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Greening the Future: A Mediation Analysis of Green Technology Innovation on the Relationship between Green Finance, Environmental Regulations, and Ecological Footprint

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Abstract
The increased urgency to address worldwide environmental problems has emphasized the importance of understanding the factors that determine one's ecological footprints. The present study investigates the complex relationship between green finance, environmental regulation, and its effect on the ecological footprint. The research then further examines the mediation effect of green technology innovation on these relationships. This paper uses structural equation modeling SEM analysis of data coming from the 81 countries in a time period from 2001 to year 2022. The findings of the study present valuable information about the potential influence that financial and governmental tools may have on environmental sustainability. The impact of green finance and stringent environmental regulation in cutting down its ecological footprint as revealed by the results, asserting the key roles that both elements have. Furthermore, the green technology development provided not only the means to lessen these advancements' adverse effects on nature but also assistance in controlling the impact of environmental regulations and green finance. Moreover, the study considers control factors such as income inequality, economic growth, unemployment and life expectancy to ensure a comprehensive analysis. The results also show that the development of green financial systems, development, and implementation of sound environment related regulations to resolve challenges in areas like water and soil pollution as well as technological advancements play significant roles in achieving sustainable growth. This translates into meaningful guidance for policymakers looking to integrate financial, regulatory, and technological efforts in a way that reduces environmental harm, while also furthering ecological sustainability. In the future, these processes should be further studied in a variety of contexts and for longer periods to gain a better understanding of sustainable development pathways.

Keywords:
Green finance, Environmental regulations, Green technology innovation, Ecological footprint, Mediation analyses, SEM

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Introduction

The desire to "go green" in current discussions serves as a symbol of hope in the face of increasing environmental problems. It emphasizes the need to support ecosystems and reduce the negative effects on environmental conditions (Yousaf, 2021). Despite ongoing environmental degradation, economists are actively researching ways to reduce its spread (Telatar & Birinci, 2022). Nevertheless, the attraction of highly developed markets frequently obscures the ability of organizations and nations to recognize the future consequences of excessive dependence on finite resources, hence intensifying the deterioration of the environment (Danish et al., 2021). Since the 1960s, the worldwide worries regarding ecological disaster, resource depletion, overall heating, concerns about land (Yang et al., 2022), resource diminution, and environmental squalor have become increasingly urgent and require immediate attention (Chien et al., 2021). The world is being confronted with escalating issues, including humanitarian crises, global warming, resource depletion, and environmental contamination (Shao et al., 2022). In response to these difficulties, the United Nations developed 17 Sustainable Development Goals (SDGs), including Climate Action, Affordable and Renewable Energy, Life on Land, and others (UNDP, 2024). Nevertheless, the formidable ecological issues, such as climate change, depletion of resources, and environmental degradation, emphasize the pressing need for collaborative worldwide endeavors in achieving sustainable development (Shao et al., 2022).

In reaction, countries the world over have started taking steps to go green economies. It refers to handling economic activity, resources, and growth that is compatible with the environments under changing global climates and increasing ecological risks (Song et al., 2022; Jiakui et al., 2023). First of all, the finance function especially green finance is needed to mobilize finances for sustainable development projects without socially passing on adverse effects and not compromising environmental quality requirements at present (Ibrahim M., 2021). Green finance supports the financing of environmentally risk-free programs and at the same time protects these projects for a longer period. This goal is achieved by either changing real activities that ruin nature or leading them towards technological development (Wen et al., 2023). In igniting efficient economic growth and managing the environment effectively, there is a need for technological innovation in the digital economy among other trends (Ding et al., 2022).

Nonetheless, the previous works have ignored illustrating the jointed impact of green finance (GF) on ecological footprints (EF) with respect to the determinant factors (green technology innovation (GTI) and environmental regulations (ERs)), particularly in areas whereabouts data on GF is scant (Mehboob et al., 2024). Consequently, there is an undiscovered domain that lies between GF and GTI on one side and ER on the other with respect to their combined effect on the reduction of EF. GTI is an essential agent in resolving environmental issues. It is feasible way to mitigate environmental degradation and facilitate economic growth. (Cai et al., 2020). Combining GTI in industries can create the capacity for low carbon economies by reducing emissions via recycling resources, sustainable operations, and cleaning processes.

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(Wang et al., 2020). At the same time, GF is playing a more moderate role of an additional source that provides finance for environmentally friendly endeavors and inspires GTI uptake and sustainability, as opposed to offering direct collaboration in such projects (Zhang et al., 2021).

Enacting regulations is one of the most important ways to determine how different elements affect environmental quality and put into practice optimal preventive actions to lessen the effects of environmental degradation (Zhang & Zheng, 2023). A policy initiative is giving environmental taxes and policies more thought. Environmental regulations have the power to effectively slow down environmental deterioration and encourage environmentally friendly innovation (Sharif et al., 2021). Through limiting the negative consequences of resource extraction and energy consumption from fossil fuels, ER are essential in directly reducing emissions. Furthermore, by lowering the discharge of pollutants from a variety of sources including agriculture, homes, transportation, and industry, environmental taxes contribute to lessen the detrimental impacts that humans have on the environment (Zhu et al., 2023). Strategic implementation of regulations is done to minimize the detrimental effects associated with climate-related problems and to encourage the efficient generation of renewable energy by means of GTI (Akram et al., 2023). The attainment of ecological sustainability is seen by several scholars to need GF, GTI, and ER.

The current study makes several contributions to the extant literature in very unique ways. First and foremost: This study introduces a unique approach by using EF as an indicator of environmental quality rather than resorting to measuring carbon emissions. (Ullah et al., 2024). The switch in focus allows much better assessment of the environmental outcomes while considering a broader scope of various ecological factors. Besides, it's unscientific to judge the level of GF only by the ratio of public expenditure on environmental protection to GDP. Some studies use green finance index (Zhao et al., 2022; Mehboob et al., 2024). Instead, we propose to measure GF using the international financial inflow in support of sustainable energies in this paper. This approach provides a wider span of analysis as well as improves the precision to assess GF. Moreover, the research attempts to bridge a substantial gap in the earlier literature by considering previously overlooked mediating effects of few factors. Through the lens of this research, GTI has been introduced as a mediator to present an elaborate view of GF-ER-EF interaction (Zhao et al., 2022). To the best of our knowledge, earlier research predominantly focused on direct associations between these parameters, whereas in this study we elucidate their interactions. Finally, the study differs by taking a global perspective and uses data from 81 countries rather than being confined to national-level studies. Therefore, the research has enhanced the validity and usefulness of its conclusion in a variety of economies which offers results that are generalizable across different geopolitical situations (Mehboob et al., 2024). By following such an inclusive methodology, we will be able to better understand the complex dynamics that affect the relationship between GF and ER, EF & GTI on a global scale.

The research holds great importance as it has the potential to provide valuable information for making decisions based on evidence and to aid in the creation of comprehensive plans to tackle environmental deterioration. This study seeks to expedite the shift towards sustainable economies

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by examining the complex connections between GF, GTI, and ER. The ultimate goal is to protect the planet for future generations. In light of the goals of our study, we have devised the subsequent research questions:

Q1: What is the relationship between GF and the EF?

Q2: How do ER impact the EF?

Q3: What is the impact of GF on the GTI?

Q4: How do ER affect the GTI?

Q5: What is the impact of GTI on the EF?

Q6: Does the GTI act as a mediator in the interaction between GF and the EF?

Q7: Does the GTI act as a mediator between ER and the EF?

Next section conducts a comprehensive theoretical analysis and formulates hypotheses on the influence of GF and ER on EF and its mechanism through GTI. This is followed by data and methodology estimation section that provides a comprehensive explanation of the materials and methods employed in this study. The result and discussion section presents the outcomes derived from the research discussion of the findings, while the last section finishes by examining the results and implications of this study and providing suggestions for future research attempts.

Theoretical Analysis and Hypotheses Formulation

Green Finance & Ecological Footprint

Promoting sustainable growth and raising environmental quality are major goals of green finance (GF), which includes environmentally friendly investments, green advances, green insurance, and other environmentally focused investment choices. By promoting sustainable practices and reducing environmental deterioration, GF has a negative impact on the EF, as this review of the literature shows. As achieving zero emissions and enhancing economic stability directly affects environmental degradation, GF is recognized as an essential possibility (Debrah et al., 2022). GF includes the deliberate distribution of funds for environmental initiatives meant to reduce emissions and control the unanticipated impacts of climate change (Huang et al., 2021). The goal of China's 13th Five-Year Plan (2016–2020) was to use structural reforms backed by green finance to remove carbon and greenhouse gas emissions from the environment. This emphasizes how much the plan has contributed to reducing EFs (Green & Stern, 2017). Guo et al. (2022) offered more proof of how GF affects agricultural emissions in Chinese areas. They showed a strong negative correlation between GF and agricultural industry environmental degradation.

In their study, Li et al. (2022) found that green funding is very influential in strengthening and promoting betterment of the environment. According to Zhou and Li (2022), GF has an important effect in supporting the transition to a low-carbon economic system. In their study, Li et al. (2022), GF has been the most effective effort to prevent environmental degradation in economies. This finding is consistent with the study carried out by Saeed Meo and Karim (2022), focusing on the top 10 economies. This result suggests that, all else equal, GF has a positive detrimental impact on emissions with the strength of this relationship contingent on market settings and policy conditions. Green funding is a great way to achieve environmental quality.

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More importantly, it is found that public–private cooperation in green investments can alleviate environmental deterioration (Yang et al., 2022). Nawaz et al. (2021) used the difference-in-differences method to examine the linkage of green investment in changing the environmental quality for BRICS and N-11 countries. The result points to the significant contribution of GF in decreasing environmental decay; this is an indication that it can be used effectively in the area. Multiple empirical studies are available to prove the positive environmental impact of GF. Batrancea et al. (2020), for example, focused on the green financial systems of Brazil, Canada, and the United States. What they found is that environmentally sustainable funding actively decreases emissions, which in turn reduces global warming, thus directly reducing the ecological footprint.

As explained by Osman et al. (2019), intentions to participate in environmentally beneficial initiatives and the resultant environmental outcomes are positively related. Hence, in Malaysia, this cause-effect relationship can be seen quite clearly. Accordingly, GF could be effective in reducing pollution and improving life quality. Wu et al. (2021) analyzed the long-term connection between GF and CO2 emissions in G7 countries. This means that a 1 percent increase in green finance enhances environmental quality by 0.375 percent. There was also empirically proof from Sun (2021) that GF would construct a carbon trading system to realize carbon neutrality. This clearly indicates the significance of backing green finance in achieving long-term environmental sustainability.

Existing literature consistently demonstrates a negative correlation between GF and environmental degradation, mostly achieved by reducing environmental degradation and promoting sustainable behaviors. The impact may differ depending on economic situations and regulatory contexts. Therefore, we put forth the subsequent hypothesis:

H_1: Green finance has a significant negative impact on the ecological footprint.

Environmental Regulations & Ecological Footprint

Environmental regulation (ER) is crucial in addressing environmental deterioration and minimizing the ecological impact by enforcing rules and actions that restrict carbon-intensive activities and encourage sustainable practices. Governments employ a range of environmental policies, including as grants, privatization regulations, and environmental taxation, to tackle ecological concerns. Recently, there was research done on how environmental taxation is impacting the negative externalities of the environment. As noted by Zhang and Zheng, environmental taxes specializing in mitigating global warming have proven they managed to decrease the volumes of emitted greenhouse gases, though carbon content taxes can hamper an economy's growth path (Zhang & Zheng, 2023). Javed et al. (2023) investigated the influence of environmental taxes on Italy's EF from 1994 to 2019. The taxes implemented by the government had a noticeable and significant effect on its environment and reduced EF. Telatar and Birinci (2022) studied the effects of environmental taxes on GHG emissions in Turkey. The results of their research indicate that environmental taxes do a good job of reducing environmental decay.

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Moreover, as Lin and Jia, (2018) state supplementary evidence supports the affiliation between environmental taxes and a fall in the ecological footprint. Further, they reported that the proper implementation of regulations in China could help reduce environmental degradation. Dogan et al. (2022) also demonstrate that environmental sustainability is positively affected by environmental regulations. Rafique et al. (2022) investigated the influence of environmental taxes on the EF in OECD countries. One thing they discovered was those policies like implementing taxes had a big impact on lowering the EF.

At the same time, as ER can regulate highly polluting enterprises, it can also promote environmentally friendly or energy-efficient businesses to expand. These limitations also work to facilitate GTI. Formal ER may be a barrier to GTI, according to Craik et al. (2018), by replacing research and development funding and removing related risks. This can, however, act as an incentive for green innovation by raising prices and creating technological obstacles. Chen et al. (2021) delved further into the impacts of GF and ER on GTI. To see how regulatory indications fit into this process, they used a complete rating system.

Current research offers several viewpoints on the correlation between ER and GTI. According to Haselip et al. (2011), stringent ERs may not immediately stimulate technical innovation in developing nations. Instead, enterprises in these countries often opt to acquire modern equipment or transfer technology from more developed nations rather than creating on their own. In contrast, Zhao et al. (2022) proposed that ERs have a beneficial impact on the implementation of research and development activities that involve both technological and market aspects. Li et al. (2017) investigated the correlation between ER and industry structure, discovering different levels of influence. Zhu et al. (2017) discovered a correlation between the level of ER and the movement of industry towards sustainability, which follows a 'U' shape.

Governments can successfully mitigate environmental degradation and encourage sustainable practices by enacting rigorous environmental rules and levying taxes. Nevertheless, the consequences of these legislation can differ depending on the economic circumstances, regulatory structures, and industry-specific elements. Thus, we proposed the subsequent hypothesis.

H_2: Environmental regulations have a significant negative impact on the ecological footprint.

Green Finance & Green Technology Innovation

GF is essential for supporting innovation in green technology by enabling the funding and investment of initiatives that support environmentally benign and sustainable technologies. The fusion of financial acumen with technology progress propels the shift towards a more environmentally sustainable economy. GTI is the application of scientific and technical progress to create products and services that have little to no harmful effects on the environment. The main objectives of GTI are to optimize the utilization of natural resources and safeguard the environment from detrimental pollutants. Green technology goods integrate environmental consciousness into their production and utilization (Umar et al., 2021). Organizations engaged in GF aggressively advocate for technological improvements that aim to decrease carbon emissions, protect the environment, and improve economic sustainability. Zakari (2022) provides empirical evidence on the impact of GF on urban haze pollution, emphasizing the intermediate influence of corporate technical innovation from a fixed viewpoint.

Recently, GF has received a lot of attention as a key driver for the growth of GTI and the encouragement of sustainable development. According to research, GF affects GTI development in a number of ways. First of all, by giving sectors with low consumption, low pollution, and energy-saving techniques, reduced interest rates on loans, it improves the distribution of social capital. Higher credit costs for significantly polluting companies result from this, which also shifts financial market funds to environmentally friendly industries (Hong et al., 2021).

Additionally, GF offers substantial financial backing to environmental firms that aid in eliminating financial barriers and offering more additional funds for trial-and-error R&D to be conducted (Guo et al., 2019). Moreover, it addresses the concern of liquidity through establishing a long-term risk-sharing financial system to decrease risks (Bai et al., 2022). GF can reduce the costs of finding suitable resources for promoting GTI by encouraging enterprises and financial institutions to collaborate with one another and share their knowledge (Huang et al., 2022).

Given the increasing harm to the environment and the changing climate, there is a growing emphasis on GF and GTI in the fields of finance and environmental research. GTI and GF are acknowledged in the literature as interconnected systems that mutually foster and exert impact on one another. Researchers have combined these factors to establish the correlation between them. Gilbert and Zhou (2017) observed that green financial instruments, such as green funds and insurance, harness civilian investment in clean industrial sectors and promote GTI. According to Chemmanur and Fulghieri (2014), a diversified green financial system improves the efficiency of GTI and promotes the development of innovative green financial products.

In their study, Fang and Shao (2022) analyze methods for promoting ecological civilization, with a particular focus on the significance of GF. Their discussion is around the potential of GF to effectively alleviate the impact of ER on GTI, while simultaneously promoting innovation. Their findings indicate that environmental rules based on a "command and control" approach have a substantial influence on the growth of regional Green Technology Index. On the other hand, environmental policies that provide market incentives and the availability of GF contribute to the promotion of innovation. Xu and Lin (2024) contend that GF helps to alleviate the negative effects of "command and control" laws on the manufacture of environmentally friendly technologies, while also boosting the favorable results of market-incentive policies. Moreover, green finance alleviates the financial limitations of GTI by offering consistent financial backing (Yu et al., 2021). The study conducted by Wang et al. (2022) provides evidence that GF has a favorable influence on GTI in emerging countries.

However, the impact of GF for countries with already strong environmental performance varies. Most of the literature has demonstrated the influence of GF on GTI, focusing on regional and national viewpoints. Therefore, this study suggests the following,

H_3: Green finance has a significant positive impact on green technology innovation.

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Environmental Regulations & Green Technology Innovation

The correlation between environmental regulation (ER) and GTI is a topic of extensive discussion and examination in academic literature. This study compiles research findings that examine the ways in which ERs can either stimulate or impede the development of GTI, therefore influencing sustainable development. ER refers to the entirety of regulations that deal with environmental matters and are considered a significant catalyst for promoting GTI (Frondel et al., 2007). One example is that ERs can lower the number of pollutants released into the environment by implementing measures like environmental taxes. These rules encourage businesses to proactively decrease their emissions in order to avoid incurring extra expenses (Hájek et al., 2019). In addition, ERs can promote the development of GTI by reducing the positive side effects associated with innovation, typically through the provision of subsidies and other forms of incentives (Liu & Feng, 2019). Additional research has substantiated the beneficial influence of ERs on environmental performance. According to Porter and Linde (1995), well-designed ERs can provide incentives for green innovation, resulting in decreased pollution emissions.

Several experts contend that the correlation between ERs and innovation is ambiguous. According to Peuckert (2014), ERs may initially decrease corporate productivity, but they can ultimately lead to favorable long-term outcomes. Peng and Lu (2017) discovered that formal and informal ERs have different effects on GTI, resulting in both "U-shaped" and "inverted U-shaped" correlations. The ambivalent effect of ERs on GTI is apparent in both beneficial and detrimental aspects. However, the implementation of strict ERs can have a negative impact on funds allocated for GTI, resulting in a decrease in innovation activities. This, in turn, can lead to negative spillover effects on product quality and investment returns.

Overall, the research presents strong evidence that ER has a substantial impact on the invention of GT. Although the relationship between ERs and GTI can be intricate and varied, when ERs are properly conceived and implemented, they can lead to substantial progress in the development of environmentally friendly technology. Consequently, this encourages the adoption of sustainable industrial practices and enhances environmental quality. Therefore, the subsequent hypothesis is suggested:

H_4: Environmental regulations have a significant positive impact on green technology innovation.

Green Technology Innovation & Ecological Footprint

Green technology innovation (GTI) plays a vital role in tackling environmental deterioration and minimizing the ecological impact. This literature review examines the notion that the GTI is closely linked to the EF. It specifically focuses on the positive effects of GTI in promoting sustainability and decreasing harmful environmental emissions. The worldwide problem of environmental degradation has prompted the implementation of several green projects with the goal of eradicating the emission of non-organic gases. GTI is widely recognized as a highly effective approach to mitigating emissions (Saqib, 2022). According to Li et al. (2019), GTI is a benchmark for the production and utilization of renewable fossil fuels that emit

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environmentally safe gases. Multiple studies have emphasized the advantages of adopting GT, emphasizing their capacity to mitigate environmental harm (Danish & Ulucak, 2020).

Recently, GTI has been highly demanded due to its ability to counter environmental issues efficiently. It consists of innovative machinery, processes, and products that lower environmental damage, limit resource use, and promote sustainability (Sadiq et al., 2022). The importance of GTI is found in its essential role in supporting corporate modifications, progression via alterations, and long-term growth endeavors, especially in high pollution industries (Ramzan et al., 2023). In 2021, Xin et al. found that reductions in environmental emissions are linked to increases in GTI in the U.S.

Sharif et al. (2023) conducted a study to investigate the effects of GTI on environmental quality. Their findings indicate that the implementation of innovation leads to improved environmental sustainability through the reduction of environmental harm. In their study, Xu et al. (2021) examined the correlation between emissions and patent technologies in the provinces of China. Their findings indicate that the adoption of patent technologies leads to a reduction in emissions and an enhancement in environmental conditions. Ali et al. (2022) discovered a robust negative correlation between emissions and GTI, which further emphasizes the importance of GTI in reducing environmental degradation.

GTI endeavors to realign socioeconomic and environmental gains with continued, lasting growth. The goal is to stabilize the supply of energy and resources without exacerbating the damage to the environment (Wang et al., 2021). Enhanced GTI can revolutionize energy industry, meaning it will have an enormous impact on economy as a whole. Du et al. (2019) specifically examined the role of GTI in emerging countries to reach carbon-neutrality. These findings imply that the impacts of GTI are low in reducing emissions for lower-income countries while they are high and statistically significant for higher income countries. Studies additionally delved into the relationship, in different economic contexts, between GTI and environmental degradation. In 2021, Razzaq et al. investigated at how GTI and CO2 emissions correlated in the BRICS countries. They found that whilst GTI reduces CO2 emissions more strongly in economies with greater emissions levels, its influence is less noticeable in countries with lower emissions levels. In the same way, Du and Li (2019) proposed that while GTI works well to reduce CO2 emissions in higher-income countries, it does not work well in lower-income countries. It follows that for GTI to be effective in less developed areas, more funding and government support are required.

All things considered; the research is quite convincing that the growth of GTI affects the EF significantly. Aiming to promote sustainability and reduce environmental harm is the GTI project. Therefore, the aforementioned arguments lead to the formulation of the following hypothesis:

H_5: Green technology innovation has a significant negative impact on the ecological footprint.

Green Finance, Green Technology Innovation & Ecological Footprint

GF is a necessary process for the sustainable development of GTI, and it plays an important role in reducing its environmental impact. Urgent measures are needed to rectify the impaired

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natural equilibrium due to climate change. Summarizing the above, an essential way forward to mitigate the impacts of climate change is to ensure proven funding of projects focusing on the environmental sustainability avenue (Leitao et al., 2021). Green Bonds and investments represent the most prominent financial instruments at the disposal of policymakers, as well as other stakeholders to finance projects aiming to reduce carbon emissions in response to environmental degradation (Wang et al., 2023). Liu et al. (2019) demonstrated that the growing of GF limits the development in polluting industries and results in an increase only of production costs, inducing sectors to change to more eco-friendly options.

Madaleno et al. (2022) stressed that GF was needed to advance the GTI as it holds the key to sustainable development and promoting environmental sustainability. Moreover, as Peimani (2018) asserts, GF not only diminishes the detrimental impact on the environment but also promotes GTI's growth and affordability by removing financial burdens. Sharif et al. (2022) argue that spill-over effect is instrumental in enabling sustainable development goals (SDGs) 7 and 13, which concern the areas of clean energy accessible at affordable rates (and apparently promoting climate action) achieve a substantial contribution. Moreover, GF allows regulations to work better and restrains the disadvantages regarding market-driven factors stemmed from a heavy policy in terms of demand for GTI (Fang, 2023).

The contribution of GF in facilitating environmentally friendly innovation is particularly remarkable. JI and Zhang (2023) conducted a study to examine the influence of GF on both innovation and environmental performance. They found that there was a notable enhancement in innovation performance and environmental results after the year 2017. Chang et al. (2022) discovered that green innovation has a crucial role in reducing emissions, highlighting the importance of GTI in enhancing environmental performance. Financial limitations are a substantial obstacle to GTI, yet the provision of funding for environmentally friendly initiatives can greatly improve the caliber and influence of GTI (Ning et al., 2023).

On one hand, as stated by Zhang et al. (2022), GF can influence environmental performance through resource allocation, financial support and technical innovation. GF promotes the emergence of technical advances that are beneficial to preserving energy conservation and stimulating green growth; however, it plays a critical role in reducing pollution and environmental damage (Sun et al., 2022; Bilal & Shaheen, 2024). Building a green economy and implementing good management mechanisms is the key we need to assess to what extent green loans, for example, or subsidies help us on this path of a green industrial revolution. According to Liu et al. (2021), government subsidies may lower companies' capital costs and will encourage them in innovation.

To summarize, GF facilitates the advancement and adoption of cutting-edge technologies that mitigate carbon emissions and enhance environmental sustainability through the provision of crucial financial assistance and incentives. Therefore, this research suggests the following,

H_6: Green technology innovation mediates the relationship between green finance and the ecological footprint.

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Environmental Regulations, Green Technology Innovation & Ecological Footprint

ERs refer to a set of governmental policies or efforts implemented to safeguard the environment. The implementation of these restrictions has effectively curtailed the negative impact on the environment caused by enterprises and has played a pivotal role in safeguarding the environment (Jinjarak et al., 2021). Researchers have predominantly examined the impact of ER on enterprises, focusing primarily on the perspective of the enterprise. The proponents argue that implementing suitable environmental rules can facilitate the development of competitive advantages for businesses, while also serving as a catalyst for them to enhance their efficiency (Hartley et al., 2019). Nevertheless, ERs have also increased the operational expenses of organizations, thereby impacted their operating circumstances and hindered performance growth.

Scientific and technological advancement has both positive and negative impacts on the biological environment. Technological innovation in environmental protection can raise environmental awareness and encourage the growth of pollution control levels. Nevertheless, the utilization of sophisticated technology to regulate pollutants and enhance the environment may inadvertently give rise to novel environmental catastrophes. Hence, the ability of technological innovation to simultaneously promote economic development and environmental conservation hinges on comprehending the environmentally conscious trajectory of technological innovation. In order to effectively promote environmental protection, it is crucial to establish a strong connection between initiatives that promote green technology innovation in firms and environmental control policies and actions. This will ensure that the full potential of such innovation is harnessed.

Various studies have found that ERs should aggressively promote green finance in industrial businesses. Shahbaz et al. (2020) categorized ERs into three distinct groups: command-control ERs, market-driven ERs, and voluntary ERs. The implementation of all three types of ER can have a favorable influence on the financing of green technology in Chinese enterprises. While the results of this study align closely with those of Li et al. (2021), it is important to note that implementing environmental rules would lead to both enhanced advantages in GF and increased production costs for firms.

Hashmi and Alam (2019) examined the correlation between ERs, GTI, and emissions of carbon dioxide within the framework of OECD countries. The results obtained from the DK error methods demonstrate that a 1% augmentation in ER leads to a reduction of emissions by 0.03% and a drop of $CO2$ emissions by 0.017% as a result of a 1% rise in green inventions. Ahmad et al. (2020) investigates the dynamic correlation between technological progress and carbon emissions by employing the Environmental Kuznets Curve (EKC) theory. Based on their research, technology advancements can help reduce environmental degradation and provide evidence for the Environmental Kuznets Curve (EKC). A separate study conducted by Ahmad et al. (2021) contends that the level of a nation's development has a substantial influence on the relationship between innovation and environmental quality. Their research reveals that eco-innovation has a significant adverse influence on environmental degradation in G7 countries, and that eco-

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innovation is more successful in cutting emissions in G7 economy compared to developing economies. Green innovation typically fosters a favorable social milieu and enhances the quality of the environment.

Eventually, by creating suitable ERs, governments would be able to effectively reduce the negative impacts of businesses on the environment and stimulate the emergence of environmentally friendly technologies vital for ensuring sustainable development. While it is possible that in the initial stage businesses will have to pay more for their operations, eventually these regulations would increase efficiency throughout having lower emissions and overall better commercial health of nature. This research therefore proposes the following hypothesis:

H_7: Green technology innovation mediates the relationship between environmental regulations and the ecological footprint.

Data and estimation Methodology

This study used a positivist paradigm approach to examine the causal links between the variables. This philosophical perspective is highly compatible with quantitative research and conventional research methodologies (Diener et al., 2000). The main aim of this study is to investigate the influence of green finance and environmental regulations on the ecological footprint, with green technological innovation acting as a mediator.

Description and sources of data

This paper utilizes an extensive collection of data. The data was collected from esteemed international institutions, including the World Bank, OECD, Our World in Data, and the Global Footprint Data Network. This article focuses on analyzing crucial aspects such as EF, GF, ER, and GTI. The EF is quantified by calculating the ecological footprint per capita, using data obtained from the global footprint network database. The EF is a comprehensive measure that is calculated by measuring the productive area, crops, carbon dioxide absorption, fishing grounds, and forest land. Moreover, this variable can provide a more comprehensive understanding of the biological landscape of the country. ERs are assessed using the metric of Environmentally related tax revenue as a percentage of GDP. This data has been obtained from the OECD. GTI is quantified by the total number of environment-related patents, which has been obtained from the OECD. For the measurement of GF, we employed a very dependable and extensively utilized proxy, namely the international financial inflow that supports sustainable energy. The data for this measurement was obtained from Our World in Data. Table 1 displays the source and descriptions of the variables.

The analysis has included data from 2001 to 2022 for a total of 81 nations, based on data availability. The data is processed using the STATA 18 software. STATA is widely utilized by researchers for automated reporting in various domains, including social science. It assists the researchers to conduct the analysis.

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Table 1. Variable source and description

Variables	Symbol	Unit	Source
Ecological Footprint	EF	Ecological Footprint per capita	GFN database
Green Finance	GF	International financial inflow in support of Sustainable energies	Our World in Data
Environmental Regulations	ER	Environmentally related tax revenue % of GDP	OECD
Green Technology Innovation	GTI	Total number of patents environment related	OECD
Income Inequality	II	Gini index	WDI
Economic Growth	EG	Real GDP per capita	WDI
Unemployment	UNEMP	Unemployment, total (% of total labor force)	WDI
Life Expectancy	LE	Life expectancy at birth, total (years)	WDI

Model construction

Countries worldwide are expressing concern for environmental sustainability, in line with the consensus reached at international climate change conferences. Regarding this matter, numerous policies and decisions are being formulated globally. Countries have transitioned into a new stage of advancement, prompting policy makers to prioritize the assurance of quality rather than quantity. As a nation transitions from a phase of its economic growth that prioritizes quantity to a phase that prioritizes quality, it is commonly believed that the country adopts new technology that reduces the environmental impact. This study expands on previous research by integrating Green Finance, environmental regulations, and green technology innovation into the study framework and forecasting their possible adverse or beneficial effects on the ecological footprint. Hence, our suggested model, as depicted in Equation (1), investigates the correlation between the exogenous and independent indicators and control indicators.

$$EF = f(GF, ER, GTI, II, GDP, UNEMP, LE) \quad (1)$$

EF represents Ecological footprint, GF defines green financing, ER stands for Environmental Regulations, GTI represents green technology innovation, II portrays Income Inequality, GDP indicates economic growth, UNEMP represents Unemployment, and LE exemplifies Life expectancy. The parameters in the data set were subjected to natural logarithm transformations in order to address issues such as heteroscedasticity and skewness. Consequently, the framework provides an improved multivariate function for the log-linear model after transformation. Additionally, it offers a more precise alignment and yields experimental findings that are more reliable and consistent. Hence, this study employs a logarithmic transformation in the econometric assumption, as depicted in Equation (2).

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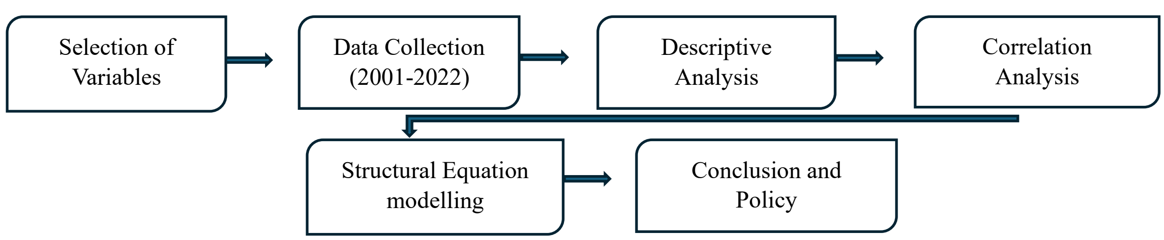
$$\ln EE_{i,t} = \beta_0 + \beta_1 \ln GF_{i,t} + \beta_2 \ln ER_{i,t} + \beta_3 \ln GTI_{i,t} + \beta_4 \ln II_{i,t} + \beta_5 \ln RGDP_{i,t} + \beta_6 \ln UNEMP_{i,t} + \beta_7 \ln LE_{i,t} + e \quad (2)$$

The subscript t represents the time period from 2001 to 2022, and the cross-sectional units are designated by i = 1,..., N. Meanwhile, the margin of error term is represented by the symbol e, while the constant value is marked as β0. The symbols β1 through β7 denote the responsiveness of the Ecological footprint to changes in green finance, Environmental laws green technology innovation, Income inequality, economic growth, Unemployment, and life expectancy. Control variables can be used to account for the impact of additional factors that may affect environmental quality, so enhancing our understanding of the relationships between the variables.

Econometric methodology

The study further employs different data analysis techniques to determine the relationships between the variables. They include descriptive statistics and visualization to characterize each dataset in detail; correlation analysis for examining pairwise relationships among all variables. The mediation modelling approach within the structural equation modelling (SEM) framework would be adopted in this paper to address the study's aims. Structural equation modeling (SEM) was introduced in 1969 by the prominent Swedish statistician Karl Gustav Joreskog. Structural equation modeling (SEM) is a versatile statistical method that allows examining complex relationships between variables (Jöreskog, 1969). Linear relationships between variables are commonly evaluated using SEM in the social, behavioral, and economic sciences.

Fig 1. Flow of the Empirical Analysis



Results and discussion

Descriptive statistics

Table 2 presents the summary statistics of the variables utilized in this study. The two primary elements of descriptive statistics are the measures of central tendency, which include the mean and median, and the measures of variability, which encompass the standard deviation, maximum, and minimum values.

The descriptive statistics of each variable in this study offer a detailed summary of the primary tendencies, variability, and ranges within the dataset, which comprises 1,782 observations. The EF, which is the dependent variable, has a mean value of 4.3033 and a standard deviation of 3.7518. The data shows high heterogeneity in EF across the observations, with values ranging from

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a minimum of 0 to a maximum of 43.7132. This suggests notable differences in environmental impacts among different countries. The independent variable, ER, has an average value of 9606.769 and a significantly large standard deviation of 20963.44. The range of ER varies significantly, ranging from 0 to 154975.4, indicating substantial variations in the level and stringency of ER. Similarly, the independent variable GF has an average value of 6.29e+07 and a significantly high standard deviation of 2.20e+08, indicating a considerable amount of variability in green financial efforts. The numbers span from 0 to a remarkable 3.37e+09, suggesting that certain locations allocate significant investments towards GF, while others do not invest anything at all. The mediator variable, GTI, has a mean of 330.5664 and a significantly high standard deviation of 1216.18. The values of GTI range from 0 to 12151.59.

Table 2. Descriptive Statistics

Variable	Mean	Std. dev.	Min	Max	N
EF	4.3033	3.751812	0.000	43.71318	1,782
ER	9606.769	20963.44	0.000	154975.4	1,782
GF	6.29e+07	2.20e+08	0.000	3.37e+09	1,782
GTI	330.5664	1216.18	0.000	12151.59	1,782
EG	18512.54	21253.38	0.000	112417.9	1,782
UNEMP	7.811401	5.304212	0.000	37.32	1,782
LE	75.2092	5.321547	49.006	83.90488	1,782
II	36.01117	8.751077	0.000	59.5	1,782

The substantial variation indicates major discrepancies in the amount of innovation in green technology among different regions. These descriptive statistics offer a fundamental comprehension of the material, establishing the groundwork for more intricate studies. The wide range and diversity of these variables highlight the different economic, environmental, and social situations found in the sample. This will be important for understanding the upcoming statistical analysis and model estimations in the study.

Correlation

Subsequently, an analysis was conducted to determine the correlation between the variables under study. The correlation matrix is presented in Table 3.

The correlation analysis uncovers significant correlations among the variables. The relationship between GF and EF is inverse, indicating that an increase in green financing could potentially contribute to its reduction. GF exhibits a positive correlation with both ER and GTI, suggesting that countries with higher levels of green finance also tend to have more stringent regulations and greater levels of innovation. ER exhibits a negative association with EF, whereas it demonstrates a positive correlation with GTI. The GTI exhibits a negative association with the

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EF. These findings emphasize the intricate interplay of economic development, environmental consequences, and social variables.

Table 3. Correlation

	ln EF	ln GF	ln ER	ln GTI	ln EG	ln UNEMP	ln LE	ln II
ln EF	1.0000							
ln GF	-0.4655	1.0000						
ln ER	-0.3645	0.1011	1.0000					
ln GTI	-0.4486	0.2539	0.1692	1.0000				
ln EG	0.6564	-0.1430	0.0440	0.2494	1.0000			
ln UNEMP	0.3742	-0.1185	0.4205	0.0649	0.3634	1.0000		
ln LE	0.3324	0.0102	-0.0669	0.3238	0.7854	0.2596	1.0000	
ln II	0.1038	-0.1130	0.0284	-0.1300	0.3549	0.1358	0.2551	1.0000

Structural equation model

The results of the structural equation modeling (SEM) demonstrate strong correlations among the important variables, such as green finance, environmental regulations, green technological innovation, and ecological footprint, as expected in the study (Table 4).

Table 4. SEM Endogenous variables**,** Observed: lnGTI lnEF
Exogenous variables, Observed: lnGF lnER lnGDP lnUnemp lnLE lnII
Estimation Method = Maximum Likelihood
Log-likelihood = -6185.2319

	Coefficient	OIM std. error	Z	P>z	95% conf. interval	
Structural						
Ln GTI						
Ln GF	.0494205	.0077481	6.38	0.000	.0342345	.0646065
Ln ER	.061493	.0158993	3.87	0.000	.030331	.0926549
_cons	.6367112	.1515861	4.20	0.000	.3396079	.9338145
Ln EF						
Ln GTI	-.0186414	.0070723	-2.64	0.008	-.0325028	-.00478
Ln GF	-.0063669	.0013435	-4.74	0.000	-.009	-.0037337
Ln ER	-.0095505	.003058	-3.12	0.002	-.015544	-.0035569
Ln GDP	.5192447	.0282527	18.38	0.000	.4638704	.5744619
Ln UNEMP	.1181777	.021821	5.42	0.000	.0754094	.1609461
Ln LE	-1.507491	.3213021	-4.69	0.000	-2.137232	-.8777505
Ln II	-.4625432	.0716174	-6.46	0.000	-.6029106	-.3221757
_cons	4.643886	1.223946	3.79	0.000	2.244996	7.042776
Var (e.ln GTI)	4.21171	.2323758			3.780024	4.692696
Var (e.ln FE)	.1146707	.0063268			.1029173	.1277663

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The data from table 4 demonstrate that GF has a statistically significant and beneficial impact on GTI, as evidenced by a coefficient of 0.0494 ($p < 0.001$). This suggests that a greater allocation of funds towards green finance is linked to elevated levels of innovation in green technologies. ER have a positive impact on GTI, as evidenced by a coefficient of 0.0615 ($p < 0.001$). This indicates that stronger ER leads to more innovation in green technologies. Several variables influence the ecological footprint. The coefficient of -0.0186 ($p = 0.008$) indicates that GTI has a noteworthy negative impact on the EF, implying that the development of green technology can be beneficial in decreasing the ecological footprint. The coefficient of -0.0064 ($p < 0.001$) demonstrates that increased levels of GF have a negative influence on the EF, resulting in a decrease. Similarly, there is a correlation between ER and a decrease in EF, with a value of -0.0096 ($p = 0.002$). Essentially, the SEM analysis emphasizes the important contributions of GF, ER, and GTI in decreasing the EF.

Table 5. Indirect effects

	Coefficients	OIM Std. error	Z	p>z	95% conf.	interval
Structural						
Ln GTI						
Ln EF						
Ln GF	-.0009213	.0003782	-2.44	0.015	-.0016625	-.00018
Ln ER	-.0011463	.0005263	-2.18	0.029	-.0021778	-.0001148

The SEM analysis results in table 5 offer further insights into the influence of GF and ER on the EF. These effects are mediated by GTI. The coefficient for the indirect effect of GF on the EF through the GTI is -0.0009213. The statistical analysis reveals that the observed effect is very significant, as indicated by a p-value of 0.015. This suggests that the indirect pathway through GTI holds important meaning. Similarly, the coefficient representing the indirect influence of ER on the EF through GTI is -0.0011. The statistical analysis confirms the significance of the indirect effects, as evidenced by a p-value of 0.029. Essentially, both GF and ER indirectly help decrease the EF by positively influencing the GTI. The significance of the mediation effect of GTI underscores the pivotal function of GTI as an intermediary in the interaction between the independent variables and the EF.

In Table 6, the Root Mean Squared Error of Approximation (RMSEA) is computed as 0.06. The number is below the widely accepted criterion of 0.08, suggesting that the model and the observed data are well-matched. The 90% confidence interval for the RMSEA is between 0.02 and 0.03, providing more evidence that the model is sufficient. Furthermore, the p-value linked to RMSEA (Pclose) is 0.00, suggesting a strong likelihood that the observed data fits the model accurately. This is because the possibility of obtaining an RMSEA value as little as the one observed, assuming the model is correct, is extremely low.

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Table 6 Overall Goodness of Fit

Fit Statistic	Value	Description
Population error		
RMSEA	0.06	Root mean squared error of approximation
90% CI, lower bound	0.02	
upper bound	0.03	
Pclose	0.00	Probability RMSEA <= 0.05
Baseline comparison		
CFI	0.92	Comparative fit index
TLI	0.935	Tucker-Lewis index
Size of residuals		
SRMR	0.085	Standardized root mean squared residual
CD	0.577	Coefficient of determination

In addition, the Comparative Fit Index (CFI) and Tucker–Lewis Index (TLI) both have values above 0.90, with CFI at 0.92 and TLI at 0.935. These values suggest that the stated model fits relatively well compared to a null model, which is a model without any predictors. Although the TLI value is approaching the threshold of 0.95 for a satisfactory fit, both indices indicate that the model adequately explains the observed data. The SRMR, which stands for Standardized Root Mean Squared Residual, is computed as 0.085. Although this result is slightly higher than the widely accepted threshold of 0.08 for a good fit, it is still within an acceptable range. This suggests a moderate level of difference between the observed and anticipated correlations. The Coefficient of Determination (CD) is 0.577, suggesting that the model accounts for around 57.7% of the variability in the observed variables, providing a moderate level of explanation (Jenatabadi, 2015). Overall, these findings indicate that the structural equation modeling (SEM) model effectively elucidates the connections between the variables being studied.

Concluding remarks and policy suggestions

Conclusion

This study offers an in-depth analysis of the associations among GF, ER, GTI, and their combined influence on the EF. The study employs structural equation modeling (SEM) to analyze data collected from 2001 to 2022 across 81 nations. The findings emphasize the substantial impact of GF and ERs in mitigating environmental degradation. The results indicate that both GF and strict ERs have a direct and negative impact on the EF. However, GTI acts as a mediator, increasing the positive effects of these factors in reducing environmental damage. By incorporating control factors such as II, EG, UNEMP, and LE to a greater EF. The findings emphasize the significance of advocating for green financial structures and implementing strict environmental rules to stimulate the development of green technology advances. These advancements, in return, contribute to substantial ecological advantages.

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Policy implications

Important policy implications can also be drawn from the results of this study, which will provide some directions for different efforts to enhance environmental quality. Consequently, it is assumed that a considerable decrease in the ecological footprint can be achieved through putting greater amounts of finance into sustainable energy projects. For this reason, green finance ought to receive more attention from policymakers. Once authorized, the mechanism could be used to promote tools like green bonds, sustainable investment funds, and other financial instruments so far designed only with a view to environmentally friendly purposes. Furthermore, the implementation of rigorous environmental rules is essential. Implementing effective legislative measures can enforce the adoption of cleaner technology by industries, leading to a decrease in their environmental footprint. Policymakers must ensure that these regulations are not only created but also strictly enforced and supervised. Furthermore, it is imperative to promote innovation in environmentally friendly technology. It is advisable for governments and the private sector to cooperate in order to enhance research and development by providing incentives such as tax exemptions, grants, and subsidies specifically for environmentally friendly patents. To expedite the implementation of environmentally friendly innovations and reduce the negative impact on the environment, it is important to create a supportive atmosphere that promotes technical progress.

Limitations

The incorporation of financial, regulatory, and technological methods is crucial in attaining sustainable development and mitigating environmental deterioration. However, there are also some limitations in relation to further research. Further studies might build on these findings and examine the long-term effects of these factors over a longer time frame or other geographical areas. In addition, qualitative studies may also provide a deeper insight into the contextual factors which affect the effectiveness of green finance and policies. A complete understanding of the mechanisms by which social and cultural aspects can affect the acceptance and efficacy of green technology innovations may recommend a realistic pathway for achieving ecological sustainability.

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