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Nexus Between Innovation and Ecological Impact: A Moderated Mediation Investigation Through Structural Equation Modeling Approach

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Abstract
Controlling ecological deterioration is critical for the well-being of current and future generations, as it ensures a sustainable environment that promotes health, productivity, and the general quality of life. This study investigates the interplay between innovation, economic growth, and ecological impact across 18 countries, which collectively account for approximately 64% of global greenhouse gas emissions, using data from 2000 to 2022. Using the structural equation modeling approach, we investigate how the regulatory framework moderates and economic growth mediates these complex relationships. The empirical results reveal that innovation positively impacts economic growth, but this effect is statistically insignificant. Similarly, economic growth contributes significantly to environmental degradation. Moreover, the interaction between innovation and the regulatory framework leads to a decline in economic growth. Furthermore, innovation alone in a direct relationship, reduces ecological impact significantly but innovation and regulatory framework jointly increase ecological impact. Economic growth plays a significant role in mediating the relationship between the interaction term and ecological impact, but it does not significantly influence the relationship between innovation and ecological impact, according to empirical evidence. These insights are vital for policymakers to develop strategies that encourage sustainable growth and innovation.
Keywords: Ecological Impact, Economic Growth, Innovation, Regulatory Framework
JEL Codes: Q55, O44, C38, F64

1. Introduction

In recent decades, sustainable development with a stable macroeconomic environment has become the prime concern of every economy. The development process has led to multi-layered challenges, encompassing not only conflicts and political and socioeconomic volatility but also mounting ecological impacts and consequent calamities (Glasser et al., 2022; Sulehri et al., 2024b; Sulehri et al., 2024a). Human activities have harmed the environment, putting the planet's survival and future generations at risk. These circumstances have signaled behavioral adjustments aimed at more rational and efficient resource management that will result in a stable economy and reduce environmental degradation, leading to sustainable development. Achieving sustainable development has become a major global issue for all countries because of ecological impact

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management (Markanday et al., 2022; Singh & Kumar, 2023; Sulehri & Ali, 2024). The term "ecological impact" refers to the influence of human actions on the natural environment, which includes changes in biodiversity, ecosystems, and global health (Ropke, 2004; Audi et al., 2020; Hickel, 2020; Fu et al., 2023; Limjaroenrat & Ramanust, 2023 Treweek, 1995). As public awareness of environmental sustainability grows, assessing ecological impact becomes critical for implementing effective environmental policies and practices.

This research focuses on two metrics for assessing ecological impact: carbon dioxide (CO_2) emissions per capita and material footprint per capita. CO_2 emissions per capita are the average carbon dioxide emissions produced by a certain population during a specified time. Because CO_2 is a primary greenhouse gas, this parameter is critical for assessing the role of human activities in global warming and climate change. Industries, transportation, and energy generation all contribute significantly to CO_2 emissions. Studying per capita emissions allows us to determine the efficiency and environmental impact of a country's or region's lifestyle and economic activity concerning its population size. Material footprint per capita is a comprehensive metric that indicates the amount of raw materials required to meet the average individual's consumption needs in a given location. This comprises biomass, fossil fuels, metal ores, and nonmetal minerals. The material footprint sheds light not only on resource exploitation but also on the overall environmental impact, such as habitat damage, resource depletion, and pollution (Wang & Manopimoke, 2023; Hickel, 2020; Ali & Audi, 2016; Bringezu, 2015). It is an important part of understanding the overall environmental impact of human consumption patterns.

Environmental research frequently discusses innovation as the creation and implementation of novel technologies, processes, and ideas that have the potential to significantly impact human-environment interactions and promote sustainable practices aimed at reducing ecological footprints. Innovation, fueled by investments in research and development, has a significant impact on the environment. It is worth noting that this approach can result in improved resource efficiency, decreased waste, and the creation of sustainable products and energy sources. However, it is important to consider that technological advancement can also lead to higher consumption and resource extraction. This is because it lowers costs and makes products and services more accessible, potentially worsening ecological impacts. Research and development play a crucial role in pioneering new technologies that effectively tackle specific environmental issues (Severo et al., 2017; Melville, 2010; Ali & Audi, 2018; Destek & Manga, 2021 Kilenthong, T., & Komain, 2023). R & D in clean energy, for example, focuses on decreasing reliance on fossil fuels, resulting in a reduction in CO_2 emissions. In the same vein, advancements in manufacturing processes could potentially decrease the amount of raw material needed to produce goods or improve the efficiency of recycling waste products.

The regulatory framework reflects a country's legal and institutional systems' ability to enforce laws and regulations that can either support or impede innovation and its impact on the environment. A government committed to integrity and an effective judicial system, in conjunction with a robust regulatory framework, ensures the implementation and strict enforcement of environmental standards. The full realization of the ecological benefits of innovations hinges on this enforcement. Property rights play a crucial role in promoting innovation by providing inventors and companies with the economic benefits they deserve for their inventions. Applying these rights to environmental assets such as land or forests can also significantly contribute to the promotion of sustainable practices and technologies. In addition, a strong regulatory framework can help promote the implementation of sustainable practices by establishing clear guidelines and standards for environmental performance. Aligning with regulatory standards can direct R&D

expenditures toward innovative solutions. Regulation that is effective and flexible should be able to adapt and evolve in response to new scientific findings and technological advancements. This flexibility can assist in the seamless integration of emerging green technologies into the market, amplifying their influence on ecological footprints (Zhang, 2016; Dempere et al., 2023; Farhadi & Zaho, 2024; Abbas et al., 2024; Sulehri et al., 2024a; Sulehri & Ali, 2024).

Environmental economics has extensively studied the relationship between economic growth and the environment. Historically, environmental degradation has often been associated with increased productivity due to the need for increased resource exploitation and increased emissions. However, a variety of circumstances, such as technological advancement and governmental regulations, have an impact on this relationship's dynamic character. Efficient innovations that boost productivity while minimizing resource consumption and emissions can help strike a balance between economic growth and environmental preservation, mitigating the impact on ecological footprints. As economies expand, there is often a heightened focus on investing in new technologies, which in turn can result in the emergence and acceptance of eco-friendly innovations. This progression has the potential to facilitate a positive shift towards greener and more sustainable practices. If economic growth is based on resource-intensive industries, the scale effect can exacerbate ecological impacts. However, the nature of economic activity can change toward less harmful and more sustainable practices with the right legislative frameworks, which will have an impact on the mediation process (Paul, 2008; Adedoyin et al., 2020; Ali et al., 2022; Ashiq et al., 2023; Roussel & Audi, 2024; Ullah & Ali, 2024; Saluy & Nuryanto, 2023 Audi & Ali, 2023; Audi et al., 2024).

This research paper aims to explore the connection between innovation and ecological impact using quantitative analysis. It will examine how the regulatory framework acts as a moderating variable and economic growth as a mediating variable, influencing the relationship between innovation and ecological impact. This research aims to provide insights into the interplay between innovation, regulatory policies, and economic growth, offering guidance for policy-making to achieve sustainable development goals.

2. Literature Review

Ecological impact assessment began as a formal discipline with the National Environmental Policy Act (NEPA), which became law in the United States in 1969 and mandated that proponents of an action examine potential environmental repercussions. Treweek (1995) highlights that there is only a partial understanding of the ecological repercussions of human activity. Society doesn’t know how much anthropogenic interference buffers 'natural' ecosystems, and assessing the risk of irreversible harm to ecosystem components and services that could be crucial for human well-being is challenging. This uncertainty has sparked significant contemporary debate about the need to protect biodiversity and promote sustainable development concepts based on the 'wise use' of finite natural resources (NEPA, 1969).

Fu et al. (2023) highlight the importance of adopting transdisciplinary approaches in ecological restoration, with a focus on achieving a harmonious balance between social and ecological outcomes. Examining China's past initiatives, the proposed framework explores the relationship between restoration efforts, ecological processes, and ecosystem services, which are essential for promoting socio-economic progress. China's restoration strategies have evolved, ranging from large-scale projects to more nuanced ecosystem service management. These strategies align with the 'Beautiful China Initiative' and adapt to the specific geographical variations across the country. This literature emphasizes the need for a more comprehensive understanding of the relationship between humans and nature to make informed policy decisions.

Rani et al. (2023) investigate the moderating role of globalization in determining the relationship between financial development and environmental degradation in SAARC countries from 1990 to 2020. The study uses a panel quantile regression approach to estimate the long-run coefficients at lower, middle, and upper quantile groups. The study finds a U-shaped relationship between financial development and carbon emissions across the three quantile groups. Moderator globalization (KOF) affects the turning point and flattens the U-shaped curve at the middle quantile, while it flattens the curve after maturity at the upper quantile. The study recommends the use of energy-efficient technologies and better financial sector interaction with globalization to enhance environmental quality in SAARC countries.

By incorporating insights from social-ecological systems, Wieland et al. (2022) redefine supply chain resilience, departing from the conventional perception of supply chains as engineered systems. It advocates for a broader framework by analyzing current resilience research and highlighting voids in existing theories through the use of five practical examples. The research presents a nuanced paradigm of resilience that encompasses three forms: perseverance, adaptation, and transformation and applies seven principles of resilience thinking to supply chains. This perspective regards supply chains as dynamic systems, encouraging managers to embrace more adaptable and inventive tactics in managing disruptions as opposed to simply reinstating pre-disruption states.

From 1982 to 2004, Wang et al. (2008) study at Daya Bay uncovered noteworthy ecological shifts, particularly a notable rise in the nitrogen/phosphorus ratio, suggesting the possibility of eutrophication. The decrease in algal and zooplankton diversity indicates potential disruptions in the food web. Although the overall benthic animal biomass remained stable, there was a noticeable decline in species diversity near nuclear power plants. The environmental stressors caused by the facilities likely contributed to this decline. In addition, they observed shifts in populations of hermatypic corals and mangrove plants, which are important indicators of the overall health of marine ecosystems.

Adebayo et al. (2021) use panel data analysis and a vector error correction model to study economic growth, urbanization, environmental deterioration, and hydroelectricity usage. Empirical research uses secondary data from the World Bank, the China Statistical Yearbook, and China's National Bureau of Statistics. The 1990–2019 study analyzes long-term trends and dynamics. Sustainable energy and environmental management strategies are crucial to balancing economic growth and environmental sustainability, according to the report. The study reveals a positive correlation between economic growth, urbanization, and environmental degradation in China. Environmental pressures rise with economic growth and urbanization, causing pollution and ecological degradation. The findings indicate that rapid urbanization and economic development can cause environmental degradation, which hydroelectric power generation can mitigate.

In Indonesia, Bashir et al. (2021) found links between urbanization, economic growth, energy use, and CO2 emissions. The empirical study uses secondary data from 1990 to 2019 collected from the World Bank, IEA, and Indonesian Statistical Yearbooks. They examine urbanization, economic growth, energy consumption, and CO2 emissions in Indonesia using econometric methods, including the autoregressive distributed lag (ARDL) model. The study shows that urbanization, economic growth, and energy consumption in Indonesia are positively correlated. Energy use increases CO2 emissions in Indonesia.

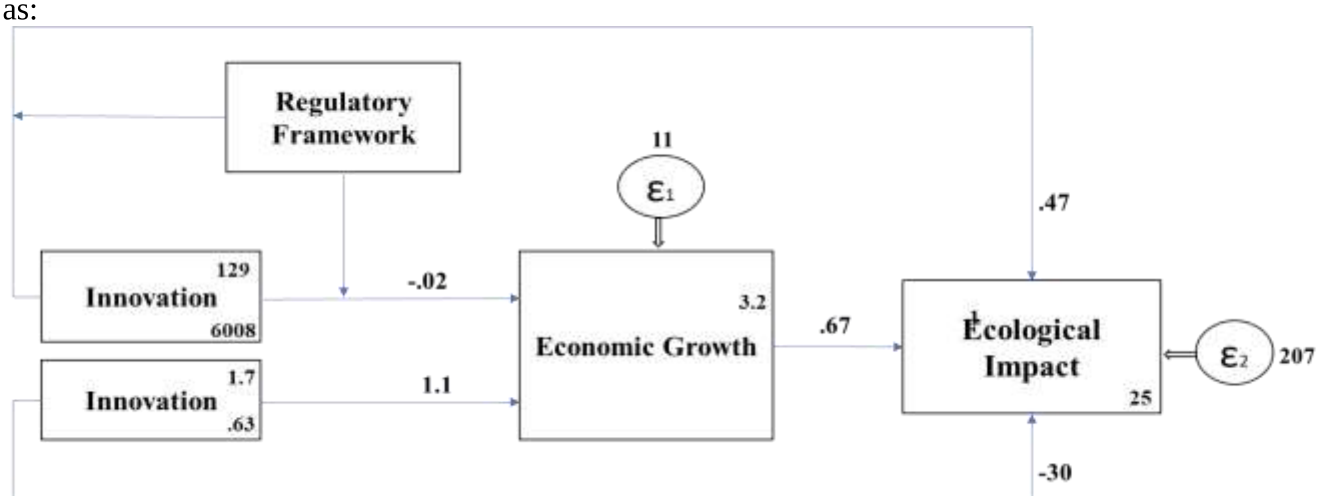
Adebayo et al. (2021) find links between globalization, energy consumption, economic growth, and CO2 emissions. The empirical study uses panel data from 111 countries during 1990–2017.

The researchers examine globalization, energy consumption, economic growth, and CO2 emissions using panel regression analysis and the dynamic panel generalized method of moments (GMM). The studies reveal a positive correlation between globalization, economic expansion, and energy usage. Researchers found a favorable association between globalization and CO2 emissions. The study implies that energy consumption moderates globalization and environmental damage. Globalization increases CO2 emissions and environmental deterioration due to higher energy use. Additionally, the research contributes to globalization's environmental impact discussions. Policymakers and stakeholders can use the study's findings to support sustainable development and reduce globalization's environmental impact.

Rjoub et al. (2021) explore that financial development moderates environmental degradation in Turkey. Financial development moderates the environmental impacts of economic activities, but the study questions its sustainability. This empirical study uses time-series data from 1970 to 2018 in Turkey. We include financial development metrics such as domestic credit, banking sector, and stock market development. They study financial development, environmental degradation, and its causes using econometric methods such as the autoregressive distributed lag (ARDL) model and Granger causality tests. Financial development moderates the relationship between environmental degradation and its causes, according to the study. Financial development, defined by domestic credit and stock market development, affects economic activities' environmental impacts. The results show a complex relationship between financial development and environmental degradation in Turkey. The study links energy use, industrialization, and urbanization to environmental degradation in Turkey. The findings emphasize the importance of environmental considerations in financial decision-making and sustainable financial technologies. Sawyer (2021) critically examines financialization, industrial strategy, climate change, and environmental deterioration. Sawyer employs a conceptual and analytical approach to scrutinize financialization, industrial strategy, and climate change/environmental degradation issues, drawing from both literature and empirical data. To grasp the problem, the author draws from economics, finance, and environmental studies. The study shows how financialization affects industrial tactics. The report stresses the significance of sustainable industrial methods to combat climate change and environmental deterioration. Industrial policies that stress sustainability, innovation, and green technology can help transition to a low-carbon economy. The analysis suggests governmental solutions to align financial incentives with environmental goals.

3. Theoretical and Conceptual Framework

Initially, people viewed nature as an endless resource that could meet the ever-increasing demands of an expanding human population. However, in the mid-20th century, scientific research started revealing the repercussions of uncontrolled industrialization and resource exploitation. Notable works like Rachel Carson's "Silent Spring" in 1962 and the Club of Rome's "Limits to Growth" in 1972 questioned this viewpoint by establishing a connection between human activities and environmental degradation while promoting the idea of sustainable development (Carson, 1962). Mathis Wackernagel and William Rees developed the broader framework of ecological impact analysis in the 1990s, supporting the concept of ecological impact. The framework evaluates the biocapacity of the earth in relation to human demand by measuring the amount of biologically productive land and water area needed to produce the resources consumed by a population and to handle the waste it produces (Wackernagel & Rees, 1995). To tackle this major global concern, the role of innovation is very important because of investment in technological advancements, new products, and processes aimed at reducing ecological footprints. Innovation, fueled by investments in research and development, has a significant impact on the environment (Huan & Qamruzzaman, 2022; Destek & Manga, 2021; Tawari, 2024; Rehman & Ahmad, 2024). In addition to this, the regulatory framework reflects a country's legal and institutional systems' ability to enforce laws and regulations that can either support or impede innovation and its impact on the environment. Historically, environmental degradation has often been associated with increased productivity due to the need for increased resource exploitation and increased emissions. However, a variety of circumstances, such as technological advancement and governmental regulations, have an impact on this relationship's dynamic character (Dempere et al., 2023; Sulehri et al., 2024a). Following Baron and Kenny (1986). Carson (1962), Wackernagel and Rees (1998), Dempere et al. (2023), Sulehri and Ali (2024), and Destek and Manga (2021) the conceptual model of this study becomes as:



Following the theoretical and conceptual ideologies, the moderated mediation econometric models can be written as:

$EG_{it} = \beta_0 + \beta_1 Inno_{it} + \beta_2 Inno*RF_{it} + \varepsilon_{it1}$ (1)

$EI_{it} = \gamma_0 + \gamma_1 EG + \gamma_2 Inno_{it} + \gamma_3 Inno*RF_{it} + \varepsilon_{it}2$ (2)

EI= Ecological Impact

RF = Regulatory Framework

EG = Economic Growth

Inno = Innovation

4. Methodology

The following 18 countries have been used for empirical analysis contributing around 65% of global greenhouse gas emissions. Those countries include the United States, United Kingdom, Japan, Germany, Switzerland, Singapore, France, Canada, Australia, China, India, Brazil, Mexico, Russia, Netherlands, Italy, Spain, and South Africa. Furthermore, we collected data from 2000 to 2022. Karl Gustav Joreskog, a Swedish statistician, first presented the concept of structural equation modeling (SEM) in 1969. His research established the basis for structural equation modeling (SEM) as a comprehensive statistical method for examining intricate connections between variables in social science studies (Jöreskog, 1969).

In this research paper, structural equation modeling (SEM) is used to understand the empirical relationship between exogenous, endogenous, moderating, and mediating variables like innovation, regulatory framework, economic growth, and ecological impact. This method reveals basic structural relationships for observed variables and has different methodologies to check the goodness of fit of the model like comparative fit index (CFI), Tucker-Lewis Index (TLI), root mean square error of approximation (RMSEA), standard root mean square residual (SRMSR) and Chi-square test (Jenatabadi, 2015; Cain, 2021).

4.1. Measurement of variables and data sources

The term "ecological impact" refers to the influence of human actions on the natural environment, which includes changes in biodiversity, ecosystems, and global health. Ecological impact has been measured by combining carbon emission per capita and material footprint per capita (Hickel, 2020). Data for the components' ecological impact like material footprint has been taken from the UN International Resource Panel Global Material Flows Database; and for CO2 emissions, the data has been taken from the EORA MRIO database with PRIMAP.

Innovation refers to novel ideas, methods, products, or services that bring about significant advancements, improvements, or disruptions in various fields. It involves creative thinking, problem-solving, and the application of new technologies or approaches to address existing challenges or meet evolving needs through research and development, ultimately driving progress and growth. Innovation data has been collected from the World Bank, which is comprised of research and development expenditures as a percentage of GDP (Todaro & Smith, 2006; Grieco, 2018). Stock market performance refers to the overall behavior and movement of stock prices in a financial market, reflecting the collective value and returns of traded equities. Data related to stock market performance has been taken from the World Bank, which comprises stock market capitalization as a percent of GDP (Montes & Tiberto, 2012; Grieco, 2018).

A regulatory framework, commonly known as a country's regulatory structure, comprises a collection of legal statutes, rules, guidelines, and standards formulated by a government or regulatory body. Its purpose is to oversee various aspects of a particular industry, sector, or the entire national economy. Regulatory framework data has been taken from the Index of Economic Freedom, and that index is comprised of property rights, judicial effectiveness, and government integrity indices (Dempere et al., 2023; Zhang, 2016; Abbas et al., 2024). Foreign direct investment is the net inflow of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. Data collected from the World Bank shows foreign direct investment as a percent of GDP (Sattar et al., 2022).

Moreover, economic growth is considered the increase in an economy's production and consumption of goods and services over time. Changes in the gross domestic product (GDP), which measures the total value of a country's goods and services, typically assess economic growth. The data for economic growth has been taken from the World Bank database (Sattar et al., 2022).

5. Results and Discussions

The results and discussion in this section consider innovation as an independent variable, the regulatory framework as a moderating variable, economic growth as a mediating variable, and ecological impact as a dependent variable. The endogenous growth theory states that investment in research and development expenditures, considered innovation, is crucial for economic growth. Innovation enhances productivity and technological advancements, leading to increased economic output. Increased research and development expenditures can lead to the creation of new products, improve economic efficiency and productivity, and ultimately increase the gross domestic product growth rate (Romer, 1990). Moreover, the sustainable development idea demands principles of sustainability that truly consider environmental, social, and economic growth in a balanced manner. Innovation, particularly in sustainable technologies, plays a crucial role in deciding integrated sustainable development goals that decrease the ecological impact (Boscoianu et al., 2018; Hickel, 2020).

Douglas North's 1990 institutional theory underscores the crucial role of institutions in upholding the rule of law and influencing economic performance. A robust and balanced regulatory framework promotes the efficiency of research and development expenditures by ensuring intellectual property protection, making the environment more conducive, fair competition, and market stability that can practically contribute to sustainable development (Scott, 1987). In addition to this, the Environmental Kuznets Curve states that initially, economic growth leads to environmental degradation by a certain level, and after that, it encourages environmental protection. Innovation promotes economic growth; ultimately, more resources will be available to invest in education, health, and sustainable infrastructure, which may increase the human development index while decreasing ecological impact. As economies grow and evolve, they will simultaneously reduce carbon emissions and material footprints by utilizing efficient technologies and practices in a mature economic system (Yandle et al., 2004).

The results presented in Table 1 of structural equation modeling show the correlations between important factors, including innovation, regulatory framework, economic growth, and ecological impact. Theoretically, according to endogenous growth theory, innovation is expected to enhance economic growth by improving productivity with the adoption of new technologies. As per the empirical results, there is a positive relationship between innovation and economic growth, with a coefficient value of 1.121509 and a p-value of 0.146 which is insignificant, suggesting that an increase in research and development expenditures is associated with higher economic growth. However, the insignificance indicates that the magnitude of innovation in terms of research and development expenditures alone is not sufficient to yield a significant impact on economic growth (Dempere et al., 2023; Lee et al., 2021; Jungo et al., 2022). Furthermore, contrary to expectation from institutional theory, it is expected that a positive moderating effect of a strong regulatory framework on innovation-led growth. However, as per the empirical results, there is a negative relationship between innovation with regulatory framework moderation and economic growth with a coefficient value of -.0196917 and a p-value of 0.013 which is statistically significant, indicating that the regulatory environment may be highly restrictive and not aligned with the needs of innovative initiatives, theoretically constraining and detracting the effectiveness of innovation in enhancing economic growth. The accuracy of the estimation, as revealed by the lower standard error in comparison with the direct innovation effect, highlights the robustness of the negative impact of innovation and regulatory framework integration (Adedoyin et al., 2020; Sulehri & Ali, 2024).

In the ecological impact model, theoretically as per the environmental Kuznets curve concept, economic growth may enhance environmental degradation initially, but after reaching a certain level of growth stage, ecological impact decreases with further economic growth. As per empirical findings, there is a positive relationship between economic growth and ecological impact with a coefficient value of .6730057 and a p-value of 0.002, highly significant indicates that the current level of economic growth is not sustainable and is being achieved at a considerable environmental cost (Wackernagel & Rees, 1995; Gaspar et al., 2017; Mushafiq & Prusak, 2023; Jun et al., 2021). In addition to this, sustainable development theory states research and development particularly initiated towards improving efficiency and decreasing environmental degradation are ultimately enhancing sustainable development, which reflects the potential of technological advancements to contribute to better human development outcomes while managing ecological footprints effectively. As per empirical results, there is a robust negative influence of innovation on ecological impact with a coefficient value of -29.63559 and a p-value of 0.000, which is statistically highly significant. This outcome indicates research and development investment enhances human development metrics or limits ecological impact, especially aligned with sustainable development theory (Mores et al., 2018; Destek & Manga, 2021).

A balanced set of regulations is very important when deciding the favorable or unfavorable consequences of economic growth and environmental degradation. A stringent and vague regulatory framework may hinder the potential positive effects of innovation on sustainability. This could be due to regulations that do not support or possibly even penalize the deployment of new technologies or methods that could lead to more sustainable practices. The empirical outcomes reveal that there is a highly significant positive impact of interaction term on ecological impact contrary to economic growth with a coefficient value of .4653849 and a p-value of 0.000. The empirical outcomes state that innovation alone influences negatively on ecological impact which is a good sign of research and development expenditures but when it is coupled with regulatory framework influences positively. It means that a set of regulations is not only failing to support sustainability but actively impeding the negative impact of innovation on ecological impact. The statistically robust significant outcome shows a consistent pattern, demanding urgent attention toward regulatory reforms (Zhang, 2016; Sulehri et al., 2024a; Sulehri & Ali, 2024). To formulate policies, all stakeholders and policymakers should consider these results before adopting an inclusive approach that includes economic, social, and environmental aspects.

Table 1: Structural Equation Model

Endogenous Variables
Observed: Economic growth (EG), Ecological Impact (EI)
Exogenous Variable
Observed: Innovation (Inno.), Innovation*Regulatory Framework (Inno*RF)
Number of Observations = 414
Estimation Method = Maximum Likelihood (ML)
Log likelihood = -5110.1219

	Coefficient	OIM Std. Error	Z	P>|z|	[95% Conf. Interval]	
Structural						
EG <-						
Inno	1.121509	.7718127	1.45	0.146	-.3912159	2.634234
Inno*RF	-.0196917	.0079174	-2.49	0.013	-.0352095	-.0041739
Cons	3.153704	.4807859	6.56	0.000	2.211381	4.096027
EI <-						
EG	.6730057	.2121233	3.17	0.002	.2572516	1.08876
Inno	-29.63559	3.339682	-8.87	0.000	-36.18124	-23.08993
Inno*RF	.4653849	.0344264	13.52	0.000	.3979104	.5328593
Cons	24.82567	2.180273	11.39	0.000	20.55241	29.09892
Var (e.EG)	11.0874	.7706278			9.675362	12.70552
Var (e.EI)	206.5414	14.35562			180.2372	236.6844

As per Table 2, the innovation through economic growth mediation does not have an indirect and significant influence on the ecological system, as indicated by the structural equation modeling

(SEM) approach. It shows that economic growth is influenced by innovation but this influence does not significantly translate into benefits for environmental sustainability. Economic growth driven by innovation involves industrialization or practices that are not aligned with sustainable development goals like growth in fossil fuel investment or industries with high carbon footprints that limit the benefits to environmental sustainability. The empirical results reveal that innovation and ecological impact have a positive relationship through economic growth with a coefficient value of .7547821 and a p-value of 0.186 which indicates insignificance (Shabir et al., 2023). However, the interaction of innovation and regulatory framework through economic growth mediation has a negative and signification influence on ecological impact with a coefficient value of -.0132527 and a p-value of 0.050. This empirical result indicates that regulatory frameworks can effectively moderate the environmental impact of innovation. Effective regulatory policies could be designed to harness innovation towards more sustainable practices, minimizing ecological footprints. Moreover, regulations might incentivize companies to adopt cleaner, more sustainable innovations rather than merely focusing on economic output (Dempere et al., 2023). However, policymakers and authorities should prioritize the establishment of a balanced regulatory framework that fosters robust economic growth, placing particular emphasis on the principles of environmental, social, and economic sustainability.

Table 2: Indirect Effects

	Coefficient	OIM Std. Error	Z	P>|z|	[95% Conf. Interval]	
Structural						
EG <-						
Inno	0	(no path)				
Inno*RF	0	(no path)				
EI <-						
EG	0	(no path)				
Inno	.7547821	.5713209	1.32	0.186	-.3649864	1.874551
Inno*RF	-.0132527	.0067706	-1.96	0.050	-.0265227	.0000174

Table 3 shows the convergence of a direct impact of innovation, with a negative coefficient value of -29.63559, and an indirect impact of innovation on ecological impact, with a positive coefficient of .7547821, yielding the total effect. It displays the total effect of the innovation on ecological impact with a coefficient value of -28.8808 (-29.63559+.7547821), and the p-value is 0.000. This outcome indicates that research and development investment reduces ecological impact, especially aligned with sustainable development theory. It is important to note that the direct effect of innovation on ecological impact is greater than the total effects due to the positive indirect effect. In addition to this, the combination of direct and indirect impact of interaction term of innovation and regulatory framework on ecological impact yield a positive impact with a coefficient value of .4521322 (-.0132527+.4653849) and a p-value of 0.000 highly significant. The empirical results show that innovation, on its own, has negative total impacts on ecological impact, highlighting the importance of research and development expenditures. However, when innovation combines with a regulatory framework, it positively impacts ecological impact. This means that this set of regulations not only fails to support sustainability but actively impedes the negative impact of innovation on ecological impact. The statistically robust and significant outcome shows a consistent pattern, demanding urgent attention toward regulatory reforms (Mores et al., 2018;

Destek & Manga, 2021; Zhang, 2016). To safeguard the well-being of present and future generations, policymakers should develop a comprehensive package of policies related to innovations that foster economic growth while prioritizing environmental sustainability.

Table 3: Total Effects

	Coefficient	OIM Std. Error	Z	P>|z|	[95% Conf. Interval]	
Structural						
EG <-						
Inno	1.121509	.7718127	1.45	0.146	-.3912159	2.634234
Inno*RF	-.0196917	.0079174	-2.49	0.013	-.0352095	-0041739
EI <-						
EG	.6730057	.2121233	3.17	0.002	.2572516	1.08876
Inno	-28.8808	3.371453	-8.57	0.000	-35.48873	-22.27288
Inno*RF	.4521322	.034585	13.07	0.000	.3843469	.5199175

The results in Table 4 demonstrate the high level of accuracy in the model, as indicated by the Root Mean Squared Error of Approximation (RMSEA) value of 0.000. This value is below the threshold of 0.05, suggesting that the model is a strong fit for the data. Furthermore, TLI and CFI values of 1.000 suggest that the model is a highly suitable fit for the provided data. The SRMR value of 0.000 is significantly lower than the criterion of 0.05, suggesting a strong match in terms of residual variability (Jenatabadi, 2015).

Table 4: Overall Goodness of Fit

Fit Statistic	Value	Description
Population error		
RMSEA	0.000	Root mean squared error of approximation
90% CI, lower bound	0.000	
upper bound	0.000	
pclose	1.000	Probability RMSEA <= 0.05
Baseline comparison		
CFI	1.000	Comparative fit index
TLI	1.000	Tucker-Lewis index
Size of residuals		
SRMR	0.000	Standardized root mean squared residual
CD	0.524	Coefficient of determination

6. Conclusions

The study concludes that the regulatory framework moderates complicated relationships between innovation, economic growth, and ecological impact. Research and development investment boosts economic growth but is statistically insignificant. This suggests that innovation's impact on economic growth may require greater assistance or more active innovation activities. The interaction term between innovation and the regulatory framework reduces economic growth, which indicates that the regulatory framework may be too restrictive and vague, limiting innovation's economic growth potential. Economic growth has a positive and significant influence on ecological impact, but it also worsens environmental degradation. Growth initiatives must integrate sustainable practices to mitigate environmental degradation. Innovation reduces ecological impact, highlighting the need for sustainable technology and processes to tackle environmental degradation. The interaction between innovation and the regulatory framework promotes ecological impact. It means that the current stringent and vague regulatory framework may limit innovative initiatives for ecological impact reduction and indicates the areas where legislative modifications are necessary to foster sustainable innovation. Innovation may affect ecological impact through economic growth; however, the study acknowledges that this effect is minimal and insignificant, which underscores that economic development alone is not adequate to improve environmental outcomes through innovation. The interaction between innovation and the regulatory framework greatly lowers the environmental impact. This means that carefully designed regulatory environments bring out the environmental benefits of new ideas, leading to more eco-friendly economic growth. Innovation alone reduces ecological impact in a greater way as compared to economic growth's mediation on environmental degradation.

We emphasize the importance of innovation in sustainable development and environmental research and development, but for long-term sustainability, a balanced set of regulations is also beneficial. Also, innovation does have a statistically significant overall effect on reducing damage to the environment, but its total effect is less than the direct effect. This is mostly because innovation has a positive indirect effect through economic growth. Due to negative indirect effects, the interaction between innovation and the regulatory framework has a lower total effect on ecological impact. The empirics show that economic growth partially mediates the relationship between the interaction terms of innovation and regulatory framework and ecological impact. These complex relationships highlight the importance of implementing specific strategies to address environmental sustainability as well as economic policies that promote sustainable growth. These insights emphasize the importance of crafting regulatory policies that not only encourage innovation but also align economic growth with sustainability goals. To foster sustainable growth and innovation, policymakers should consider these dynamics when creating regulations and policies. The approach should prioritize integrating economic activities with environmental sustainability goals for long-term ecological health and economic stability.

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