Impact of Financial Development and Technological Innovation on Environment Sustainability: Does Government Effectiveness Moderate?

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Abstract

This research examines the complex interplay between financial development, technological innovation, and environmental sustainability, with particular focus on the moderating role of government effectiveness in these relationships. Financial development serves as a critical catalyst for investments in sustainable technologies and environmental improvements, while technological innovation drives eco-friendly advancements. However, these factors alone may prove insufficient for achieving sustainability goals without robust governance structures to effectively implement environmental policies and manage natural resources. Using panel data from five South Asian countries Pakistan, India, Sri Lanka, Bangladesh, and Nepal spanning the period from 1996 to 2022, this study employs the Fully Modified Ordinary Least Squares (FMOLS) model to analyze these relationships. The empirical findings reveal that technological innovation exerts a positive and significant effect on environmental sustainability, while financial development demonstrates a negative and substantial impact on environmental outcomes. Furthermore, government effectiveness plays a crucial moderating role in the relationship between financial development and environmental sustainability, though it does not significantly moderate the relationship between technological innovation and environmental sustainability. These results underscore the pivotal importance of effective governance in bridging the gap between innovation, finance, and sustainable environmental practices. The study contributes valuable insights for policymakers seeking to align economic development strategies with global sustainability objectives, emphasizing the need for strong institutional frameworks to maximize the environmental benefits of financial and technological progress.

Keywords: *Financial development, Technological Innovation, Sustainability*

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INTRODUCTION

Background

Environmental sustainability has become a vital global concern due to increasing environmental challenges such as climate change, loss of biodiversity, and reduction of resources. Finding a sustainable equilibrium between economic advancement and environmental safeguarding is among the most urgent issues we face today. Among the numerous factors affecting this equilibrium, financial growth and technological advancements hold important positions. Nevertheless, the question remains: can these factors alone ensure sustainability, or does the effectiveness of government policy serve as a crucial moderating factor

Financial development and Environment Sustainability

Financial development, defined by the growth and advancement of financial institutions, markets, and instruments, greatly influences the direction of economic activities. On the one hand, financial advancement promotes investments in green technologies, renewable energy initiatives, and sustainable business practices. Capital access allows companies to implement cleaner production techniques, create environmentally-friendly products, and comply with tougher environmental standards. In a similar fashion, families can fund energy-saving appliances and renewable energy setups, aiding in overall environmental sustainability **(Jamal Hussain, 2021)**

Conversely, uncontrolled financial growth could promote excessive consumption and industrial growth, resulting in environmental harm. Expanded access to credit and financial services can encourage actions that deplete natural resources at unsustainable levels, worsening pollution and habitat loss. Therefore, the connection between financial development and environmental sustainability is complex and relies on the allocation and use of financial resources.

Technological Innovation and Environmental Sustainability

Technological advancement is frequently seen as a crucial element in sustainable development. Technological advancements allow societies to tackle environmental issues by enhancing energy efficiency, minimizing waste, and developing alternatives to harmful ecological methods Advancements such as electric vehicles, sustainable energy options, and

advanced waste management strategies have revolutionized efforts to tackle environmental deterioration. (Hummera Saleem, 2019) Nonetheless, technological advancements are not automatically advantageous for the environment. The creation and implementation of innovative technologies may lead to unforeseen repercussions, including heightened electronic waste, resource-heavy manufacturing methods, and energy requirements (Jamal Hussain, 2021). Additionally, in the absence of suitable regulations and incentives, technological progress might focus on profit rather than environmental factors.

The Moderating Role of Government Effectiveness:

Within the intricate connection among financial progress, technological advancement, and environmental sustainability, the efficacy of government becomes a crucial element. Government efficacy encompasses the standard of public services, the expertise of policymakers, and the enforcement of regulations. Effective governance ensures that economic and technological advancements align with ecological objectives. Governments can influence the connection between financial development and sustainability by implementing policies that promote green financing and penalize harmful environmental practices. For example, financing renewable energy projects and implementing carbon pricing can allocate resources towards eco-friendly endeavors. Similarly, governments can promote technological advancement by distributing research funding, offering tax breaks, and supporting collaborations between public and private sectors, all while making sure that new technologies adhere to environmental regulations. (Emmanuel Uche, 2021) Conversely, poor governance may hinder these initiatives, causing financial and technological progress to lead to environmental harm. Corruption, weak enforcement, and inadequately crafted policies can obstruct progress in sustainability, despite strong financial frameworks and innovative technologies. Recent discussions have notably focused on sustainable economic growth due to increasing environmental damage, leading organizations to adopt environmentally friendly practices. The main challenge for economies is fulfilling the demands of their populations without worsening the environmental emergency. A major issue has come up recently: how can countries ensure that advancement does not adversely affect the environment? This is significant as the connection between financial and economic growth ties together environmental health and human well-being. While considerable studies have been carried out on how financial growth and technological progress affect

environmental sustainability, additional exploration is required to completely grasp the role of education in this connection. A thorough examination is necessary to understand how education alleviates the negative impacts of economic development and technological advancement on environmental sustainability. These observations will assist stakeholders in developing improved strategies that utilize financial and technological resources to advance environmental sustainability goals. Government Effectiveness includes initiatives for public awareness, traditional educational settings, informal learning opportunities, and skill-development initiatives. (Hussain Ali Bekhet, 2018) Essentially, education empowers individuals to acquire the skills required to tackle intricate environmental issues, including critical thinking, problem-solving, and social responsibility. It also allows individuals to actively back laws that emphasize both environmental sustainability and technological advancement. This research aims to address a gap in existing literature by examining how education affects the relationship among financial development, technological progress, and environmental sustainability. The goal is to empower individuals to advocate for legislation centered on technological progress and environmental sustainability. The goal is to enable individuals to champion policies focused on technological advancement and ecological sustainability. This research seeks to address a gap in existing studies by investigating how education influences the relationships among financial development, technological advancement, and sustainable practices The aim of the research is to improve overall fitness and strength levels. It also allows people to actively back laws that emphasize both ecological sustainability and technological advancement. This research aims to address a gap in existing literature by examining the role of education in shaping the relationship between financial growth, technological progress, and environmental sustainability. The aim is to enable individuals to support laws that focus on environmental sustainability and technological progress. This research seeks to address a gap in existing studies by exploring how education influences the relationship among financial development, technological progress, and sustainable practices.

Though financial growth and technological progress offer considerable potential for enhancing environmental sustainability, their effects are not consistently beneficial. On one side, economic expansion can encourage investments in eco-friendly technologies and infrastructure, promoting sustainable development. Conversely, it could also promote resource-heavy industries

and city growth, worsening environmental degradation. (Dr Muhammad Zubair Mumtaz, 2019) In the same way, advancements in technology can act as a double-edged sword: they provide answers to environmental issues, but they can also result in unforeseen outcomes, like higher energy use and electronic waste. In this context, the effectiveness of the government, defined by the quality of public services and the formulation and implementation of policies, serves as a vital moderating factor Effective governance guarantees that monetary assets and technological advancements are directed towards environmentally sustainable practices. Conversely, ineffective governance may lead to regulatory lapses, corruption, and inefficiencies, threatening sustainability efforts. Despite growing awareness of this interaction, empirical research on the moderating role of government effectiveness remains limited, particularly in developing nations where institutional capacities often lag behind economic and technological advancements.

LITERATURE REVIEW

Over the past several decades, significant advancements in financial growth and technological innovation have occurred worldwide, coupled with growing concerns about environmental sustainability. This literature review seeks to examine the interaction of these factors and assess the impact of their collective effects on environmental sustainability (Ahmed, 2023). Over the past several decades, significant advancements in financial growth and technological innovation have occurred worldwide, coupled with growing concerns about environmental sustainability. This literature review seeks to examine the interaction of these factors and assess the impact of their collective effects on environmental sustainability (Kuia, 2021). Additionally, effective financial intermediation directs funds toward green projects, aiding in sustainable development (Effio, 2020).

Technological Innovation:

Over the past several decades, significant advancements in financial growth and technological innovation have occurred worldwide, coupled with growing concerns about environmental sustainability. This literature review seeks to examine the interaction of these factors and assess the impact of their collective effects on environmental sustainability (Ahmed, 2023). Similarly, advancements in eco-friendly agriculture, energy efficiency, and waste management can improve resource efficiency and reduce environmental effects. The connection between financial prosperity, technological advancement, and environmental sustainability is

intricate and continuously evolving. Financial institutions play a crucial role in financing research and development (R&D) activities, as these initiatives drive technological advancements aimed at improving environmental sustainability. Additionally, by fostering favorable conditions for sustainable initiatives or integrating environmental factors into investment decisions, financial markets motivate companies to adopt eco-friendly technologies. Conversely, technological progress enhances the viability and profitability of eco-friendly investments, drawing increased financial backing for sustainable initiatives. Moreover, to remove obstacles to green financing and encourage the use of eco-friendly technologies, government incentives and regulatory systems could be essential (G20 Green Financing Study Group, 2018). Through the adoption of specific policies, directing investments, and encouraging partnerships, governments, alongside global organizations and the business sector, are essential in creating a setting that supports sustainable finance and innovation (Ahmed, 2023).

Additionally, the G20 Green Financing Study Group in 2018 highlighted the importance of government incentives and regulatory structures in removing obstacles to green financing and encouraging the use of eco-friendly technologies. In 2023, Ahmed stated that governments, along with international organizations and businesses, are essential in creating a supportive atmosphere for sustainable finance and innovation via focused policies, investments, and collaborations. The research concludes by emphasizing the possible benefits of technological progress and economic development for attaining environmental sustainability outcomes. To tackle existing problems and create favorable conditions for green finance and innovation, realizing this potential would necessitate coordinated efforts from various stakeholders. Future research should focus on exploring how financial organizations and technological advancements can be effectively utilized to promote environmental sustainability objectives. A vast amount of studies exists concerning the main factors behind economic growth. Energy plays a crucial role in economic development. Nona et al. found that effective governance can facilitate the development of suitable policies for environmental protection and economic advancement.

Carbon Emissions (CO2) Global Agenda:

A panel data analysis by Danish et al. indicates that effective governance aids BRICS countries in reducing their CO2 emissions. Examining the literature regarding the main causes of carbon emissions is essential to achieve the study's goals. The primary source of global CO2

emissions is the combustion of fossil fuels. Many investigations have analyzed the impact of fossil fuel consumption on CO2 emissions in different countries and found an inverse relationship between them (see, for example).

Additionally, Hanafi and colleagues (2000) discovered through the ARDL method that fossil fuel energy consumption raises carbon emissions. The utilization of renewable energy sources is another factor that may influence CO2 emissions in a way that differs from fossil fuel consumption. Many studies indicate that employing nuclear energy and renewable sources is the primary method for lowering carbon emissions. They have illustrated that while the consistent use of renewable energy decreases CO2 emissions, the disadvantages are more significant in low-carbon countries compared to high-carbon ones. Khan et al. showed a negative impact of renewable energy use on CO2 emissions through a panel quintile method. Mahmood, along with Salaryman and others. Examined the impact of commerce on CO2 emissions. The development of finance can also influence CO2 emissions.

According to (Effio, 2020), financial development can improve environmental quality, particularly in regions that are more advanced. However, (Ahmed, 2023) noted a positive impact of financial development on CO2 emissions in G8 and D8 countries by applying the pooled mean group method. (Raheem et al.) found a minimal connection between financial growth and CO2 emissions in G7 countries employing the same approach. Numerous studies also consider the exchange rate as a factor influencing CO2 emissions, similar to this one. It affects CO2 emissions through imports, exports, and foreign direct investment. Real exchange rates have been associated with rising CO2 emissions in Asian and African countries, as shown by Xiao et al. Ahmad et al. also highlighted the negative impact of the real exchange rate on CO2 emissions in Pakistan using an ARDL model. Finally, sound policy creation via good governance could reduce environmental degradation. Liu et al. illustrated the connection between environmental quality and effective governance through the application of FMOLS and DOLS methods.

Effio, (2020) demonstrated that institutional governance may lower CO2 emissions in sub-Saharan African nations using a generalized method of moments (GMM) model. Sadie et al. used a similar technique to show that improving MENA nations' institutional frameworks may often result in lower greenhouse gas emissions. The literature review above clarifies the

difficulties in examining how government actions affect CO2 emissions.

It focuses on the limitations associated with monetary support for environmental sustainability, political stability, and exchange rate volatility. This restriction also exists in the governance's effects, the financial burden of natural resources and the influence of political stability on policy stability and economic progress. Consequently, the goal of this study is to close these gaps and significantly add to the little body of existing material. The outcomes of this research will provide significant understanding to New Zealand policymakers, enabling well-informed decision- making. examines the connection between energy, CO2 emissions, renewable energy, and technological advancements. The literature on FDI and energy finance is covered in the second section, along with renewable energy and CO2 emissions. The last section clarifies the connection between finance, CO2 emissions, energy, and renewable energy. J. Hussain Chenggang et al. Renewably Sourced Energy Technological advancements, usage of renewable energy, and emissions of CO2 Numerous studies have linked technological advancement and the usage of bothrenewable and non-renewable energy to the development of environmental concerns. Studies that investigate the factors that influence renewable energy are, nonetheless, few and have not been objectively recognized. Aperies and Payne have discovered the bidirectional causal relationships for OECD nations between renewable, non- renewable energy, and economic growth. Numerous researches have examined various factors to assess their impact in renewable energy.

Similarly, Attiaoui et al. looked at 22 African states' renewable energy utilization, CO2 emissions, and economic development between 1990 and 2011.It was shown that in situations when CO2 is negative, GDP has no effect on the consumption of renewable energy, and that conventional fossil fuels have a positive effect on renewable energy consumption. (Ahmed, 2023) demonstrates the conflicting effects of economic expansion and technical advancement on the use of renewable energy in OECD nations. Yu and Du also came to the conclusion that environmental damage is a result of China's autonomous inventions. Similarly, research indicates that innovations are not dependable for enhancing the environment, but they do have a major influence on economic growth. Research has indicated that technological advancements are essential for attaining energy efficiency, leading to the encouragement of renewable energy consumption. One such study, conducted by Fisher-Vanned et al., discovered. Adverse impacts

on energy consumption, implying that innovations serve as sources of energy efficiency promotion in China. According to Hang and Tub's analysis of energy intensity and pricing data in China, increasing the cost of fossil fuel-based energy might be a great way to achieve energy efficiency. of fossil fuel-based energy might be a great way to achieve energy efficiency.

Impact of Financial development on environmental sustainability

Numerous research efforts have concentrated on how financial advancement affects environmental sustainability. (Kuia, 2021) discovered that boosting investment in green technologies and renewable energy may enhance environmental sustainability while fostering economic growth. Other researchers, such as an (2008), have countered that unchecked financial expansion in a fast-paced economy might result in higher carbon emissions and worsening environmental conditions.

We begin by examining several studies whose findings indicate that financial development both enhances and reduces environmental harm. Omak et al. (2020) investigate how financial development affects Nigeria's overall ecological footprint, non-carbon footprint, and carbon footprint. Specifically, the research addresses the shortfall of prior studies by providing a more comprehensive measure of environmental sustainability (degradation), specifically the ecological footprint analyzed into factors of environmental degradation that are based on carbon and non-carbon sources. Employing the distributed lag of the nonlinear autoregressive (NARDL) dynamic analysis, the research finds that a decrease in financial development notably worsens the environment, an increase in financial development significantly reduces ecological footprint (Ahmed, 2023), who looked at how financial development affected carbon footprint. Utilizing information spanning The research, which examined 49 One Belt and Road (BRI) nations from 1990 to 2017, discovered a statistically significant but unfavorable relationship between financial development and carbon footprints. AlMulali et al. (2015) used data from 93 countries spanning the years 1980–2008 to investigate the impact of financial development on environmental sustainability. split into economies with high and low incomes. The research results, which employed ecological footprint as an indicator of environmental damage, indicated that the ecological footprints of less affluent nations are not significantly affected by economic progress. Nonetheless, it was found that the growth of the financial industry had a notable and negative effect on the ecological footprint.

Proof of the decreasing environmental consequences of economic development can be found in the second set of writings. In his research on the Indian economy, Bout Abba (2014) discovered that greater financial development resulted in higher levels of carbon emissions, ultimately harming the environment. According to Baloch et al. (2019), the ecological footprint in 59 Belt and Road (BRI) countries increases with financial development. Nathaniel et al. (2019) show how financial growth worsens environmental damage in South Africa. The results of Shabazz et al. (2020), Sahib et al. (2020), and Ibrahim (2020) are in agreement with one another. The study carried out by Fakher (2019) on the impact of financial development on seven OPEC membernations is noteworthy. The study showed different findings on the impact of financial development on environmental degradation by including the square of ecological footprint in a Bayesian model. More specifically, the findings showed that the ecological footprint initially increases as the financial sector grows, but eventually decreases as financial development advances and becomes more mature. A recent research conducted by Kuia (2021) uncovered a minor correlation between economic advancement and carbon dioxide emissions in a selection of Middle East and North Africa (MENA) countries, presenting ambiguous evidence of the relationship. A smallnumber of studies make up the third branch of research on the link between environmental sustainability and economic growth. Ahmed's (2023) research discovered that the ecological footprint rises with financial sector growth, then declines as efficiency and maturity improve. A tenuous link between financial development and carbon dioxide emissions was observed in MENA countries, offering uncertain evidence of the connection. A couple of studies can be found in the third category of literature that explores the relationship between environmental sustainability and financial development.

Impact of technological innovation on environmental sustainability

Technological innovation refers to a tactic that provides a company with a competitive advantage by encouraging market diversification and generating new business opportunities. Creativity is perceived as the organization’s implementation of a fresh idea or practice. The degree to which a firm adopts novel concepts or technological advancements in comparison to its rivals in order to obtain a competitive edge interms of cost, time, and service quality is referred to as innovativeness, according to (Kuia, 2021). Not only is innovation necessary for economic survival, but it also playsa significant role in promoting growth, productivity.

Technological innovation is important in a competitive corporate climate, but so is adherence to sustainable practices; as a result, SMEs are increasingly implementing CSR policies. Environmental sustainability primarily focuses on excellent organizational management, with careful focus on employee conditions and the quality of operational practices related to the economic, social, and environmental aspects of sustainable development. A dedication to enhance social welfare by means of voluntary business practices and the allocation of corporate assets is the general definition of corporate social responsibility? A large body of literature has been written about the connection between environmental sustainability and innovation. Therefore, the addition of goods, procedures, and management tasks related to the delivery of goods or services constitutes the conceptualization of innovation. Bansal (2005) found a connection between innovation and environmentally sustainable practices, and recommended businesses to implement new, eco-friendly technological in their production methods to follow the principles of corporate social responsibility (CSR). with careful focus on employee conditions and the quality of operational practices related to the economic, social, and environmental aspects of sustainable development. A plethora of efforts have surfaced to enshrine corporations' pledge to sustainable development in their transparency operations. The beneficial effects of technological innovation on environmental sustainability have been emphasized by numerous research. For example, Jaffe and Stains (1994) discovered that businesses have been compelled by environmental restrictions to engage in the R&D of cleaner technological, resulting in notable enhancements in environmental performance. (Ahmed, 2023)) also showed that nations with higher levels of innovation typically had lower per- capita carbon emissions, highlighting the significance of technical innovation in tackling environmental issue.

Government effectiveness as a Moderator

The significance of government effectiveness in influencing the effects of financial development and technological innovation on environmental sustainability has received notice in recent years. Government effectiveness, characterized by the standard of public services, policy development, and regulatory enforcement, is critical for aligning economic and technological advancements with environmental objectives. Disrupt et al. (2001) highlight that strict environmental regulations and enforcement measures can enhance the beneficial impacts of

financial growth and technological advancement. For example, funding for renewable energy initiatives and carbon levies can promote sustainable behaviors. In contrast, ineffective governance can compromise these initiatives, as highlighted by Bezel and Rises (2010), who contend that corruption, inadequate enforcement, and poorly constructed policies obstruct sustainability efforts.

HYPOTHESES

H1: Environmental sustainability is significantly impacted by financial development.

H2: Technological innovation significantly impact on environmental sustainability.

H3: Government effectiveness acts as a moderator in the link between financial developments on environmental sustainability

H4: Government effectiveness acts as a moderator in the link between technological innovations on environmental sustainability.

RESEARCH METHODOLOGY

Research Approach

The Approach we are using in this research is Quantitative methodology; this research contains the secondary data. We collected the data by the secondary, interpreting the results of annual reports of Manufacturing Firms. This study thoroughly investigates how technological innovation and financial development affect environmental sustainability by combining both quantitative and qualitative research methods. It also explores if government effectiveness influences this connection.

Data and Variables

Data on financial advancement, technological creativity, environmental responsibility, and Government Effectiveness initiatives will be collected from reputable databases like those run by the World Bank, World Development Indicator, world Government indicator.

Variables: We will assess important factors related to technological advancement patent requests, technological uptake), economic growth (like financial inclusion, availability of credit, financial market depth), and environmental sustainability (like carbon emissions.)

Variables and Measurement

Independent Variable Financial Development

Measures: Credit to the private sector at home is a key indicator of financial development. Assess the influence of extra financial resources on environmental sustainability by examining both the beneficial and adverse effects.

The amount of domestic credit assigned to the private sector is crucial for evaluating financial progress. Evaluate how additional financial resources affect environmental sustainability, considering both beneficial and detrimental impacts. Channels: Investigate how financial development impacts environmental results, like investing in eco-friendly technologies or increasing industrial activity causing pollution.

Technological Innovation

Measures: (percentage of GDP spent on research and development), patent applications (number of patents filed), technological adoption rates (percentage of population using new technologies), and digitalization indices (level of digital infrastructure and usage).

Moderating Variable Government effectiveness

Measures: Evaluated through the World Government Indicators (WGI) provided by the World Bank, concentrating on regulatory effectiveness, policy implementation, and public service efficiency.

Dependent Variable Environmental Sustainability

Measures: Amount of carbon emissions (CO2 per person), level of energy usage (total energy used per person), Evaluated through the World development indicator provided by the World Bank.

Model details

Green innovation, which is seen as a key aspect of environmental quality, can be measured through patents for environmental technological. Any major impact on these factors could have significant economic implications for South Asian countries. Previous studies have shown how trade openness, GDP per capita and energy usage are crucial for economic advancement. We have established our model based on these considerations as follows:

$$CO2i = \int (FD, TI, GE, GDP)$$

Co2 emission, Financial development, Technological innovation, Environment sustainability, Real GDP per capital,

Model 1

$$CO2it=\beta0+\beta1FDit+\mu it$$

Model 2

$$CO2it=\beta0+\beta1FDit+\beta2FD*GEit+\mu it$$

Model 3

$$CO2it=\beta0+\beta1TIit+\mu it$$

Model 4

$$CO2it=\beta0+\beta1FDit+\beta2FD*GEit+\mu it$$

The subscript I and t indicate the time and cross section βit and Eit regression slope and error term of regression equation and other term coefficient of the selected variable which have estimated.

Information and variables:

We used the dataset covering five developing nations in South Asia from 1996 to 2022: Bangladesh, India, Pakistan, Sri Lanka, and Nepal. For the dependent variable CO2 emission, the most recent data were accessible till 2014. As a result, we have data from 1996 to 2022 for every variable.

As a stand-in for environmental quality, CO2 emissions expressed as metric tons per person serve as the explanatory variable in this study. It is assumed that increased CO2 emissions are a sign of poorer environmental quality and vice versa. The World Bank provided the CO2 emissions statistics.

The use of empirical methods:

To utilize the most suitable estimator before estimating the long-term relationship coefficients, specific necessary econometric procedures, such as cross-sectional dependence (CD), unit root analysis, and integrating relationships, must be conducted.

Tests for unit root:

Determining the order of integration in the variables is the next stage in panel data econometrics, which is why the current study uses "cross-sectional (CADF) and cross-sectional Am-Psarian-Shin (CIPS) in the survey of the chosen panel data sample.

Correlation matrices analysis financial development and Technological innovation on environment sustainability

Correlation matrix analysis is a statistical technique utilized to assess and condense the linear associations among various variables in a dataset. This analysis aids in examining the links between financial growth, technological advancements, environmental sustainability, and governmental efficiency.

Long-run estimators:

Once the co-integration relationship between the models has been established, the long-term correlations identifying how and to what degree an explanatory variable influences the dependent variable should be developed. To assess the long-term relationship coefficient in panel data models while establishing a long-run link, fully modified-OLS (FMOLS) was developed.

$$\hat{\gamma}_{FMOLS} = \left[\frac{1}{N}\sum_{i=1}^{N}\sum_{t=1}^{T}\left(J_{it}-\bar{J}_i\right)^2\right]^{-1} \times \left[\sum_{t=1}^{T}\left(J_{it}-\bar{J}_i\right)\hat{k}_{it} - T\hat{\partial}_{eu}\right]$$

They utilized the test statistics listed below to estimate the FMOLS: where the dependent and independent variables are J and k, respectively. The EU stands for the Kernel estimator, which takes into consideration the estimated value covariance term's serial correlation. In a similar vein, the study's duration and cross-sections are mentioned by the N and T in the equation

RESULTS AND FINDINGS

Descriptive states

The descriptive statistics offer crucial insights regarding your data. On average, CO_2 emissions (LNC02) are significantly high, displaying considerable variations between countries, highlighting major disparities in environmental sustainability. Financial development (LNFD) shows moderate stability, suggesting that most countries have a similar degree of financial

progress, with minimal variation. Technological innovation (LNPN), however, varies greatly, highlighting that some nations are far more developed than others. GDP per capita (LNGDPC) shows moderate fluctuation, marked by a slight positive tilt, suggesting that many countries face lower degrees of economic advancement. Overall, the data for CO_2 emissions and technological progress do not demonstrate an ideal normal distribution, whereas financial growth and GDP per capita appear to correspond more closely with normality.

Table 4.1 Descriptive states

	C02	FD	PN	GDPC
Mean	11.40488	3.433924	5.362201	25.98179
Median	11.36002	3.439318	4.779123	25.85013
Maximum	14.71493	4.246218	10.04936	28.62027
Minimum	8.556260	2.630281	1.386294	23.73859
Std. Dev.	1.843258	0.405670	2.118110	1.329151
Skewness	0.405469	-0.23395	0.765197	0.340992
Kurtosis	1.958317	2.151104	2.534969	2.235638
Jarque-Bera	7.479194	4.032264	10.97962	4.503461
Probability	0.023764	0.133170	0.004129	0.105217
Sum	1174.703	353.6942	552.3067	2676.124
Sum Sq. Dev.	346.5551	16.78598	457.6117	180.1975
Observations	103	103	103	103

Note: CO2= Carbon di emissions, FD= Financial development, PN= Technological innovation, GDPC

Correlation matrices analysis

Technological innovation and environmental sustainability

Impact of technological innovation on environmental sustainability. The correlation matrix displays robust positive associations among the variables. CO_2 emissions show a strong correlation with technological innovation (0.343) and GDP per capita (0.391), indicating that as economies expand and technological progress occurs, CO_2 emissions generally increase. Likewise, there is a strong correlation (0.367) between technological innovation and GDP per capita, suggesting that nations with higher economic development are typically more

technologically sophisticated. These robust correlations underscore the relationships among economic growth, technological advancement, and environmental effects in your dataset.
Correlation matrices.

Table 4.2 Correlation metrics of technological innovation and environmental sustainability

	CO2	PN	GDPC
CO2 carbon emission	1.000	0.343	0.391
PN	0.343	1.000	0.367
GDPC	0.391	0.367	1.000

Note: Co2= carbon di emission, PN= Technological innovation, GDPC

Correlation matrices analysis

Financial development on environmental sustainability:

The correlation matrix concerning financial development reveals a highly positive correlation between CO_2 emissions and technological innovation (0.391), indicating that as financial development grows, CO_2 emissions significantly increase. Nonetheless, the relationship between CO_2 emissions and GDP per capita is fairly weak (0.309), suggesting a less straightforward connection between economic growth and emissions when considering financial development. In a similar vein, the relationship between technological innovation and GDP per capita is also weak (0.291), indicating that although there is a connection, technological progress does not have a strong association with increased GDP in this scenario.

Correlation matrices

Table4.3 Financial developments on environmental sustainability

	CO2	FD	GDPC
CO2	1.000	0.391	0.309
FD	0.3910	1.000	0.291
GDPC	0.309	0.291	1.000

Note: Co2= carbon di emission, FD= Financial development, GDP

Unit root

The unit root tests for each variable show varied outcomes at both levels and first

differences. The test for CO_2 emissions at the level indicates a value of 1.585, implying a unit root; however, after differencing, the value decreases to -1.897, which is significant at the 5% level, suggesting that CO_2 emissions are stationary in first differences. Likewise, financial development indicates a value of -0.356 at the level, which implies a unit root; however, after differencing, the test statistic changes to -3.223, significant at the 5% level, thereby affirming stationarity in first differences. For technological innovation, the level test statistic (0.0120) shows a unit root, but after differencing it becomes highly significant at -7.359, indicating it is stationary in first differences. Ultimately, GDP exhibits a unit root at the level (3.534); however, after differencing, the test statistic is -3.783, which is significant at the 5% level, suggestion.

Table 4.4 Unit root

Variables	Level	1st Diff
Co2 carbon emission	1.585	-1.897**
Financial development	-0.356	-3.223**
Technological innovation	0.0120	-7.359***
GDP	3.534	-3.783**

Results of impact of Technological innovation on environmental sustainability through FMOLS Model

The FMOLS (Fully Modified Ordinary Least Squares) results for Model 1 (Technological Innovation - PN) show that technological innovation has a negative and statistically significant relationship with the dependent variable, with a coefficient of -0.176 and a t-statistic of -3.31 (p-value = 0.0013), suggesting that an increase in technological innovation results in a reduction of the dependent variable. GDP exhibits a robust positive and highly significant correlation with the dependent variable, with a coefficient of 1.206 and a t-statistic of 14.16 (p-value = 0.0000), indicating that economic growth significantly affects the dependent variable. The R-squared value of 0.806 suggests that the model explains roughly 80.6% of the variability in the dependent variable.

Table 4.5 Results of impact of Technological innovation on environmental sustainability through FMOLS Model

Variable (Independent)	Coefficient	Standard. Error	t-Statistic	Prob.
Technological innovation	-0.176	0.053	-3.312	0.001
GDP	1.206	0.08	14.158	0.000
R-squared	0.806			

Result of moderation of Government effectiveness between technological innovation and environmental sustainability.

In the moderated model with government involvement (GOV*TI) introduced as a moderator, the coefficient for technological innovation stays negative (-0.170) and statistically significant (t-statistic = -2.96, p-value = 0.0040), although it is marginally lower than in the initial model. GDP still demonstrates a robust positive correlation with the dependent variable, exhibiting a coefficient of 1.246 and a t-statistic of 13.55 (p-value = 0.0000). Nonetheless, the moderation effect of government involvement (GOV_TI) is not notable (coefficient = -2.50E-05, t-statistic = -1.29, p-value = 0.2014), indicating that government involvement does not significantly influence the relationship between technological innovation and the dependent variable. The R-squared value rises modestly to 0.817, suggesting a slight enhancement in explanatory strength with the inclusion of the moderator.

Table 4.51: Result of moderation of Government effectiveness between technological innovation and environmental sustainability.

Variable (Independent)	Coefficient	Standard. Error	t-Statistic	Prob.
Technological innovation	-0.169	0.057	-2.960	0.004
GDP	1.246	0.092	13.545	0.000
Government effectiveness*Technological innovation	-2.50E-05	1.94E-05	-1.287	0.201
R-squared	0.816723			

Results of impact of Financial Development on environmental sustainability through FMOLS Model

In the initial model (FDS), the use of panel FMOLS indicates that financial development (FD) exhibits a positive and significantly substantial relationship with the dependent variable, indicated by a coefficient of 0.0174 and a t-statistic of 6.98 (p-value = 0.0000), implying that financial development has a favorable effect on the dependent variable. LNRDGP, which denotes the logarithm of GDP, demonstrates a robust positive and statistically significant correlation, exhibiting a coefficient of 0.747 and a t-statistic of 9.91 (p-value = 0.0000), highlighting the critical role of economic growth in affecting the dependent variable. An R-squared value of 0.845 suggests that the model accounts for roughly 81.5% of the variation in the dependent variable.

Table 4.6: Results of impact of financial development on environmental sustainability through FMOLS Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Financial development	0.017	0.002	6.976	0.000
RDGP	0.746	0.075	9.908	0.000
R-squared	0.845			

Result of moderation of Government effectiveness between Financial Development and environmental sustainability.

The FMOLS results for the Financial Development (FD) model reveal that financial development (FD) shows a positive but insignificant relationship with the dependent variable, having a coefficient of 0.096 and a t-statistic of 0.88 (p-value = 0.3831), suggesting that financial development does not have a statistically significant impact on the dependent variable in this model. Conversely, GDP shows a strong and notably significant positive correlation with the dependent variable, featuring a coefficient of 0.941 and a t-statistic of 13.84 (p-value = 0.0000), suggesting that economic growth is an important contributor. The variable indicating government involvement in financial development (GOV*FD) displays a significant negative correlation with the dependent variable, having a coefficient of -0.0128 and a t-statistic of -5.75 (p-value =

0.0000), implying that government involvement diminishes the effect of financial development on the dependent variable. The R-squared value of 0.836 signifies that the model accounts for roughly 83.6% of the fluctuations in the dependent variable.

Table 4.61: Result of moderation of Government effectiveness between Financial Development and environmental sustainability.

Variable (Independent)	Coefficient	Standard. Error	t-Statistic	Prob.
Financial development	0.095780	0.109361	0.875819	0.3831
GDP	0.940515	0.067966	13.83794	0.0000
GOV*FD	-0.012802	0.002227	-5.749789	0.0000
R-squared	0.835965			

CONCLUSION AND RECOMMENDATION

Conclusion

This research investigates the intricate relationship among financial development, technological innovation, and environmental sustainability, highlighting the influence of governmental efficiency. The results emphasize that economic development and technological progress can greatly enhance environmental sustainability by facilitating the use of cleaner technologies, promoting green investments, and aiding sustainable infrastructure. However, the dual-natured traits of these elements highlight that their advantages are not assured. Economic expansion may lead to the overexploitation of resources, industrial progress, and environmental contamination, whereas technological advancements could produce unexpected consequences, such as increased energy consumption and electronic waste. The effectiveness of government emerges as a crucial element impacting the overall effect of financial and technological advancement on environmental sustainability. Effective governance guarantees that financial and technological assets are directed towards environmentally friendly projects, minimizes regulatory inefficiencies, and lessens risks linked to unsustainable methods. On the other hand, weak governance can erode these advantages, causing environmental harm due to corruption, flawed policies, and poor management.

This study offers theoretical and practical insights, addressing gaps in existing literature by examining how governance affects the connection between economic and technological development and environmental results. The results highlight the importance of combined strategies that merge financial and technological systems with robust governance frameworks to reach sustainability objectives. Policymakers are urged to enhance institutional capabilities, refine regulatory structures, and promote transparency to optimize the beneficial effects of economic expansion and technological advancement. In summary, attaining environmental sustainability necessitates a thorough and strategic method that takes into account not just progress in economic and technological fields, but also the efficiency of governance overseeing their execution. This research establishes a foundation for additional inquiries in this field, especially in developing nations, where the effectiveness of governance frequently falls short of economic and technological advancements, creating distinct challenges for sustainable development.

Recommendations

This study presents several recommendations for policymakers, researchers, and stakeholders aimed at enhancing environmental sustainability through financial development and technological progress, with government effectiveness acting as a crucial moderating factor.

Strengthen Governance Frameworks: Authorities should focus on improving institutional quality by enhancing public service delivery, reducing corruption, and strengthening regulatory frameworks. Efficient governance ensures that advancements in finance and technology are focused on sustainable methods, minimizing environmental risks.

Promote Green Finance Initiatives: Policymakers should promote financial organizations to support eco-friendly projects. This can be achieved through tax benefits, grants, and green bonds, encouraging investments in renewable energy, energy-saving technologies, and sustainable infrastructure.

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