerate green innovation in specific sectors (Aldieri et al., 2019). On the contrary, while sprawling urbanization can strain environmental resources, compact, well-planned cities can foster innovation through knowledge networks and access to resources (Rosenzweig et al., 2018). The negative correlation might reflect the dominance of less environmentally friendly industries in some urban areas or the lack of supportive infrastructure for green technologies.

The correlations among the main independent variables and the control variables (ranging from -0.66 to 0.41). This implies that as the score on one scale changes, the corresponding change in the other variable is considered weak in magnitude.

Furthermore, an examination of the Variance Inflation Factor (VIF) reveals that the majority of utilized variables exhibit low multicollinearity. Notably, the Mean VIF stayed at 1.32, thereby indicating the absence of significant multicollinearity concerns (Lindner, Puck, & Verbeke, 2020).

4.3. Baseline results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Full	**Full**	**Developing**	**Developing**	**Developed**	**Developed**
GI	.076***	.063***	.059***	.056***	-.003	.371***
	(.007)	(.007)	(.006)	(.007)	(.034)	(.082)
OER		-.028***		-.018***		.032*
		(.006)		(.006)		(.019)
IDU		-.058***		-.096***		-.09**
		(.02)		(.022)		(.04)
INF		0		0		.013
		(.001)		(.001)		(.15)
GCF		-.072***		-.058***		.141
		(.016)		(.015)		(.09)
l_POP		-16.019***		-10.125***		-50.104***
		(1.123)		(1.137)		(7.254)
UPOP		-.491***		-.443***		-.315***
		(.038)		(.039)		(.116)
AGR		.408***		.322***		-.883
		(.03)		(.03)		(.555)
_cons	29.633***	318.577***	34.142***	221.501***	17.182***	866.622***
	(.181)	(17.811)	(.2)	(17.984)	(.372)	(122.235)

Observations	4316	3089	3309	2593	1005	496
R-squared	.964	.976	.972	.98	.945	.942
Country FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

**** p<.01, ** p<.05, * p<.1*

Table 5: Green Innovation and Green Development

This table depicts the findings of effects of green innovation on green development. Models (1) to (6) describe the regression outcomes for each subsample (i.e., full sample, developing countries, and developed countries). The dependent variable for all specifications is GD. Table 1 offers the definitions of the variables.

The estimation to test **Hypothesis 1** in **Table 5**. The findings of **Equation (1)** are shown for the entire sample in column (1) and (2), while the results for the developing countries subsample are depicted in columns (3) and (4). Then, the last two (5) and (6) columns illustrate the result for developed nations subsample. Wherein, the control variables are not included in column (1), (3), and (5)

Table 5 provides the statistical estimations for conducting the first hypothesis test. After running the regression test for the main explanatory variable which is Green Innovation, we discover that Green Innovation and Green Development is reported to have a beneficial relationship which is significant in both the entire sample, developing, and developed nations. These findings indicate that countries experience more sustainable use of renewable energy under the increase of Acquisitions in Green Innovations, which is consistent with a study conducted by Salvarli & Salvarli in 2020. Green innovation develops solutions like better solar panels, wind turbines, and energy storage, making renewable energy more affordable and efficient, thus increasing usage, as reduced costs and improved performance of renewable technologies make them commercially competitive with fossil fuels, driving market adoption. **Figure 2** plots the fitted regression for the impact of Green Innovation on Green Development for the full sample. Specifically, we obtain country-level GI and GD by taking the averages over the sample period. The fitted regression line shows an upward-sloping trend with the correlation equals 0.48.

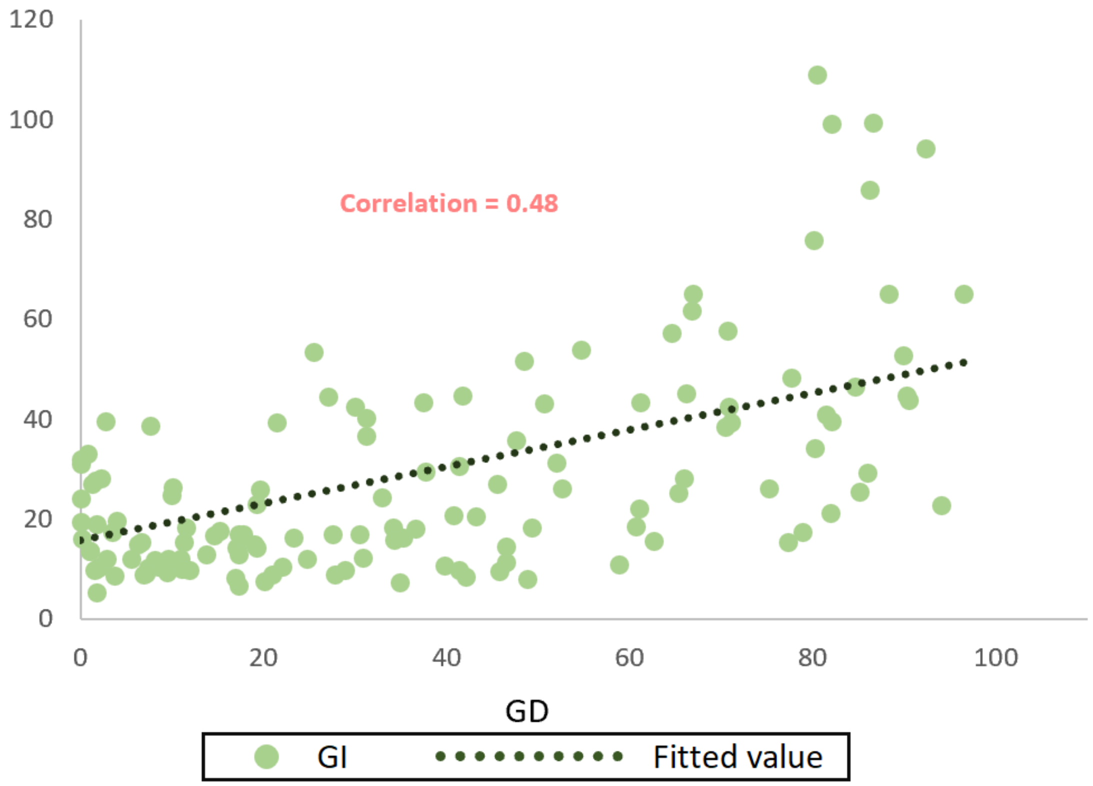

Figure 2: Scatter plot on Green Innovation and Green Development as country-level average values

As given in Columns (1) and (2), the coefficients of Green Innovation are 0.076 and 0.063, respectively, explaining approximately from 0.076% and 0.063% of Green Development(i.e the increase in the use of renewable energy relative to total energy consumption) with a one-unit increase in Green Technology Patents when other factors are kept constant. This result support **Hypothesis 1** and bears similarity to the findings from the study by Geissdoerfer et al., 2017.

Based on our analysis in Models (3) and (4), nations with developing economies experiencing a one-unit increment in Green Innovations could enhance their performance in the range of 0.059%–0.056% in Green Development, ceteris paribus, the results in model (3) and (4) witnessed consistency in terms of coefficient and significance level at 1%

Meanwhile, the coefficients are witnessed to be divergent for developed countries in model (5) and (6), wherein the coefficient of GI switches from insignificance in model (5) to positive significance level at 1% when other control variables are included in model (6). Also, the impact of GI on GD in developed countries appears stronger than that of developing nations, witnessing the difference of over 0.3%. Developed nations often have well-established infrastructure (e.g., efficient grids, energy distribution networks) and financial resources that facilitate the integration and utilization of new renewable technologies driven by GI. This existing infrastructure creates a fertile ground for green innovation to translate into concrete impacts on renewable energy adoption. Technically, the inclusion of control variables in model (6) might have "controlled out" confounding factors that previously obscured the positive relationship between GI and GD in developed nations. These factors could include variations in economic development, energy mix, or institutional capacities. Addressing these factors allows the true impact of GI to emerge for developed nations. This outcome has the team confirm **Hypothesis 1.a**

4.4. Endogeneity concerns

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Full	**Full**	**Developing**	**Developing**	**Developed**	**Developed**
L.GD	.994***	.954***	.992***	.955***	1.015***	.961***
	(.001)	(.002)	(0)	(.002)	(.008)	(.119)
GI	-.002***	.015***	0***	.015***	.059***	.2***
	(0)	(.001)	(0)	(0)	(.018)	(.109)
OER		.008***		.005***		.05**
		(0)		(0)		(.024)
IDU		.01***		-.003***		-.021
		(.001)		(.001)		(.064)
INF		.001***		.001***		-.08
		(0)		(0)		(.126)
GCF		.062***		.034***		-.171
		(.002)		(.001)		(.263)
UPOP		.02***		.008***		-.028
		(.003)		(.002)		(.076)
l_POP		.044***		-.026***		-.966

		(.015)		(.01)		(1.122)
AGR		.114***		.106***		-.259
		(.007)		(.006)		(.992)
_cons	.194***	-4.339***	.073***	-1.458***	-.33	19.284
	(.024)	(.29)	(.005)	(.222)	(.314)	(25.379)
Observations	3161	2811	2472	2372	689	407
p-value for Hansen J test	0.492	0.534	0.627	0.912	0.925	0.931
p-value for AR(2) test	0.473	0.707	0.506	0.680	0.440	0.849
Country FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Table 6: Endogeneity addressing. GMM approach.

This table depicts the findings of effects of green innovation on green development, as estimated by the country's fixed-effects model. Models (1) to (6) describe the regression outcomes for the full sample, and two subsamples (developing countries and developed countries). The dependent variable for all specifications is L.GD. Standard errors are robust and clustered at the country level. Table 1 offers the definitions of the variables.

Taking the potential of endogeneity problems into consideration, although the team has included year and country fixed effects that capture time-invariant unobservable factors, omitted important variables that may influence the coefficient of Green Innovation. In dealing with this, the study controls the lagged dependent variable in a model and employs lagged independent variables as instruments. We used the GMM - Hansen test and AR (2) test to make sure the validity of the model (Hansen & Lee, 2021). The results are reported in **Table 6**. We find consistent results that the coefficients on GI are positive and statistically significant at 1% significance level for the full sample and stronger for developed countries compared to developing ones. Overall, the results are robust and consistent with baseline results. Therefore, endogeneity caveats are not a big problem in our model.

4.5. The interaction term role of Gross Capital Formation

	OLS			GMM		
	Full	**Developing**	**Developed**	**Full**	**Developing**	**Developed**
GI	.052***	.046***	.426***	.067***	.018***	1.309
	(.008)	(.008)	(.116)	(.022)	(.004)	(1.003)
GI_high_gcf	.025***	.024***	-.082	.142***	.063***	-1.843
	(.008)	(.008)	(.121)	(.021)	(.005)	(1.206)
high_gcf	-.634*	-.678*	.754	-8.936***	-.053	19.588
	(.345)	(.378)	(1.472)	(1.43)	(.168)	(11.649)
OER	-.027***	-.018***	.032*	.082***	.016***	.18*
	(.006)	(.006)	(.019)	(.028)	(.006)	(.096)
IDU	-.056***	-.096***	-.091**	.327***	.3***	.233
	(.02)	(.022)	(.041)	(.074)	(.028)	(.198)
INF	0	0	.003	-.011**	-.018***	-1.149
	(.001)	(.001)	(.152)	(.005)	(.001)	(.671)
GCF	-.077***	-.061***	.151	.422***	-.515***	.304
	(.019)	(.018)	(.11)	(.062)	(.024)	(.604)
l_POP	-.493***	-.444***	-.316***	-1.006***	-.921***	.45
	(.038)	(.039)	(.118)	(.098)	(.026)	(.321)
UPOP	-15.979***	-10.124***	-50.111***	5.891***	6.474***	-18.25***
	(1.124)	(1.137)	(7.327)	(1.35)	(.608)	(4.199)
AGR	.407***	.321***	-.836	1.657***	2.21***	-2.356
	(.03)	(.03)	(.56)	(.146)	(.047)	(1.457)
_cons	318.405***	221.91***	865.974***	-41.728**	-48.301***	249.091***
	(17.831)	(17.989)	(123.486)	(21.119)	(10.801)	(72.736)
Observations	3089	2593	496	3093	2596	492
R-squared	.976	.98	.942			

p-value for Hansen J test				0.985	0.524	0.917
p-value for AR(2) test				0.201	0.425	0.143
Country FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Table 7: Interaction of green innovation and Gross capital formation.

This table reports the effects of green innovation and green development on the degree of gross capital formation. Models (1) through (6) show the basic regression results for each of the examined samples (full sample, developing countries, and developed countries) with GD as the dependent variable. The variables definitions are as shown in Table 1.

Table 7 illustrates the statistical significance and how the effect of Gross Capital Formation implies on the relationship between Green Innovation and Green Development for the **Hypothesis 2**. We then progress the interaction term with three samples, including the all tested countries reported in the 1st column, developing countries subsample in the 2nd column, and the 3rd model for developed countries subsamples . We define high_gcf as a dummy variable that equals 1 for countries which experience higher-than-median Gross Capital Formation, and equals 0, otherwise. Empirically, the result provides that Gross Capital Formation has significant impacts on the relationship in full sample (1) and developing nations (2) at 0.025 and 0.024, respectively. The coefficients on the interaction terms of these two samples are reported to be statistically significant at 1% positive, with the exception for developed nations, allowing the team to conclude a confirmation towards the **Hypothesis 2** that stronger impact on the relationship between Green Innovation and Green Development in countries with high-level Gross Capital Formation.

This finding is consistent with the study conducted by Li et al in 2023. Higher GCF (i.e increased investment in physical capital) can empower countries to adopt and integrate green technologies when: First, improved infrastructure facilitates the deployment of renewable energy systems and other green solutions. Second, develop domestic green innovation capacity as increased R&D investment and infrastructure can foster homegrown innovation in clean technologies, tailored to local needs and context. Finally, attracting foreign green investments with stable financial environments and skilled workforces incentivize foreign companies to bring their green technologies and expertise.

Moreover, the pattern also witnessed significance within the context of developing countries, implying that the impact of Gross Capital Formation on the relationship between Green Innovation and Green Development appears to be effective in developing countries in contrast to developed ones. The effects of control variables are also shown in the tables. Similarly, we found that almost all the coefficients (except for UPOP) are statistically insignificant for the developed countries group.

The team also used the GMM - Hansen test and AR (2) test to make sure the validity of the model (Hansen & Lee, 2021). The results are reported in the next 3 columns to the right of **Table 7**. We find consistent results that the coefficients of GI_high_gcf in are positive and statistically significant at 1% significance level for the full sample and developing countries. Overall, the results are robust and consistent with baseline results. Therefore, endogeneity caveats are not a big problem in our model.

4.6. The interaction term role of Education

	OLS			GMM		
	Full	**Developing**	**Developed**	**Full**	**Developing**	**Developed**
GI	.076***	.077***	-.275*	.116***	.104**	-1.005*
	(.009)	(.009)	(.141)	(.02)	(.052)	(.515)
high_edu	2.673***	3.036***	-2.097	12.844***	21.949***	-9.184
	(.539)	(.578)	(1.675)	(1.145)	(3.756)	(12.404)
GI_high_edu	.084***	.078***	-.778***	.22***	.392***	-1.814***
	(.012)	(.012)	(.141)	(.027)	(.059)	(.605)
OER	-.028***	-.019***	.046***	.001	-.06	.316***
	(.006)	(.006)	(.018)	(.017)	(.041)	(.101)

IDU	-.061***	-.098***	-.111***	.295***	-.103	-.108
	(.02)	(.022)	(.037)	(.055)	(.117)	(.216)
INF	0	0	.002	-.002	-.001	.547
	(.001)	(.001)	(.14)	(.002)	(.003)	(.567)
GCF	-.075***	-.061***	.228***	.219***	.144**	-.445
	(.016)	(.015)	(.086)	(.035)	(.06)	(.609)
l_POP	-.479***	-.434***	-.208*	-1.06***	-1.098***	.423
	(.038)	(.039)	(.11)	(.08)	(.119)	(.385)
UPOP	-16.072***	-10.002***	-64.305***	7.255***	4.278***	-19.413***
	(1.119)	(1.131)	(6.989)	(1.281)	(1.328)	(3.413)
AGR	.411***	.32***	-.587	1.757***	1.321***	-2.666
	(.03)	(.03)	(.519)	(.101)	(.143)	(2.222)
_cons	317.43***	217.627***	1092.486***	-51.187**	15.472	310.255***
	(17.743)	(17.9)	(117.393)	(19.843)	(23.568)	(66.636)
Observations	3089	2593	496	3093	2596	480
R-squared	.977	.98	.949			
p-value for Hansen J test				0.663	0.839	0.902
p-value for AR(2) test				0.402	0.671	0.660
Country FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Table 8: Interaction of Green innovation and Education.

This table reports the effects of green innovation and green development on the degree of education. Models (1) through (6) show the basic regression results for each of the examined samples (full sample, developing countries, and developed countries) with GD as the dependent variable. The variables definitions are as shown in Table 1.

Table 8 illustrates the statistical significance and how the effect of Education implies on the relationship between Green Innovation and Green Development for the **Hypothesis 3**. We then progress the interaction term with three samples, including the all tested countries reported in the 1st column, developing countries subsample in the 2nd column, and the 3rd model for developed countries subsamples . We define high_edu as a dummy variable that equals 1 for countries which experience higher-than-median Education, and equals 0, otherwise. Empirically, the result provides that Education has significantly positive impacts on the relationship in full sample (1) and developing nations (2) at 0.025 and 0.024, respectively. By contrast, the figure witnessed a negative coefficient for developed countries at -0.778. The coefficients on the interaction terms of the three samples are reported to be statistically significant at 1%. Thereby, the team concluded a stronger impact on the relationship between Green Innovation and Green Development in countries with high-level investment in Education as of **Hypothesis 3**. This finding is consistent with the study from Filho et al. in 2019 that Countries with high EDU levels would see a stronger impact as the larger pool of skilled individuals contributes to innovation, technology adoption, and sustainable practices. Also, robust universities and research institutions provide continuous knowledge generation and diffusion and governments in countries with high EDU levels often prioritize green development, creating a receptive environment for innovation.

Additionally, the coefficients appear to be divergent between developing and developed countries at 0.078 and minus 0.778, sequentially, indicating that the impact of investment on Education on the relationship between Green Innovation and Green Development in developing countries is on a positive trend, whereas the remarkable negative effect occurred towards developed nations. This implies that in countries where education levels are higher than the median, the positive effects of green innovation on green development are amplified. Conversely, the results for developed countries show a negative coefficient on the interaction term between education and green innovation. This suggests that in developed countries, higher levels of education may not necessarily strengthen the relationship between green innovation and green development; instead, there might be mitigating factors at play that lead to a dampening effect.

The team also used the GMM - Hansen test and AR (2) test to make sure the validity of the model (Hansen & Lee, 2021). The results are reported in the next 3 columns to the right of **Table 8**. We find consistent results that the coefficients of GI_high_edu in are positive and statistically significant at 1% significance level for the full sample, developing countries and negative figure for developed ones. Overall, the results are robust and consistent with baseline results. Therefore, endogeneity caveats are not a big problem in our model.

4.7. The interaction term role of Digital Transformation

	OLS			**GMM**		
	Full	**Developing**	**Developed**	**Full**	**Developing**	**Developed**
GI	.084***	.079***	.108	.118***	.071***	-1.228**
	(.009)	(.009)	(.106)	(.029)	(.017)	(.56)
high_dtf	1.486***	1.504***	-4.248***	6.587***	5.668***	-8.78
	(.315)	(.336)	(1.248)	(1.166)	(1.267)	(11.816)
GI_high_dtf	.032***	.034***	-.446***	.238***	.119***	-1.681***
	(.009)	(.008)	(.115)	(.032)	(.02)	(.837)
OER	-.03***	-.02***	.045**	.052**	-.186***	.659***
	(.006)	(.006)	(.019)	(.021)	(.022)	(.107)
IDU	-.054***	-.092***	-.104***	.132**	-.002	.421
	(.02)	(.022)	(.04)	(.063)	(.084)	(.369)
INF	0	0	-.001	.001	0	1.098
	(.001)	(.001)	(.149)	(.002)	(.001)	(1.229)
GCF	-.071***	-.057***	.099	-.12***	-.057	-2.477**
	(.016)	(.015)	(.09)	(.045)	(.035)	(.931)
l_POP	-.487***	-.442***	-.265**	-.93***	-1.091***	-.228
	(.038)	(.039)	(.115)	(.106)	(.073)	(.378)
UPOP	-14.99***	-9.162***	-48.783***	4.653***	5.435***	-20.122***
	(1.143)	(1.156)	(7.16)	(1.324)	(1.274)	(4.111)

AGR	.407***	.324***	-1.212**	1.945***	1.581***	-14.721**
	(.03)	(.03)	(.558)	(.152)	(.126)	(5.479)
_cons	300.752***	204.952***	844.611***	-20.297	-3.646	416.044***
	(18.186)	(18.337)	(120.679)	(21.073)	(21.76)	(104.25)
Observations	3089	2593	496	3093	2596	480
R-squared	.977	.98	.949			
p-value for Hansen J test				0.564	0.432	0.897
p-value for AR(2) test				0.891	0.252	0.770
Country FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Table 9: Interaction of Green innovation and Digital transformation.

This table reports the effects of green innovation and green development on the degree of digital transformation. Models (1) through (6) show the basic regression results for each of the examined samples (full sample, developing countries, and developed countries) with GD as the dependent variable. The variables definitions are as shown in Table 1.

Table 9 illustrates the statistical significance and how the effect of Digital Transformation (i.e the growth in ICT) implies on the relationship between Green Innovation and Green Development for the **Hypothesis 4**. We then progress the interaction term with three samples, including the all tested countries reported in the 1st column, developing countries subsample in the 2nd column, and the 3rd model for developed countries subsamples . We define high_dtf as a dummy variable that equals 1 for countries which experience higher-than-median Digital Transformation, and equals 0, otherwise. Empirically, the result provides that the growth in Digital Transformation has significantly positive impacts on the relationship in full sample (1) and developing nations (2) at 0.032 and 0.034, respectively. By contrast, the figure witnessed a negative coefficient for developed countries at -0.446. The coefficients on the interaction terms of the three samples are reported to be statistically significant at 1%. This suggests that in countries experiencing higher levels of digital transformation, characterized by increased adoption and integration of Information and Communication Technologies (ICTs), the positive effects of green innovation on green development are amplified. This could be attributed to several factors, including the potential of ICTs to enhance efficiency, optimize resource utilization, and facilitate the implementation of sustainable practices in these countries (Malmodin et al., 2014, Coroamă et al., 2020). This finding enables the team to confirm **Hypothesis 4** that the positive impact of Green Innovation on Green Development is more pronounced for high digital transformation levels countries

Additionally, the coefficients appear to be divergent between developing and developed countries at 0.034 and minus 0.446, sequentially, indicating that the impact of development in ICT services on the relationship between Green Innovation and Green Development is on a positive trend for developing countries, whereas the remarkable negative effect occurred towards developed nations. In developing countries, where digital transformation may be associated with leapfrogging traditional development pathways and accelerating economic growth, the positive impact on the relationship between green innovation and green development is more pronounced. Conversely, in developed countries, where digital transformation may be more incremental and intertwined with issues such as automation, job displacement, and environmental externalities, the relationship may be more complex and potentially negative (Shen & Wang, 2023) .

The team also used the GMM - Hansen test and AR (2) test to make sure the validity of the model (Hansen & Lee, 2021). The results are reported in the next 3 columns to the right of **Table 9**. We find consistent results that the coefficients of GI_high_dtf in are positive and statistically significant at 1% significance level for the full sample, developing countries and negative figure for developed ones. Overall, the results are robust and consistent with baseline results. Therefore, endogeneity caveats are not a big problem in our model.

4.8. Implications for GDP Growth

	(1)	(2)	(3)	(4)	(5)	(6)
	Full	**Full**	**Developing**	**Developing**	**Developed**	**Developed**
GI	.002***	.002**	.002***	.002**	0	.005**
	(.001)	(.001)	(.001)	(.001)	(.001)	(.002)
high_GD	-.125***	-.079***	-.127***	-.06	-.054*	.021
	(.024)	(.028)	(.037)	(.04)	(.029)	(.036)
GI_high_GD	.003***	.002***	.003***	.003***	0	-.006**
	(.001)	(.001)	(.001)	(.001)	(.002)	(.003)
OER		.002***		.003***		0
		(0)		(0)		(0)
IDU		.001		.003***		-.004***
		(.001)		(.001)		(.001)
INF		0		0		.002
		(0)		(0)		(.003)
GCF		.003***		.003***		0
		(.001)		(.001)		(.002)
UPOP		.005**		.005**		-.004
		(.002)		(.002)		(.003)
l_POP		.116**		.162**		-.195
		(.056)		(.065)		(.155)
AGR		.001		.002		-.046***
		(.002)		(.002)		(.012)
_cons	1.509***	-.917	1.436***	-1.83*	1.647***	5.343**
	(.016)	(.906)	(.026)	(1.05)	(.015)	(2.617)
Observations	3006	2308	2140	1851	866	457
R-squared	.814	.823	.798	.809	.818	.891
Country FEs	YES	YES	YES	YES	YES	YES

Year FEs	YES	YES	YES	YES	YES	YES

Standard errors are in parentheses

*** p<.01, ** p<.05, * p<.1

Table 10: The impact of green development and green innovation on GDP Growth.

This table reports the effects of green development and green innovation on GDP Growth. Models (1) through (6) show the basic regression results for each of the examined samples (full sample, developing countries, and developed countries) with GI as the dependent variable. The variables definitions are as shown in Table 1.

In order to determine the moderating role of Green Development in the linkage between Green Innovation and economic growth, we define high_GD as a dummy variable that equals 1 if a country's level of Green Development is higher than the median level , and 0 otherwise. We then attach this dummy variable to Green Innovation. Specifically, we estimate the following model:

$$log\ (GDP) = \beta_0 + \beta_1 GI_{i,j} + \beta_2 high\_gd_{i,j} + \beta_3 GI_{i,j} \times high\_gd_{i,j} + \alpha' Control\ variables_{i,j} + \delta_i + \delta_j + \mu_{i,j} \ (5)$$

In this equation, we focus on the coefficient on β_3. If high Green Development can strengthen the positive impact of Green Innovation on Economic Growth, we expect that the coefficient on this interaction term will be positive and statistically significant. The results are reported in **Table 10**. Results obtained suggest that while Green Innovation solely has a positive effect on economic growth, this influence is strengthened to positive impact for instances where there is high Green Development. We can infer that conclusion through the coefficients of GI and GI_high_GD. This results support **Hypothesis 5** which is consistent with recent study related to the role of Green Development (Ha et al., 2023).

In comparison with countries with low Green Development, the effects of Green Innovation on economic growth appears to be positive for countries with high Green Development by 0.002. Furthermore, the positive impact appears to be stronger within the context of developing nations by 0.003. Whereas, the developed countries experienced an opposite direction at -0.006. Hence, these findings unveil a potential topic for further research on the divergence between developing and developed nations in the contributions of Green Innovation and Green Development in improving the national GDP.

5. CONCLUSION, LIMITATIONS, AND POLICY IMPLICATIONS

5.1. Conclusion

Our thorough investigation offers strong proof for the claim that green innovation is essential to achieving the goals of green development. Our analysis shows a strong and positive correlation between investments in green innovation and several measures of sustainable development across a sample of 161 nations from 1975 to 2022. The study's descriptive statistics provide an in-depth look at the distribution and patterns of important factors associated with green innovation and green development. These figures, which range from mean scores to extreme values, highlight the scope and complexity of our investigation and provide our findings a solid basis.

Moreover, the analysis we conducted on trendlines and country group comparisons reveals noteworthy variations and trends in the correlation between green innovation and green development in various settings. Whether examining the difference between developing and developed countries or the effects of particular moderating factors like Gross Capital Formation, Education, and Digital Transformation, our results consistently indicate that green innovation has a positive impact on the outcomes of sustainable development.

The regression results, which show statistically significant and positive coefficients for the association between green innovation and green development across a variety of models and nation groupings, support these conclusions even more. The addition of interaction categories, such digital transformation, education, and gross capital formation, is noteworthy because it clarifies the complex ways in which these variables enhance the benefits of green innovation on sustainable development goals. The robustness of our findings is further supported by our sensitivity analyses that address endogeneity issues, adding further weight to the claim that green innovation and green development are causally related.

As a result, our study emphasizes how revolutionary green innovation may be in creating a future that is resilient and sustainable for future generations. Through the adoption of green innovation and the implementation of focused policies and interventions, we can create a more sustainable, just, and affluent society that benefits everyone.

5.2. Limitations

There are several restrictions that need to be taken into account, even if this study offers useful information on the connections between the previously listed factors. First off, we are limited in our capacity to conclusively demonstrate causal linkages by the observational character of our data. Secondly, our study relies on aggregated country-level data, which can obscure heteroskedasticity within countries and fail to capture localized effects of green innovation initiatives. Variations in policy environments, institutional frameworks, and socio-economic conditions across different regions within countries may affect the observed relationships and limit the generalizability of the findings. Additionally, while our analysis includes a wide range of control variables and interaction terms to account for the complex interplay between green innovation and green development, there may be other unobserved factors that could confound the results. Examples of variables not included in our analysis but that could potentially impact the outcomes are cultural attitudes towards sustainability, political stability, and access to technology. Furthermore, the reliance on secondary data sources for variables like Green Innovation scores, Gross Capital Formation, Education, and Digital Transformation may introduce measurement errors that constrain the analysis. Finally, the topic discussed is still quite new. When it comes to gathering pertinent data and including significant variables that might be more thoroughly controlled to provide outcomes better suited for serious scientific inquiry, there are still numerous gaps in our understanding.

5.3. Policy implications

Several types of support may be offered to help countries that have not yet achieved green development in their transformation. They consist of lending money, sharing technology, developing capacity, and offering policy recommendations.

Nations that want to make investments in facilities, sustainable practices, and green technology need financial backing. Green development initiatives can be implemented with the cooperation of prosperous countries and global organizations, which might offer loans, subsidies, financial aid, or a link to sustainable investment resources. Furthermore, technology helps countries in their endeavors toward sustainable development. Rich nations can exchange technical know-how and give access to eco-friendly technology. By facilitating information sharing, encouraging collaboration in study and development, and aiding in the integration of innovations to local settings, global initiatives and groups can help to enhance technology transmission. Besides, building capacity may be achieved at several levels through the implementation of technical instruction programs, seminars, and educational activities. Ecological legislation, clean energy systems, coping with climate change, and environmentally friendly resource management are a few areas where capacity-building initiatives might be concentrated.

Adopting and implementing successful green development programs need policy direction and cooperation from governments. Policies, best practices, and frameworks for policy that are customized for each country's unique circumstances can be obtained from global organizations, research centers, and specialists. Authorities must set up structures of laws and regulations that encourage innovative green practices and sustainable growth to foster an enabling climate. This might involve actions like grants, tax breaks, and subsidies for eco-friendly activities and technology. To pool assets and knowledge for green development projects, governments should also support collaboration between the public and private sectors. Implementing policies also depends on strong organizational capacity and efficient governance. The government must fortify its ecological governance frameworks, delineate definite duties and obligations, and augment cooperation among pertinent ministries, agencies, and interested parties. By doing this, green development initiatives may be implemented, tracked, and evaluated effectively. The efficient execution of green development strategies necessitates stakeholder participation and public knowledge. To develop a sustainable culture and motivate behavior shifts toward eco-friendly behaviors, governments, civil society groups, and educational institutions can support public involvement initiatives, educational efforts, and activities.

Our papers provide policymakers with the information they need to develop plans that are tailored to their nation and involve global collaboration, networks, and platforms. These can help in the sharing of best practices, lessons discovered, and experiences. Hence, assisting nations in adapting policies to their unique settings and learning from another's triumphs and problems.

In summary, helping countries on their path to green development may be accomplished through the provision of financial support, technological transfer, capacity training, and policy advice. It takes a mix of supporting regulations and laws, effective management and organizations, public understanding, stakeholder involvement, and global cooperation to enact the regulations that ecological innovation delivers to its research in real-life situations. Together, these components enable countries to make the shift to sustainable growth and reap the rewards of green innovation.

5.4. Further research

According to our research, developing nations hold great future potential for sustainable economic growth. They have bountiful renewable assets like solar, wind, water, and geothermal vitality, which can lessen reliance on fossil fuels and contribute positively to a greener energy mix. Developing locations can also skip outdated technologies and directly embrace modern and eco-friendly practices in areas for example energy, farming, transportation, and waste management. By encouraging invention and entrepreneurship, they can tackle local environmental challenges through reasonably priced and clean energy solutions, sustainable agriculture methods, and earth-friendly products. Expanding customer markets in these countries offer chances for sustainable businesses to thrive by meeting the increasing demand for environmentally friendly goods and services. Developing countries can also benefit from their natural resources, like diverse ecosystems and biodiversity, to develop sectors like ecotourism and sustainable agriculture. Supportive policies, access to finance and technology, skills training, and international collaboration are crucial for achieving sustainable progress in these places.

Further analyzing, studying their linkages in certain developing areas through qualitative and quantitative analysis could offer useful understanding of effective funding methods at the project level. Examining projects like renewable energy or sustainable agriculture initiatives could provide insight into how gross capital formation delivery and regulations influence results. Comparatively assessing these dynamics across regions with diverse economic profiles, governance systems, and natural resources may also provide valuable information given potential differences in gross capital formation impact. Regions such as sub-Saharan Africa, Southeast Asia, and small island developing nations could offer interesting comparisons. Additionally, analyzing policy interventions aiming to optimize gross capital formation contributions to national green progress deserves consideration. Deeper localized and cross-regional evaluations may recognize policies best suited to leverage financial resources for environmental and economic benefits.

Our findings suggest that comprehending the relationship between GD and GI is only the preliminary step. It is vital to examine differences in effects based on national characteristics to learn more about this connection. We also explore the heterogeneity in the effects due to country characteristics. Particularly developing countries may benefit much from innovation if they concentrate on important areas such as digital transformation, fundamental facilities, and literacy. Educating more people as well as being equipped to lead innovation in sustainable technology. Enhancing fundamental infrastructure, such as dependable electricity and transport, helps create a climate in which companies and sectors can embrace and disseminate environmentally friendly ideas. By facilitating efficient utilization of resources, easing the transition to energy from sustainable resources, and improving connections for faraway places, the digital revolution also promotes ecology. The governments of developing nations may optimize the advantageous effects of the GI-GD connection and steer sustainable and equitable prosperity by prioritizing certain areas.

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