sustainability

MDPI

Article

Greening the Future: Harnessing ICT, Innovation, Eco-Taxes, and Clean Energy for Sustainable Ecology—Insights from Dynamic Seemingly Unrelated Regression, Continuously Updated Fully Modified, and Continuously Updated Bias-Corrected Models

Yupu Wang [1], Md. Qamruzzaman [2] and Sylvia Kor [2,*]

[1] School for Marxism Studies, Shanxi University, Taiyuan 030006, China; benci40086@163.com
[2] School of Business and Economics, United International University, Dhaka 1212, Bangladesh; qamruzzaman@bus.uiu.ac.bd
* Correspondence: skor183055@bba.uiu.ac.bd

Abstract: This research endeavors to investigate the impacts of information and communication technology, green technological innovation, and environmental tax on the attainment of ecological sustainability with advanced panel date estimation for 2001–2019. The results of this study demonstrate a noteworthy inverse relationship between information and communication technology and ecological footprint, suggesting that progress in ICT has the potential to yield positive consequences in terms of ecological restoration and the promotion of environmental sustainability. Furthermore, this study underscores the significance of GTI in mitigating carbon emissions and effectively addressing environmental challenges. The findings indicate that the incorporation of environmentally sustainable technology can yield favorable ecological consequences and make significant contributions towards the attainment of worldwide climate targets. Nevertheless, the study highlights the importance of considering potential rebound effects. It underscores the imperative for ongoing research and the implementation of comprehensive policies within the realm of environmentally sustainable technology. Moreover, the present study elucidates the favorable ramifications of GF on ecological sustainability, underscoring its pivotal contribution in curtailing carbon emissions, augmenting environmental benchmarks, and facilitating the ecological footprint. Enhancing the utilization of green finance, making adjustments to national regulatory frameworks, and achieving harmonization of public financial incentives to bolster sustainable development are important. Additionally, the study posits that the incorporation of ET can catalyze businesses and individuals to embrace environmentally friendly energy sources and sustainable practices, thereby fostering positive outcomes for the environment. The study offers significant insights into the contributions of information and communication technology, green technology innovation, and environmental technology to advancing ecological sustainability. It emphasizes the need for collaborative endeavors among academia, industry, and government to cultivate a supportive ecosystem for sustainable development.

Keywords: information and telecommunication; green technological innovation; green finance; CUD-FM; CUP-BC; DSUR

check for updates

Citation: Wang, Y.; Qamruzzaman, M.; Kor, S. Greening the Future: Harnessing ICT, Innovation, Eco-Taxes, and Clean Energy for Sustainable Ecology—Insights from Dynamic Seemingly Unrelated Regression, Continuously Updated Fully Modified, and Continuously Updated Bias-Corrected Models. *Sustainability* **2023**, *15*, 16417. https://doi.org/10.3390/su152316417

Academic Editors: Davorka Hackenberger and Olga Jovanović Glavaš

Received: 3 October 2023
Revised: 23 November 2023
Accepted: 27 November 2023
Published: 29 November 2023

1. Background of the Study

In the current context, the rapid expansion of worldwide populations and economic endeavors has intensified apprehensions regarding environmental degradation (ED, hereafter), thereby necessitating an increased emphasis on this matter [1]. The increasing significance of ED has emphasized the necessity of evaluating the effectiveness of various environmental policy instruments. Upon careful examination of past endeavors in environmental policy implementation, it becomes apparent that the prevailing strategies frequently entailed the establishment of regulatory structures that encompass obligatory directives and punitive actions. These measures were designed to address the escalating environmental challenges and the resulting ecological disturbances [2–4]. Paradoxically, despite the longstanding existence of these regulations, which have established a range of standards to protect environmental quality, the prevailing trend has been toward degradation rather than improvement. In situations where the adverse effects of pollution are not immediately apparent, the efficacy of regulatory or "command-and-control" measures in addressing the issue has been called into question [5].

ED is a significant and pervasive global issue that engenders detrimental consequences for human well-being, air quality, the depletion of the ozone layer, economic stability, biodiversity, and the availability of natural resources [6,7]. The interplay between energy, food, water, and infrastructure presents significant challenges to ecosystems, ultimately instigating ecological stress and consequent detrimental impacts on the environment [8]. In order to tackle this matter effectively, nations must undertake measures aimed at mitigating carbon emissions, curbing energy consumption, and regulating various activities that contribute to the contamination of air, water, and land resources. Notwithstanding, the issue of environmental pollution persists as a formidable global challenge, as discernible and substantial advancements in the reduction of CO_2 emissions and other pollutants have yet to materialize [1,9]. While individuals who have been directly impacted by pollution may have the option to seek legal recourse within the existing legal framework, the limitations of such instruments become evident when the harm caused by pollutants is uncertain. Solarin et al. [10] posit that CO_2 serves as a metric for assessing the extent of environmental degradation. Nevertheless, it is widely acknowledged among scholars that the ecological footprint (EF, hereafter) holds significant value as an indicator for assessing environmental degradation [11].

The degradation of the environment can arise from a combination of anthropogenic and natural factors. Human-induced ED encompasses a myriad of detrimental factors, including but not limited to water and air pollution, acid rain, agricultural runoff, urban expansion, and habitat fragmentation. The accelerated depletion of natural resources is a consequence of the heightened demand [1]. Additional factors contributing to ED encompass anthropogenic land disturbance, pollution, population growth, landfills, deforestation, and natural calamities [12]. The potential degradation of the environment can disrupt the intricate dynamics of the water cycle, thereby impeding the regular functioning of various organisms, both flora and fauna. Additional factors contributing to the ongoing degradation of the environment encompass the detrimental processes of deforestation and mining, as highlighted in the scholarly literature [13–15].

Additionally, ED can be ascribed to various macroscopic factors, encompassing economic growth, population growth, land disruption, pollution, overpopulation, landfills, deforestation, natural phenomena, and climate change [16,17]. Economic policy uncertainty has been identified as a significant factor that can potentially amplify CO_2 emissions and contribute to ED [18–21]. The extant corpus of scholarly literature suggests a discernible correlation between environmental contaminants and a multitude of parameters. Furthermore, it is imperative to acknowledge the substantial implications that arise from the correlation between socioeconomic determinants and ED in the context of evaluating and formulating policy strategies intended to improve environmental quality [22]. The preservation of the environment poses a substantial challenge to humanity, as it is susceptible to various forms of degradation, including pollution, ecological destruction, depletion of freshwater resources, and loss of arable land [23,24]. Therefore, it is imperative to recognize and address these variables when promoting sustainable behavior as a strategy to reduce the ecological footprint and promote ecological sustainability.

The study considered information and communication technology (ICT, hereafter), green finance (GF, hereafter), green technological innovation (GTI, hereafter), environmental tax (ET, hereafter), and clean energy (CE, hereafter) in the equation of the ecological footprint (FF, hereafter). In recent times, ICT has garnered recognition as a powerful tool for addressing pressing ecological issues [25]. The literature elucidates potential enhancements in efficiency and waste reduction that can be achieved through advancements in ICT [26]. Smart grids enable the seamless monitoring, control, and optimization of energy distribution by integrating cutting-edge communication technology into power distribution infrastructure. Consequently, the reduction of energy waste leads to an improvement in grid reliability. Through the facilitation of the transition from paper-based to digital workflows, ICT plays a crucial role in the modernization of various business operations. Technological innovation stands as a fundamental driver of economic progress, a notion substantiated by various scholarly works [27,28]. Grounded in the Schumpeterian theory of innovation, the premise is that significant transformations in technology are pivotal for accelerating financial gains [29]. It is within this framework that ecological advancement and eco-friendly innovations have gained prominence, with their dual role in enhancing environmental performance and mitigating harmful emissions well documented. Notably, the confluence of economic development and increased energy consumption for commodity production has given rise to heightened ecological contamination. However, the tide can be turned through the lens of green technological advancement, which holds the potential to enhance energy efficiency and reduce atmospheric pollution [30]. Moreover, the strategic utilization of efficient energy practices and eco-friendly innovations has demonstrated the capacity to curtail carbon emissions [31].

The field of GF possesses the inherent capacity to effectively foster ecological sustainability through its active promotion of sustainable development and robust mitigation of adverse environmental impacts. The extant body of research suggests that GF possesses the capacity to yield substantial contributions in the pursuit of ecological sustainability. The achievement of this objective can be facilitated through various approaches, including the reduction of carbon emissions, the improvement of environmental quality, and the mitigation of ecological footprints [32]. The implementation of GF holds promise for promoting accountability and transparency by incentivizing enterprises to actively monitor and openly disclose their environmental performance [23]. Policymakers wield the capacity to promote the widespread adoption of environmentally sustainable financial practices through the implementation of regulatory framework modifications, the cultivation of alignment among public financial incentives, and the enhancement of green financing accessibility across diverse sectors. The utilization of GF presents a valuable opportunity for enterprises and regulators alike to effectively foster sustainable growth and address the ecological consequences [33]. Therefore, the incorporation of GF holds significant promise for augmenting the ecological footprint by fostering sustainable development and mitigating environmental degradation. The facilitation of ecological sustainability can be effectively promoted through the utilization of green financing mechanisms aimed at bolstering clean energy consumption. The utilization of clean energy sources possesses significant potential for effectively mitigating carbon emissions and promoting the progression of sustainable development [34].

Through the promotion of sustainable growth and mitigation of environmental harm, GF has the potential to safeguard the enduring viability of ecosystems. GF employs environmental levies as a strategic approach to promote and enhance environmental sustainability. Environmental levies have been found to have positive impacts on carbon emissions, water quality, and ecological footprints [35]. In addition to cultivating a culture of accountability and transparency, the implementation of green financing has the potential to enhance the monitoring and reporting of environmental performance by businesses [36]. There are several strategies that policymakers can employ to promote GF, including modifications to regulatory frameworks, the alignment of public financial incentives, and the augmentation of green funding from various sectors [37,38]. Businesses and governments have the potential to contribute to sustainable development and mitigate their environmental impact through the utilization of green funding mechanisms.

The utilization of CE plays a pivotal role in promoting ecological sustainability through the reduction of carbon emissions and the promotion of sustainable development. The extant literature suggests that the utilization of RE sources holds promise for fostering economic growth while concurrently enhancing environmental quality [35]. The utilization of RE sources has demonstrated a significant influence on the mitigation of the ecological footprint in diverse geographical regions [39]. The utilization of RE sources has garnered substantial empirical evidence, thereby substantiating its advantageous influence on the conservation of natural resources [39,40]. Alternatively, non-RE sources lead to increased exploitation of limited resources, such as coal and oil, thereby exacerbating the degradation of the environment [35]. Therefore, the utilization of RE sources has the potential to significantly alleviate the ecological consequences and facilitate the progression of sustainable development. Policymakers and companies possess a unique opportunity to leverage the potential of CE as a means to propel ecological sustainability forward. The desired outcome can be realized through the implementation of strategic investments in RE sources and the facilitation of sustainable energy practices.

The rest of the structure of the study is as follows. Section 2 deals with the literature review, hypothesis development, data, and methodology of the study presented in Section 3. Empirical model estimation and interpretation of the results are available in Section 4. Discussion, conclusion, and policy suggestions are available in Sections 5 and 6, respectively.

2. Literature Review and Hypothesis Development

2.1. ICT and Ecological Footprint

The impact of ICT on the environment is multifaceted, encompassing both direct and indirect consequences. The direct environmental impacts of ICT encompass the utilization of resources and the generation of emissions throughout the lifecycle of ICT hardware, including its manufacturing, operation, and disposal [41–43]. Conversely, the indirect environmental ramifications of ICT pertain to the alterations observed in consumption and production patterns as a result of ICT implementation.

The existing body of literature elucidates a complex and intricate relationship between ICT and its ecological ramifications [3,25,44,45]. Several studies indicate that the proliferation of ICTs, coupled with environmental innovation and the efficient utilization of natural resources, may potentially mitigate the ecological footprint associated with expanding economies. However, it is worth noting that the adoption and integration of ICT, along with the development of economic complexity and the enhancement of human capital, have been identified as factors that contribute to an increase in pollution levels [46]. The proliferation of ICTs, advancements in environmental technology, and the accessibility of natural resources collectively constitute the fundamental elements of green growth. The utilization of ICT to reduce carbon emissions yields greater advantages for low-income developing nations in comparison to high-income developed nations [47,48]. When considering the EF, it is essential to analyze the implications of importing and exporting ICT infrastructure, as it can yield both advantageous and detrimental outcomes for environmental sustainability. The implementation of state-of-the-art ICT infrastructure has the potential to mitigate the environmental unsustainability observed in the researched area. However, it is important to acknowledge that the production and global distribution of these ICT facilities may come at a significant ecological cost.

The existing literature collectively emphasizes the intricate and multifaceted relationship between ICT and its ecological impact. The ecological footprint resulting from the use of ICT is influenced by various factors, such as the level of development of a country, the type of ICT employed, and the extent of ICT infrastructure imports and exports. Thus, the study formulated the following hypothesis for assessment.

H1: *There is a positive association between ICT and environment sustainably.*

2.2. Green Technological Innovation and Ecological Footprint

The global proliferation of green innovation can be attributed to two interconnected factors: the growing demand for energy and the pressing issue of environmental pollution [44]. The surge in energy consumption, particularly in correlation with population growth and urbanization, has necessitated intensified endeavors in energy production. Concurrently, the ongoing global crisis of ED serves as a compelling reminder of the imperative to transition towards a paradigm shift that prioritizes the utilization of RE sources. RE sources have gained significant prominence in recent years due to their sustainable and environmentally friendly nature. These sources include hydroelectric, solar, geothermal, wind, and wave energy [49–51].

In the past decade, the domain of RE has experienced a significant and remarkable upward trajectory, consistently surpassing annual projections. Despite the considerable advancements made in this domain, the proportionate contribution of RE within the broader context of overall energy consumption has exhibited a relatively stable trend, as evidenced by the findings of [23,44,52,53]. Hence, the importance of green innovation is widely acknowledged and considered to be of utmost significance. The multidimensional process under consideration encompasses the strategic allocation of resources towards energy research and development (R&D), the facilitation of patent grants pertaining to environmental innovations, and the adoption of RE sources. The successful execution of a holistic approach holds promise for mitigating environmental harm through the utilization of advanced technologies aimed at diminishing reliance on finite energy resources [54,55]. Furthermore, the continuous development of innovative storage and transportation technologies holds promising prospects for enhancing the utilization of RE sources. The phenomenon above can potentially enable the simultaneous fulfillment of escalating energy demands while efficiently mitigating environmental deterioration.

The relationship between green innovation and ecological footprint has been examined in the context of the top 20 nations known for their advancements in sustainable innovation, indicating that the implementation of green innovation plays a crucial role in diminishing the ecological footprint. Furthermore, the study reveals a positive and substantial correlation between green innovation and the reduction of the ecological footprint [50,56]. The investigation of the relationship between RE use, energy research and development spending, and green patents on the ecological footprint has been conducted in EU nations. The research conducted indicates that the implementation of green innovation has a noteworthy influence on the reduction of the ecological footprint. Furthermore, the analysis reveals a statistically significant and negative correlation between green innovation and the ecological footprint [50]. The role of technological progress in promoting green innovation and mitigating ecological impact has been well acknowledged. Research has shown that the implementation of green technology breakthroughs has favorable outcomes in terms of enhancing environmental quality and fostering global environmental efficiency. Based on the literature, the study hypothesizes a positive association between GTI and EF.

H2: *Green Technological Innovation reduces the ecological footprint by promoting sustainable practices and reducing waste.*

2.3. Green Finance and Ecological Footprint

Energy consumption and environmental degradation have extensively investigated and established a catalyst role in aggravating environmental degradation, especially the heavy reliance on conventional energy sources [11,57–59]. However, the introduction of green finance has a contributory role in mitigating environmental adversity with the reduction of conventional energy through the inclusion of clean energy in the energy mix. Thus, green financing has a positive influence on environmental sustainability by contracting CO_2 emissions [23,54,55,60–64]. In the study of Numan, Ma, Sadiq, Bedru, and Jiang [23], utilizing panel data, it was established that ecological degradation could be managed through innovation in the financial and technological context. That is, GF and technological innovation foster environmental sustainability.

In order to assess the efficacy of its efforts in fostering a sustainable environment, GF employs a range of strategies, including ecological securities, the interdependent development of environmental protection, and the utilization of natural resources as restorative practices. Financial and investment decision-makers stand to gain valuable insights by taking into account the positive ecological implications highlighted by Yuan et al. [65]. The study asserts that environmental conservation represents a pivotal strategy that warrants careful consideration. The prioritization of environmental protection, encompassing air quality improvement and the promotion of efficient green energy utilization, is a key focus. GF actively encourages and supports this transition in investment strategies. However, it is noteworthy to mention that despite the acknowledged significance of GF, there remains a dearth of comprehensive and substantial research publications pertaining to the intricate relationship between GF and environmental quality. Consequently, it is imperative to conduct an in-depth investigation into the potential of GF to mitigate environmental degradation and facilitate the transition towards a more sustainable future. Hence, there exists a significant impetus to investigate the impact of research and development in the field of GF on enhancing ecological quality [66].

Green investments often require a significant initial capital investment, but they provide substantial long-term returns. Furthermore, it is important to acknowledge that the existence of emerging technology brings about a certain degree of inherent unpredictability in terms of its potential returns. As a result, this often leads to the expectation of decreased credit ratings. Tran et al. [67] have established a correlation between the returns on green technology and carbon pricing, suggesting that fluctuations in the emissions market can have a significant influence on the volatility of investments in green technologies. These factors collectively contribute to higher expenditures and decreased profitability associated with environmentally conscious initiatives. Based on the findings of Katircioğlu and Katircioğlu [68], it has been proposed that government-sponsored bonds have the potential to serve as an effective mechanism for mitigating risks. By implementing a comprehensive guarantee mechanism, the government can effectively mitigate the financial risks associated with green investments, which, in turn, reduces the potential return and capital expenditures involved in such endeavors. Furthermore, this phenomenon effectively facilitates the involvement of smaller enterprises in the transition towards environmentally sustainable technologies, thereby promoting a more comprehensive economic transformation. This presents a significant juxtaposition to a hypothetical situation in which only prominent corporations, unhindered by financial constraints, can participate in this transformative process.

Furthermore, it is worth noting that bonds are highly suitable for financing expansive infrastructure projects that are essential for the successful implementation of green technology. The suitability of bonds arises from their possession for extended durations, which aligns with the long-term nature of projects of this kind. Green bonds, in particular, exhibit a reduced level of risk due to their increased disclosure requirements when compared to conventional bonds. The characteristic, as mentioned above, serves not only to ensure favorable financial outcomes for investors but also fosters a deep commitment to societal well-being. The present investigation, conducted by Shen et al. [69], explores the complex domain of green central banking. In this realm, central banks assume a crucial role in promoting the advancement of green financing frameworks and implementing mechanisms to integrate environmental and carbon risk pricing.

In light of the available evidence, it can be inferred that the adoption of a green investment approach holds promise as a viable strategy for mitigating costs and enhancing environmental outcomes. This is primarily achieved through the amplification of environmentally sustainable technologies and practices. The promotion of RE sources and the implementation of energy-efficient infrastructure yield several advantageous outcomes, including but not limited to the reduction of reliance on fossil fuels, the mitigation of climate change, the alleviation of environmental pollution, and the minimization of ecological impact. Publicly funded green investment banks with a commercial focus have the potential to serve as effective instruments for governments to mobilize private capital towards climate-friendly and sustainable initiatives, thereby facilitating the transition towards a greener economy.

H3: *Green Finance fosters environmental sustainability*.

2.4. Environmental Tax and Ecological Environment

In recent years, there has been a growing emphasis on examining and comprehending the complex relationship between environmental taxation and the ecological environment [70–72]. The environmental tax, also known as the green tax or eco-tax, is a policy instrument designed to internalize the external costs associated with environmental deterioration while advancing the overarching goal of sustainable development. The existing corpus of literature emphasizes the critical importance of environmental taxation as a highly effective policy instrument for addressing the complex and diverse problems posed by environmental degradation. Numerous empirical studies have repeatedly demonstrated that environmental taxes have a strong propensity to encourage both corporations and individuals to adopt cleaner technologies, reduce pollution, and promote sustainable practices [43,47,73]. In a comprehensive examination of the relationship between ET and CO_2 emissions in Turkey, Sarıgül and Topçu [74], and Shahbaz et al. [75] conducted an analysis using annual data spanning from 1994 to 2015, employing both fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) techniques, consistently demonstrating that ETs exerted a notable mitigating effect on CO_2 emissions. In contrast, Akkaya and Hepsag [76] adopted a distinctive approach, employing nonlinear time series analysis to investigate the subject and the discernible relationship between fuel taxes and CO_2 emissions in Turkey. This divergence underscores the intricacies of the relationship, warranting further exploration and consideration of nonlinear dynamics.

Extending the investigation beyond Turkey, [76–78] delved into the effects of ETs on CO_2 emissions in Brazil, China, India, and South Africa by employing a nonlinear smooth transition regression estimation of their study, unveiling a nuanced relationship. In regions characterized by lower levels of globalization, a positive relationship between ET and CO_2 emissions emerged. In contrast, regions with higher levels of globalization exhibited a negative relationship between these variables. This finding underscores the role of globalization in shaping the impact of ETs on CO_2 emissions on a global scale. The study of [79] utilized a panel-augmented mean group estimation approach to examine the effects of environmental and energy taxes on CO_2 emissions across nine countries. Their findings revealed disparities between linear and nonlinear models. In the linear model estimations, environmental and energy taxes appeared to have no discernible effect on CO_2 emissions. However, the nonlinear model estimations provided a contrasting perspective, indicating that both types of taxes were indeed effective in reducing CO_2 emissions. This dual perspective highlights the importance of considering nonlinear dynamics when assessing the impact of taxation policies on environmental outcomes.

H4: *There is a positive relationship between environmental taxes and ecological stability*.

2.5. Clean Energy Consumption and Ecological Environment

The relationship between clean energy consumption (CEC) and ecological footprint is multifaceted, as they are intricately linked in terms of their implications for the sustainability of human activities and their environmental consequences. The utilization of clean energy sources, including wind, solar, hydro, and nuclear power, has been observed to yield significantly lower quantities of greenhouse gas emissions in comparison to conventional fossil fuels such as coal, oil, and natural gas [40]. The augmentation of CE has the potential to yield substantial reductions in carbon emissions, thereby mitigating the adverse effects of global warming and climate change. Clean energy plays a crucial role in mitigating the ecological footprint linked to climate change, which encompasses various adverse effects such as escalating temperatures, rising sea levels, and the occurrence of extreme weather events. This is achieved through the reduction of carbon emissions, which is a pivotal aspect of clean energy's contribution to addressing these pressing environmental concerns.

Clean energy technologies frequently exhibit a reduced reliance on natural resources compared to their fossil fuel counterparts. Solar panels and wind turbines demonstrate a commendable utilization of resources subsequent to their production and installation. The implementation of strategies aimed at minimizing resource consumption plays a crucial role in mitigating the adverse ecological impacts stemming from resource extraction and depletion. These impacts have the potential to inflict harm upon ecosystems and biodiversity [8,49,59,80]. One of the significant benefits of transitioning to RE sources is the reduction in air and water pollution. The combustion of fossil fuels emits harmful pollutants that have detrimental effects on the environment and pose health risks to both humans and wildlife. By shifting towards renewable energy, we can mitigate these negative impacts and promote a cleaner and healthier ecosystem [81]. Clean energy sources, such as RE technologies, have been found to exhibit minimal to negligible levels of air and water pollution, thereby making significant contributions towards mitigating the ecological impact typically associated with these pollutants [55,82].

It is generally observed that clean energy sources tend to possess a smaller physical footprint in comparison to fossil fuel infrastructure. For example, the installation of a solar farm or wind turbine occupies a smaller land area compared to that required for a coal mine or oil refinery. The implementation of reduced land use practices has the potential to effectively safeguard ecosystems and natural habitats, thereby mitigating the adverse ecological consequences linked to habitat destruction and fragmentation [4,30,36]. Additionally, clean energy technologies frequently facilitate the adoption of energy efficiency measures. Electric vehicles and LED lighting exhibit superior energy efficiency compared to their conventional counterparts. Enhanced energy efficiency yields a notable reduction in aggregate energy consumption, thereby leading to a proportional decrease in the ecological footprint linked to energy generation and dissemination.

Transitioning to sustainable lifestyles is a crucial step towards addressing the pressing issue of climate change. One effective approach to facilitating this transition is the widespread adoption of clean energy sources. By embracing clean energy technologies, individuals and communities can contribute to a broader shift towards sustainable consumption patterns and lifestyles [35,39,81,83]. This shift entails a conscious effort to reduce reliance on fossil fuels and embrace RE sources such as solar, wind, and hydroelectric power. By doing so, we can mitigate the environmental impacts associated with traditional energy sources and pave the way for a more sustainable future. This strategic transition has the potential to significantly mitigate the collective ecological footprint through the promotion of conscientious resource utilization and the implementation of waste reduction measures.

H5: *There is a positive tie between clean energy consumption and ecological stability.*

2.6. Theoretical Development

ICT holds the potential to play a pivotal role in fostering ecological development. ICT's contributions to this endeavor are diverse and encompass several key facets, including the reduction of carbon dioxide emissions, the facilitation of environmental progress, the promotion of sustainable agriculture, the enhancement of energy efficiency, and the cultivation of environmentally friendly practices. These attributes establish ICT as a multifaceted driver of ecological advancement. Similarly, green innovation emerges as a critical agent in the quest for ecological sustainability. Its capacity lies in the creation of sustainable technologies and practices that serve to curtail the ecological footprint [84]. Likewise, GF assumes significance as a catalyst for sustainable investment, potentially leading to a substantial reduction in the ecological footprint [82]. Furthermore, environmental tax policies have the potential to incentivize both individuals and businesses to proactively reduce their environmental impact, thus fostering a marked reduction in the ecological footprint [47,85]. Clean energy consumption, too, emerges as a linchpin in the quest for ecological sustainability. Its pivotal role resides in the mitigation of greenhouse gas emissions, the diminishment of reliance on fossil fuels, the conservation of precious natural resources, the preservation of delicate ecosystems, and the stimulation of a positive feedback loop conducive to the development of RE sources. In essence, the theoretical underpinning of this study weaves a complex and multifaceted tapestry of interactions among these factors and their collective impact on ecological degradation. Notably, the literature reveals intriguing insights. Environmental tax policies are found to exert a negative influence on both the ecological footprint and carbon dioxide emissions, indicating their potential to contribute significantly to ecological sustainability [43]. Meanwhile, green innovation emerges as a powerful driver, significantly reducing the ecological footprint and bolstering ecological sustainability. Similarly, GF demonstrates its prowess in enhancing environmental quality [51]. CEC is pivotal, contributing to ecological sustainability by curbing carbon emissions and elevating environmental quality. To summarize, the theoretical edifice of this study posits that ICT, green innovation, green finance, environmental tax, and CEC hold the potential to wield significant influence in mitigating ecological degradation and advancing ecological sustainability. Yet, these effects are far from linear, underscored by their complex and multifaceted nature. The need for further empirical research to unravel this intricate relationship remains a compelling imperative.

3. Methodology of the Study

3.1. Model Specification and Justification of the Study

The motivation of the study is to assess the effects of ICT, GTI, GF, ET, and CEC in restoring ecological sustainability for the period 2001–2019. The study considered a panel of 30 nations based on the ICT development index. The generalized relations are displayed in Equation (1):

$$\mathrm{EF}_{\mathrm{it}} \int \mathrm{ICT},\ \mathrm{GI},\ \mathrm{GF},\ \mathrm{ET},\ \mathrm{CE} \tag{1}$$

Further elucidation regarding the potential impacts of independent variables on the ecological footprint can be expounded upon as follows:

$$\mathrm{EFit} = \beta 0 + \beta_1 \cdot \mathrm{ICT}_{\mathrm{it}} + \beta_2 \cdot \mathrm{GTI}_{\mathrm{it}} + \beta_{\mathrm{it}} 3 \cdot \mathrm{GF}_{\mathrm{it}} + \beta_4 \cdot \mathrm{ET}_{\mathrm{it}} + \beta_5 \cdot \mathrm{CEC}_{\mathrm{it}} + \varepsilon \mathrm{it} \tag{2}$$

The literature has portrayed that the utilization of ICT has been found to have a profound impact on mitigating the ecological footprint, which is achieved through facilitating remote work, minimizing the need for travel, and enhancing energy efficiency. One notable example pertains to the potential of remote work to mitigate the necessity of commuting, thereby resulting in a consequential decrease in greenhouse gas emissions. Furthermore, the utilization of ICT has the potential to facilitate the adoption of energy-efficient strategies, such as the implementation of virtual meetings and cloud computing. These practices can effectively curtail energy consumption and mitigate the corresponding emissions. Thus, it is anticipated that there is a negative linkage between ICT and ecological footprint. Green finance, also known as GF, plays a crucial role in promoting investment in sustainable projects and practices, thereby facilitating a significant decrease in the ecological footprint [3]. GF encompasses a diverse range of financial instruments, including green bonds and sustainable investment funds, which serve as crucial mechanisms for channeling funds toward initiatives that foster sustainable development and mitigate environmental degradation. The adoption of environmental taxes has the potential to serve as a powerful tool in motivating both individuals and businesses to actively mitigate their environmental impact, thereby resulting in a noteworthy decrease in their overall ecological footprint [4]. An illustrative instance involves the implementation of a carbon emissions tax, which catalyzes individuals and enterprises to curtail their greenhouse gas emissions. This is achieved through the incentivization of energy-efficient methodologies and the adoption of

RE sources. Clean energy consumption (CEC) has been identified as a crucial strategy for mitigating the ecological footprint and addressing environmental concerns, particularly in relation to greenhouse gas emissions and other detrimental environmental impacts. RE sources, including solar, wind, and hydropower, offer a viable and sustainable solution to the prevailing reliance on fossil fuels. By substituting conventional energy sources with these clean alternatives, the adverse environmental consequences associated with energy generation and consumption can be mitigated. In summary, the potential impacts of independent variables on the ecological footprint exhibit a nuanced and intricate nature. The existing body of literature indicates that the variables above have the potential to significantly contribute to the advancement of sustainable development and the mitigation of environmental impact. By implementing energy-efficient practices, fostering sustainable investment and finance, and providing incentives for individuals and businesses to mitigate their environmental footprint, these factors can significantly contribute to the realization of a more sustainable future. The proxy measures of research variables and data sources displayed in Table 1.

Table 1. Variables measures and data sources with the anticipated sign of coefficients.

Variables	Notation	Measures	Data Sources	Expected to Sign
Ecological footprint	EF	Ecological footprint (gha per person)	Global footprint network	
Information and communication technology	ICT	Total ICT investment, % share of GDP	Our data world	-
Green technological innovation	GTI	Annual patents filed for renewable energy technologies,	Our data world	-
Green finance	GF	Investment in RE energy development	OECD	-
Environmental tax	ET	Environmental tax revenue as a % of total revenue	Our data world	-
Clean energy consumption	CEC	renewable energy consumption measured in terawatt-hours (TWh) per year	Our data world	-

3.2. Estimation Strategies

Slope of Heterogeneity

Based on the following equation, we can construct LM test statistics as follows:

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \quad \mathrm{i = 1 \ldots\ldots N, t = 1 \ldots\ldots T} \tag{3}$$

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{IJ\underset{d}{\rightarrow}X^2N(N+1)2} \tag{4}$$

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(T\hat{\rho}_{ij} - 1\right) \tag{5}$$

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\hat{\rho}_{ij}\right) \tag{6}$$

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\frac{(T-K)\hat{\rho}_{ij}^2 - u_{Tij}}{v_{Tij}^2}\right)\vec{d}\,(N,0) \tag{7}$$

where k refers to the number of regresses and u_{Tij} and v_{Tij}^2 specify the mean and variance of $(T-K)\hat{\rho}_{ij}^2$, respectively.

The utilization of second-generation panel unit root tests, specifically CIPS (ross-sectionally augmented IPS) and CADF (cross-sectionally augmented Dickey–Fuller), is extensively prevalent in the analysis of the presence of a unit root in panel data. The present study has followed a similar line of assessment. The CIPS test effectively tackles the concern of cross-sectional dependency in panel data by augmenting the IPS test with additional lagged levels of the dependent variable. This methodology aids in effectively addressing the potential existence of correlation among the different units within the panel. In contrast, the CADF test improves upon the Dickey–Fuller test by incorporating cross-sectional averages of lagged values of the dependent variable. The present methodology facilitates the identification of unit roots in panel data while duly considering the presence of cross-sectional dependency.

The following equation is to be estimated in assessing the stationary properties of the research variables:

$$\Delta Y_{it} = \beta_i + \gamma_i y_{i,t-1} + \pi_i \overline{y}_{t-1} + \beta_i \overline{y}_t + \rho_{it} \tag{8}$$

$$\Delta Y_{it} = \mu_i + \gamma_i y_{i,t-1} + \pi_i \overline{y}_{t-1} + \sum_{k=1}^{p} \beta_{ik} \Delta y_{i,k-1} + \sum_{k=0}^{p} \beta_{ik} \overline{\Delta y}_{i,k-0} + \alpha_{it} \tag{9}$$

$$CIPS = N^{-1} \sum_{i-1}^{N} \partial_i(N,T) \tag{10}$$

$$CIPS = N^{-1} \sum_{i-1}^{N} CADF \tag{11}$$

For the cointegration test, the study considered the panel cointegration test, which incorporates error correction and is widely employed in econometric research, particularly in studies involving panel data [86]. Its primary objective is to investigate the existence of cointegration and the persistent equilibrium relationships among variables. Following the error correction-based panel cointegration test, the test statistics for group statistics, i.e., G_T and G_α and panel statistics, i.e., P_T and P_α, which can be extracted by executing the following equation:

$$G_T = \frac{1}{N} \sum_{i-1}^{N} \frac{\zeta_i}{SE\zeta_i}\,; G_a = \frac{1}{N} \sum_{i-1}^{N} \frac{T\zeta_i}{\zeta_i(1)} \tag{12}$$

$$P_T = \frac{\zeta_i}{SE\zeta_i}\ ;\ P_a = T\zeta_i \tag{13}$$

The present study has executed the advanced and novel panel data estimation techniques familiarized by Bai and Kao [87], which are commonly known as CUP-FM and CUP-BC. The panel estimation methodologies referred to as “continuously updated fully modified” (CUP-FM) and “continuously updated bias-corrected” (CUP-BC) are advanced approaches employed in the estimation of panel data models. The methodologies above can be perceived as advancements of the conventional fully modified ordinary least squares (FM-OLS) and bias-corrected least squares (BC-OLS) estimators, correspondingly. The CUP-FM estimator has been specifically developed to address the issue of endogeneity in panel data models by incorporating instrumental variables (IVs) that are consistently updated into the estimation procedure. The present study employs a methodology that incorporates the utilization of lagged values of the endogenous variables as instruments. The instruments utilized in this study are subject to regular updates in order to ensure their efficacy in capturing the ever-changing dynamics inherent in panel data. The utilization of this particular methodology serves to significantly augment the effectiveness and consistency of the computed coefficients. On the contrary, the CUP-BC estimator has been specifically developed to effectively tackle the concern of potential bias in panel data models that may arise due to endogeneity and measurement errors. The proposed methodology incorporates a bias-correction term to adjust the estimated coefficients, thereby mitigating the bias introduced by the inclusion of endogenous variables. This modification enhances the ability to obtain estimations that are characterized by increased precision and reliability.

Furthermore, the empirical estimation has been extended with the implementation of dynamic SUR, which was introduced by and is well appreciated in empirical investigation. The Dynamic Seemingly Unrelated Regression (DSUR) model is a highly influential econometric framework that extends the conventional Seemingly Unrelated Regressions (SUR) approach by incorporating dynamic elements into the estimation procedure. The utilization of this particular methodology proves to be particularly advantageous when examining panel data that demonstrate intertemporal dependencies and time-varying coefficients. The incorporation of dynamic interactions between variables in the Seemingly Unrestricted Regression (SUR) method enables the capture of the evolving nature of the data, leading to estimations that exhibit enhanced precision and reliability in comparison to static models. The general equation for a dynamic SUR model can be written as follows: For cross-sectional unit i and period t, the dynamic SUR model for equation j can be expressed as follows:

$$y_{\{ijt\}} = \alpha_{\{j\}} + \sum_{p-1}^{k} \beta_{jk} \mathrm{y}_{\mathrm{ijt}} - \mathrm{k} + \sum_{m-1}^{p} \gamma_{jm} \mathrm{x}_{\mathrm{ijt}} + \varepsilon_{\{ijt\}} \tag{14}$$

The Dynamic Seemingly Unrelated Regression (DSUR) model is a statistical framework that integrates historical values of both the dependent and independent variables. This enables the examination of dynamic effects and the portrayal of the persistent influence of disturbances over a specific period. The dynamic spatial autoregressive (SUR) model possesses a distinct advantage, rendering it a more desirable alternative in contrast to static models, owing to its heightened capacity to capture the intricate dynamics and interdependencies inherent in panel data. The detailed flow of statistical execution is displayed in Figure 1.

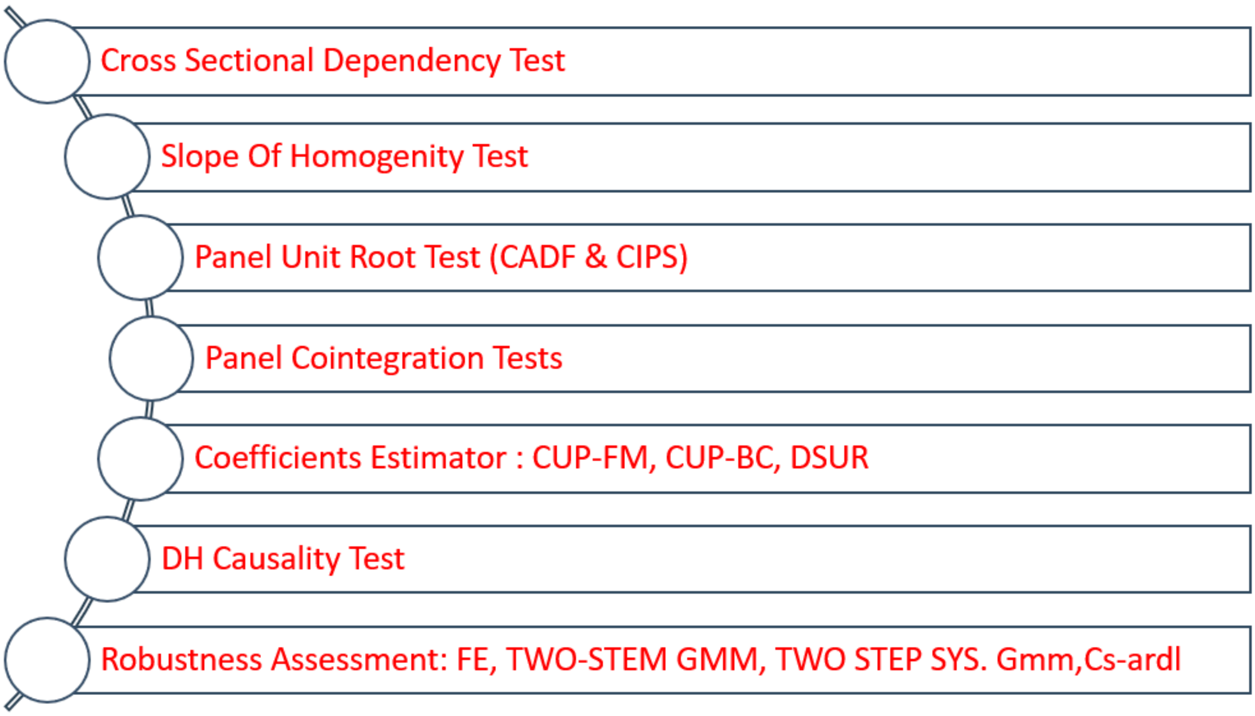

Figure 1. Flows of econometric estimation strategies.

4. Estimation and Interpretation

4.1. Slope of Heterogeneity, Cross-Sectional Dependency, and Panel Unit Root Test

In our empirical analysis, we conducted a systematic examination of the slope of heterogeneity, cross-sectional dependency, and panel unit root tests within our dataset, and their results are displayed in Table 2, including Panel A, which exhibits the test statistics for SHT and CSD, and Panel B for PURT. Significantly, the results consistently demonstrated rejection of the null hypothesis in all estimations. The rejection highlights the existence of considerable heterogeneity among the cross-sectional units, suggesting that the individual entities within our panel display varied characteristics and behaviors. Additionally, the cross-sectional dependency tests have verified the presence of interdependencies and interactions among these units, suggesting that the observations are not independent and that spatial or temporal correlations are present. Finally, the panel unit root tests have resulted in the rejection of the null hypothesis. This indicates that the time series properties of the data demonstrate non-stationary behavior. The consistent rejections observed across the three dimensions emphasize the intricacies and complexities present in our dataset. This underscores the importance of employing rigorous analytical methods that consider both heterogeneity and cross-sectional dependencies in future investigations.

Table 2. Results of SHT and CSD.

	LM_{BP}		LM_{PS}	LM_{adj}	CD_{PS}	Δ	Adj.Δ	
Panel A: CSD and SHT								
POV	430.24 ***		17.439 ***	145.665 ***	40.479 ***	88.897 ***	89.497 ***	
FII	159.469 ***		26.558 ***	226.907 ***	27.953 ***	91.937 ***	81.615 ***	
REC	323.708 ***		20.773 ***	140.76 ***	9.642 ***	32.618 ***	137.925 ***	
EQ	284.924 ***		35.984 ***	250.971 ***	20.997 ***	47.603 ***	63.835 ***	
FDI	434.82 ***		28.35 ***	114.508 ***	50.817 ***	64.198 ***	102.884 ***	
PREM	450.844 ***		30.96 ***	224.582 ***	14.012 ***	22.751 ***	69.35 ***	
FD	192.773 ***		43.781 ***	224.519 ***	15.646 ***	21.388 ***	85.425 ***	
GS	159.412 ***		39.685 ***	240.308 ***	33.754 ***	24.298 ***	86.244 ***	
Panel B: Panel Unit Root Test								
Variables	**CADF test statistic for constant**		**CIPS test statistic for constant**		**CADF test statistic for constant & and trend**		**CIPS test statistic for constant & and trend**	
	Level	**1st diff.**	**Level**	**1st diff.**	**Level**	**1st diff.**	**Level**	**1st diff.**
EF	−2.418	−2.285 ***	−2.757	−3.751 ***	−1.086	−3.249 ***	−1.558	−6.291 ***
FD	−1.384	−4.796 ***	−1.714	−3.46 ***	−2.939	−5.058 ***	−2.738	−5.59 ***
EG	−1.794	−4.29 ***	−2.962	−6.201 ***	−2.741	−6.234 ***	−2.812	−4.465 ***
NRE	−1.15	−4.039 ***	−1.557	−4.373 ***	−2.433	−3.728 ***	−2.188	−5.468 ***
TO	−1.949	−5.72 ***	−2.019	−2.163 ***	−2.196	−4.705 ***	−1.975	−5.288 ***
	−2.622	−4.754 ***	−1.813	−7.614 ***	−1.201	−5.411 ***	−1.877	−4.095 ***
	−1.17	−2.013 ***	−2.061	−2.079 ***	−2.466	−6.229 ***	−1.561	−6.169 ***

Note: the superscripts of *** denote the level of significant at a 1% level.

The present study has implanted panel cointegration tests following [86,88,89], respectively, and their test statistics for testing the null hypothesis “no-cointegration” are displayed in Table 3. Referring to the test statistics, it is apparent that all the test statistics derived in difference PCT are statistically significant at a 1% level, suggesting a long-run association established in the empirical relations.

Table 3. Results of the panel cointegration test.

Model	ICT--->EF	GTI--->EF	GF--->EF	ET--->EF	CEC--->EF
Gt	−11.292 ***	−10.554 ***	−7.282 ***	−14.438 ***	−7.729 ***
Ga	−13.611 ***	−5.299 ***	−13.04 ***	−14.604 ***	−11.31 ***
Pt	−12.506 ***	−14.874 ***	−15.509 ***	−13.1 ***	−14.847 ***
Pa	−11.618 ***	−8.663 ***	−12.828 ***	−14.088 ***	−5.105 ***
KRCPT					
MDF	13.607 ***	2.606 ***	10.444 ***	3.34 ***	20.728 ***
DF	13.027 ***	−2.46 ***	−7.331 ***	22.375 ***	22.413 ***
ADF	−2.873 ***	8.714 ***	20.925 ***	−5.925 ***	20.018 ***
UMDF	7.411 ***	4.907 ***	14.141 ***	9.001 ***	−1.723 ***
UDF	17.922 ***	5.027 ***	13.299 ***	12.721 ***	−2.617 ***
PCT					
MDF	−0.715 ***	12.443 ***	3.026 ***	−6.702 ***	−2.335 ***
PP	−2.174 ***	14.231 ***	3.145 ***	4.375 ***	−4.159 ***
ADF	8.686 ***	8.362 ***	14.786 ***	8.885 ***	8.548 ***

Note: the superscripts of *** denote the level of significant at a 1% level.

The results of the target empirical equation with CUP-FM, CUP-BC, and DSUR are displayed in Table 4. For ICT effects on EF, according to the coefficients derived with CUP-FM (a coefficient of −0.1423), CUP-BC (a coefficient of −0.1369), and DSUR (a coefficient of −0.1138), they exhibited a negative and statistically significant linkage with EP, suggesting future development in ICT can produce beneficial effects on the ecological correction that is environmentally sustainable. In terms of the existing literature, our findings are supported by Saleem et al. [90]. Study findings advocate that ICT can receive considerable attention as a powerful tool for reducing global carbon dioxide emissions. This achievement is accomplished by developing and implementing intelligent solutions in diverse domains, including urban infrastructure, transportation networks, industrial operations, and electrical grids [1,2]. The implementation of this measure has the potential to effectively address the issue of climate change by mitigating its impacts and simultaneously reducing the ecological footprint associated with the emission of greenhouse gases. ICT has emerged as a significant catalyst in driving environmental progress and addressing the pressing concern of environmental pollution (1). The potential role of implementing ICT innovation in mitigating environmental pollution is significant.

Table 4. Coefficients of IV derived from CUP-FM, CUP-BC, and DSUR.

	Coeff.	Std. Error	t-Stat	Coeff.	Std. Error	t-Stat	Coeff.	Std. Error	t-Stat
		CUP-FM			CUP-BC			DSUR	
ICT	−0.1423	0.0465	−3.061	−0.1369	0.0295	−4.6132	−0.1138	0.0284	−4.0073
GI	−0.1492	0.0211	−7.0744	−0.1657	0.045	−3.684	−0.1268	0.0228	−5.5640
GF	−0.1618	0.0412	−3.9286	−0.0854	0.0443	−1.9288	−0.16618	0.0394	−4.2177
CEC	−0.1602	0.0302	−5.3076	−0.1247	0.0446	−2.7979	−0.12321	0.0153	−8.0529
ET	−0.097	0.0414	−2.3623	−0.1101	0.0349	−3.1572	−0.15867	0.0268	−5.9205
C	10.531	0.24013	43.8554	13.171	0.24013	54.8494	17.351	0.24013	72.2566

Green technological innovation revealed a catalyst role in improving ecological upgradation, that is, acceleration of GTI in the economy, fostering ecological correction through energy-efficient technological upgradation. In particular, a 10% innovation in GIT could result in ecological improvement, in accordance with the coefficients derided from CUP-FM, CUP-BC, and DSUR, by 1.492%, 1.657%, and 1.268%, respectively. The study findings are in line with the literature offered. Our study acknowledges the findings offered by the study of [4,36,79,81,91]. Study findings postulate that in an era characterized by increasing environmental concerns and the need for sustainable practices, green technological innovations are emerging at the forefront of change. These innovations encompass a diverse range of advancements, spanning from energy-efficient appliances and RE technologies to environmentally friendly materials and waste reduction solutions. Green technological innovations are inherently designed to explicitly focus on minimizing resource consumption, reducing emissions, and enhancing overall environmental efficiency. By implementing these technologies, industries are able to optimize production processes, preserve valuable resources, and mitigate detrimental emissions.

The coefficient of GF has been found to be negatively associated with EF in CUP-FM (a coefficient of 0.1618), CUP-BC (a coefficient of −0.0854), and DSUR (a coefficient of −0.1661), advocating the expansion of GF's positive contribution in ensuring environmental sustainability through ecological enhancement. Our findings are supported by the literature of Gong, Ying, and Dai [49]; Zhan, Wang, and Zhong [54]; Sun, Bao, and Taghizadeh-Hesary [55]; Alharbi, Al Mamun, Boubaker, and Rizvi [64]; and Zhang et al. [92]. GF plays a crucial role in enhancing the ecological footprint through its promotion of sustainable development and reduction of environmental impact. GF encompasses financial instruments that are designed to support environmental and social goals. These instruments can include the acquisition of environmentally friendly products and services as well as the establishment of green infrastructure [23]. The literature suggests that GF has the potential to contribute to ecological sustainability through various means, including the reduction of carbon emissions, the enhancement of environmental quality, and the decrease in ecological footprint. GF has the potential to foster accountability and transparency by incentivizing businesses to actively monitor and disclose their environmental performance. Policymakers can advance the cause of GF through the implementation of adjustments to regulatory frameworks, the establishment of harmonized public financial incentives, and the augmentation of green financing from diverse sectors. Businesses and policymakers have the opportunity to promote sustainable development and minimize their ecological impact by fully harnessing the potential of green finance.

The coefficients of environmental tax on ecological footprint have revealed negative and statistically significant values at a 1% level, conveying a positive intent of ET in the economy to foster the overall ecological correction. In particular, a 10% positive variation in ET might augment the ecological sustainability in accordance with CUP-FM by 0.97%, CUP-BS by 1.101%, and DSUR by 1.586%, respectively. The possible ways of mitigating ecological degradation through the imposition of the ET are in the form of financial incentives for the inclusion of eco-friendly energy and operation processes. Our study is in line with Sarıgül and Topçu [74], Shahbaz, Topcu, Sarıgül, and Vo [75]. Our research findings provide strong evidence that supports the effectiveness of environmental taxation as a method for promoting ecological remediation. The findings of this study offer valuable insights for policymakers and businesses, empowering them to strategically implement environmental tax policies and embrace sustainable practices. By engaging in this practice, individuals can actively contribute to the realization of a more environmentally sustainable future.

The inclusion and consumption of clean energy revealed a positive connection with environmental sustainability, namely that CEC reduced ecological instability. More precisely, 10% additional consumption of CE will result in the upgradation of ecological correction in the range of 0.1602% to 1.262%. The findings of a negative association between CEC and EF are supported by the study of [80,93]. The consumption of clean energy is of paramount importance in the context of enhancing the ecological footprint, as it effectively mitigates carbon emissions and fosters the advancement of sustainable development. According to the existing literature, there is evidence to suggest that the utilization of RE sources has the potential to stimulate economic growth and concurrently enhance environmental conditions [81,83]. The utilization of RE sources has been observed to have a substantial impact on the reduction of the ecological footprint across various regions. The empirical evidence further substantiates the positive impacts of RE on the preservation of ecological resources. The utilization of non-RE sources is associated with a consequential rise in the extraction of finite resources such as coal and oil, thereby exacerbating ecological degradation. Hence, the utilization of RE sources has the potential to effectively mitigate the ecological footprint while concurrently fostering sustainable development. The utilization of CEC holds significant promise for policymakers and businesses alike in their pursuit of advancing ecological sustainability, which can be achieved through strategic investments in RE sources and the active promotion of sustainable energy practices.

Table 5 displays the results of robustness estimation through the execution of AMG, system GMM, two-step system GMM, and CSARDL, referring to the sign of explanatory variables; it confirms the similar line of association between explanatory variables and ecological footprint.

Table 5. Results of the robustness estimation.

	AMG	**STEM GMM**	**TWO STEP SYS. GMM**	**CS-ARDL**
DIV(−1)		0.0362	0.0822	
ICT	−0.1571	−0.1604	−0.2036	−0.2512
GI	−0.2666	−0.1628	−0.2654	−0.1009
GF	−0.2846	−0.1184	−0.1001	−0.2577
CEC	−0.1232	−0.1014	−0.1976	−0.0554
ET	0.0722	0.0822	−0.1817	−0.0302
Constant	−6.364	−4.0685	−2.0845	−2.496
AR(1)			0.0002	
AR(2)			0.9342	
Hansen J-test			0.273	
Difference in the Hansen test			0.2484	

Table 6. Results of the DH-causality test.

	EF	**ICT**	**GTI**	**GF**	**ET**	**CEC**
EF		(2.0106) *	(4.7778) ***	(5.0106) ***	(5.459) ***	(4.1965) **
		[2.1192]	[5.0359]	[5.2812]	[5.7538]	[4.4232]
ICT	0.9564		(5.9319) ***	(3.4144) **	(6.2337) ***	1.1062
	[1.008]		[6.2523]	[3.5988]	[6.5704]	[1.166]
GTI	(5.2369) ***	(4.8427) ***		1.1934	(2.7247) *	0.8204
	[5.5197]	[5.1042]		[1.2578]	[2.8718]	[0.8647]
GF	1.5313	(5.5897) ***	(4.2082) **		1.3018	(5.3219) ***
	[1.614]	[5.8916]	[4.4355]		[1.3721]	[5.6093]
ET	1.8692	(2.7375) *	(3.6918) **	1.4899		(6.1137) ***
	[1.9702]	[2.8853]	[3.8911]	[1.5703]		[6.4438]
CEC	(3.95) **	(4.9989) ***	(3.95) **	(4.4218) **	1.1253	
	[4.1633]	[5.2688]	[4.1633]	[4.6606]	[1.1861]	

Note: the superscripts of ***, **, and * explained the significance level at a 1%, 5%, and 10%, respectively.

The directional causality between explained and expletory variables has been assessed by executing the non-granger causality framework introduced by Dumitrescu and Hurlin [94]. Table 6 displays the results of the D-H causality test. In terms of the causality assessment, a study discovered that the feedback hypothesis holds between green technological innovation and ecological footprint [GIT $\longleftrightarrow$ EF] and clean energy consumption and ecological footprint [CEC $\longleftrightarrow$ EF]. Additionally, the study has unveiled unidirectional causal effects running from [ICT $\rightarrow$ EF, GF $\rightarrow$ EF, and ET $\rightarrow$ EF], respectively.

4.2. Country-Wise Assessment

In the following section, the study extended the empirical estimation for documenting the effects of target explanatory variables on ecological footprints by implementing dynamic OLS, with results displayed in Table 7. The study examines the ecological footprint (FF) as the dependent variable while considering several independent variables: information and communication technology (ICT), green technological innovation (GTI), GF (GF), environmental tax (ET), and clean energy consumption (CEC). These variables are assessed for various countries, and their impact on the ecological footprint is analyzed. Here is a summarized overview of the findings: Switzerland, Denmark, and the United Kingdom all exhibit positive relationships between the ecological footprint and information and communication technology (ICT), green technological innovation (GTI), green finance (GF), and environmental fax (ET), suggesting that an increase in these variables is associated with a higher ecological footprint. Several countries, such as Iceland, Luxembourg, Germany, and Singapore, show mixed effects. For instance, while they have positive associations with some of the independent variables (e.g., ICT, GTI), they have negative associations with others (e.g., green finance, environmental tax), which implies that a combination of factors influences their ecological footprint. Some countries, including South Korea, Norway, Sweden, New Zealand, France, Israel, Spain, and Cyprus, exhibit negative relationships between the ecological footprint and certain independent variables like green finance (GF) and environmental tax (ET), which suggests that these countries tend to have a lower ecological footprint when these variables increase. Other countries, such as Monaco, Belgium, and Andorra, demonstrate inconsistent relationships between the ecological footprint and the independent variables. They may have positive associations with one variable and negative associations with another. Canada stands out with strong positive relationships with most of the independent variables (ICT, GTI, GF, ET, and CEC), indicating that these factors are associated with a significantly higher ecological footprint in the country. Countries like Estonia, Macau, and Malta exhibit various relationships with the independent variables, making it challenging to discern clear patterns in their ecological footprint based solely on these factors. In summary, the study finds that the impact of information and communication technology (ICT), green technological innovation (GTI), green finance (GF), environmental tax (ET), and clean energy consumption (CEC) on the ecological footprint varies across different countries. Some countries experience positive impacts, some negative, and others show mixed or inconsistent effects. These findings emphasize the importance of considering multiple factors and country-specific contexts when analyzing the ecological footprint and its determinants.

Table 7. Results of a country-wise investigation.

	ICT	GTI	GF	ET	CEC
Iceland	0.019	0.036	0.027	0.04	0.262
South Korea	0.085	−0.14	0.008	−0.168	0.2
Switzerland	0.241	0.107	0.163	0.245	0.025
Denmark	0.203	−0.133	0.24	0.191	0.105
United Kingdom	0.18	0.15	−0.035	0.227	0.245

Table 7. *Cont.*

	ICT	GTI	GF	ET	CEC
Hong Kong	−0.059	0.103	−0.083	−0.124	0.26
Netherlands	0.131	0.201	0.033	0.216	−0.003
Norway	−0.029	−0.075	0.212	−0.105	0.074
Luxembourg	0.106	−0.17	0.011	0.07	0.147
Japan	0.182	−0.155	0.144	0.032	0.128
Sweden	−0.061	0.016	0.112	−0.058	0.037
Germany	0.205	0.208	0.112	0.154	0.019
New Zealand	−0.044	0.119	−0.05	−0.145	0.15
Australia	0.034	0.126	0.242	−0.13	0.098
France	0.092	0.239	−0.083	0.119	−0.037
United States	0.021	0.015	−0.113	0.183	0.017
Estonia	0.238	0.001	−0.064	−0.079	0.099
Singapore	0.24	0.072	0.051	0.123	0.127
Monaco	0.165	−0.154	−0.051	0.21	0.246
Ireland	0.224	0.201	0.223	0.13	0.192
Austria	0.195	0.091	0.016	0.005	0.048
Finland	0.067	0.124	0.103	0.068	0.105
Israel	0.105	0.155	−0.044	0.229	−0.07
Malta	0.184	0.21	−0.018	0.118	0.049
Belgium	−0.058	−0.146	0.175	−0.157	0.032
Macau	0.254	0.167	0.093	0.023	0.12
Spain	−0.022	0.079	0.076	−0.042	−0.044
Cyprus	0.005	−0.101	−0.014	0.053	0.149
Canada	0.272	0.194	0.246	0.206	0.27
Andorra	−0.011	−0.13	0.004	−0.092	0.257

5. Discussion

For ICT effects on EF, the findings indicate a noteworthy and statistically significant negative correlation between ICT and ecological footprint (EF). This conclusion is supported by the coefficients obtained through various estimation methods, specifically CUP-FM, CUP-BC, and DSUR, suggesting a 1% change in ICT will result in EF correction by −0.1423%, −0.1369%, and −0.1138%, respectively. The presence of an inverse correlation implies that progress in ICT has the potential to yield favorable results in the realms of ecological restoration and the advancement of environmental sustainability. Our findings are supported by the existing literature posted by [52,82,95]. The utilization of a data-driven approach enables the identification of discernible patterns, prevailing trends, and potential solutions to ecological challenges. In addition, the utilization of ICT enables the implementation of remote monitoring and control systems, which, in turn, reduces the need for direct human intervention and helps to alleviate the negative environmental impacts that are often linked to human activities. The utilization of smart grids and sensors holds great promise in the realm of energy consumption optimization, offering the potential for a noteworthy decrease in carbon emissions [15,85,95].

Furthermore, it is important to acknowledge that the utilization of ICT serves as a pivotal factor in enabling the widespread distribution of knowledge and promoting cooperation among researchers, policymakers, and communities on a worldwide level. The reciprocal exchange of information promotes the development of inventive concepts and the progress of sustainable methodologies. Furthermore, it is crucial to recognize the substantial influence exerted by ICT in fostering environmental awareness and facilitating educational initiatives pertaining to ecological sustainability [3,66,96]. The dissemination of information concerning environmental issues has been greatly improved by utilizing various digital platforms, such as websites, social media platforms, and online courses. The facilitation of the broadening of the audience base, thereby enabling increased access and engagement with said information, has been observed. The platform's heightened accessibility facilitates the acquisition of knowledge pertaining to the importance of ecological sustainability and the proactive actions that individuals from various backgrounds can undertake to make constructive contributions in this field.

Additionally, the utilization of ICT serves to facilitate the creation and implementation of interactive tools and applications. These tools and applications effectively engage individuals in the adoption and promotion of sustainable practices. Mobile applications possess the inherent capability to provide individuals with current and punctual information pertaining to recycling centers, environmentally friendly products, and sustainable modes of transportation. The availability of information functions as a catalyst for the promotion and encouragement of environmentally conscious decision-making among users. Furthermore, it is important to acknowledge that the utilization of ICT is of utmost significance in facilitating the effective implementation of smart city endeavors. These initiatives encompass the seamless integration of cutting-edge technology into urban infrastructure, thereby augmenting the efficiency of.

The study documented that the coefficient of GTI derived from CUP-FM, CUP-BC, and DSUR exhibited negative signs toward EF, indicating a pivotal role in ecological sustainability. The results of the study offer valuable insights into the role of green technological innovation (GTI) in promoting ecological improvement, indicating that the acceleration of GTI within the economy acts as a catalyst for promoting ecological rectification by facilitating the adoption of energy-efficient technological advancements. Study findings suggest that the adoption and widespread use of eco-friendly technology could result in positive environmental outcomes by reducing energy consumption and promoting sustainable practices. The results align with previous studies that have highlighted the efficacy of GTI in addressing environmental concerns, including the research of Li, Li, Ozturk, and Ullah [91]. The GTI possesses the capability to make a noteworthy contribution towards the reduction of carbon emissions and the mitigation of adverse environmental effects arising from human activities, which is primarily due to its focus on energy-efficient technical advancements. The significance of this issue is particularly noteworthy in the context of climate change because the achievement of global climate objectives is heavily dependent on the successful implementation of sustainable technical solutions. Additionally, it is of utmost importance to take into account the potential rebound effects that may be linked to GTI. While the utilization of energy-efficient technology holds promise for reducing energy consumption, it is crucial to recognize the possibility of rebound effects across various domains. Both individuals and organizations can increase their energy consumption or participate in other activities that can have negative effects on the environment, thereby undermining the intended ecological benefits. It is crucial to meticulously monitor and manage these rebound effects to ensure that the overall impact of GTI remains positive.

A beneficial role of GF has been documented in all three estimations, and there is a negative tie available between GI and EF. Precisely, a 10% innovation in GF may result in flourishment in ecological correction, which eventually leads to environmental sustainability. Study findings acknowledge the findings offered in the study in [19,23,82,97,98]. The successful integration of environmental preservation and economic growth is facilitated by the utilization of green finance, which plays a pivotal role in promoting and maintaining ecological sustainability. Liu and Wu's [99] study established that GF can contribute positively to the environment through various means, such as reducing carbon emissions, enhancing environmental standards, and mitigating ecological footprints. A similar line of evidence is available in the study of [100]. Regions that have underdeveloped credit and capital markets may potentially experience greater benefits from the utilization of green finance, as it has the potential to enhance energy and environmental performance. Additionally, it has the potential to incentivize corporations to disclose their environmental performance, thereby promoting greater accountability and transparency. By prioritizing green companies and low-carbon technological innovation efforts in the allocation of social resources, GF policies have the potential to foster the desired development of the economic and social environment. In situations where farmers are provided with increased awareness regarding the advantages of environmentally friendly products, the implementation of green financing could potentially contribute to poverty alleviation.

The financing for sustainable natural resource-based green economies and climate-smart blue economies needs to be enhanced. There should be a greater emphasis on increasing the utilization of green finance. Additionally, there is a need for modifications to be made to national regulatory frameworks in order to support these initiatives. It is important to harmonize public financial incentives and encourage greater green financing from various sectors. Furthermore, the decision-making process for public sector financing should be aligned with the environmental aspect of the sustainable development goals. It is crucial to promote increased investment in clean and green technologies and foster the greater utilization of green finance. The integration of environmental safeguards and economic growth within GF is a significant driver in promoting ecological sustainability. The potential benefits of carbon emissions reduction include the lowering of carbon emissions, enhancement of environmental quality, and reduction of the ecological footprint. Green financing has the potential to be utilized by policymakers and corporations as a means to promote sustainable development and mitigate its environmental impact.

The findings of our study suggest a statistically significant inverse correlation between the implementation of environmental tax (ET) and the ecological footprint, which implies that the integration of ET has a beneficial effect on fostering ecological rectification. The results of our study suggest that a positive correlation exists between a 10% increase in ET and a significant improvement in ecological sustainability. The conclusion is substantiated by the coefficients obtained from the CUP-FM, CUP-BS, and DSUR models. The findings of this study align with previous research conducted by [38,45,71,79,96,101], thus offering further support for the positive impacts of environmental taxation on ecological sustainability. In their study, Sarıgül and Topçu [74] found that the implementation of environmental tax policies leads to substantial reductions in environmental pollution levels while also promoting sustainable development. In a similar vein, Shahbaz, Topcu, Sarıgül, and Vo [75] emphasize the importance of environmental taxation as a strategy for mitigating carbon emissions and improving overall environmental conditions.

The implementation of an environmental tax can serve as a powerful financial incentive for businesses and individuals, encouraging them to adopt and incorporate eco-friendly energy sources as well as make essential adjustments to their operational processes [33]. By implementing financial penalties that specifically target environmentally detrimental practices and providing incentives to encourage the adoption of sustainable alternatives, environmental tax policies have the potential to promote the integration of eco-friendly energy sources and facilitate the adoption of more sustainable operational procedures [63,85]. By implementing financial incentives and disincentives, the utilization of environmental taxation can effectively stimulate the widespread adoption of environmentally sustainable energy sources and motivate businesses to make necessary modifications to their operational procedures, which, in turn, helps to mitigate their ecological disruption [38,45,82,97,98]. On the contrary, businesses have the opportunity to proactively embrace environmentally friendly energy sources and modify their operational procedures to align with sustainable principles. By participating in such practices, organizations have the potential to not only make substantial contributions towards ecological restoration but also enhance their reputation as entities dedicated to environmental responsibility.

6. Conclusions and Policy Suggestion

The primary aim of this study is to investigate the interrelationship between several key variables, namely information and communication technology (ICT), green technological innovation (GTI), green finance (GF), environmental tax (ET), and the ecological footprint (EF), across a diverse set of countries. The findings of this research study make noteworthy contributions to our comprehension of the intricate interplay among these variables and their potential ramifications for ecological sustainability. Based on the evidence presented, it can be inferred that the hypothesis put forth in this study is supported. The key findings are as follows.

The research findings elucidate a statistically significant inverse correlation between information and communication technology (ICT) and the ecological footprint (EF). The coefficients derived from various estimation techniques, specifically CUP-FM, CUP-BC, and DSUR, consistently demonstrate that a 1% increment in ICT is associated with a decrease in EF by approximately −0.1423%, −0.1369%, and −0.1138%, correspondingly. The observed inverse correlation implies that advancements in information and communication technology (ICT) hold the potential to yield favorable outcomes in the domains of ecological restoration and environmental sustainability. The correlation between the adoption and extensive utilization of environmentally friendly technologies and the resultant positive environmental outcomes, including reduced energy consumption and the promotion of sustainable practices, has been well established in scholarly research. However, it is imperative to diligently observe any potential rebound effects to ensure that the overall ecological impact remains advantageous. The analysis reveals compelling evidence of a significant inverse correlation between GF and EF across all three estimates. The statement above suggests that a 10% increase in green financing has the potential to yield improvements in ecological remediation, thereby fostering the advancement of environmental sustainability. Governmental policies, specifically those related to Green Finance (GF) policies, possess the inherent potential to significantly mitigate carbon emissions, enhance environmental standards, and alleviate the ecological impact. The adoption of environmental taxation (ET) serves as a compelling economic incentive for individuals and businesses alike to embrace environmentally friendly energy sources and incorporate sustainable operational practices. The implementation of the approach above holds immense potential for effectively fostering the widespread adoption of ecologically sustainable practices, thereby making a substantial and noteworthy contribution towards the restoration of fragile ecological systems.

Based on the findings above, it is prudent to consider the following policy recommendations: First, advocate for the advancement of information and communication technology. The allocation of resources towards the enhancement and widespread use of information and communication technology (ICT) is of utmost importance for governments and organizations. This research paper elucidates the profound importance of information and communication technology (ICT) in the realm of remote monitoring and control systems. ICT assumes a central and indispensable role in diminishing the necessity for direct human intervention and ameliorating the detrimental environmental repercussions. Second, facilitate and nurture the progression of environmentally sustainable technologies through dedicated research and development efforts. The successful execution of strategies designed to foster the responsible and sustainable integration of energy-efficient technological advancements, alongside the proficient monitoring and management of rebound effects, is of utmost importance. Third, the initiative is to enhance the effectiveness and efficiency of green finance mechanisms. By bolstering the framework and infrastructure supporting green finance, we aim to facilitate the flow of capital towards environmentally sustainable projects and initiatives, which will involve conducting, proposing, and championing policy measures aimed at fostering the proliferation of green finance initiatives through incentivization. Fourth, environmental taxation is a mechanism that aims to internalize the external costs associated with environmental degradation by imposing taxes on activities that generate negative environmental impacts. This research aims to provide a comprehensive analysis. The prioritization of the implementation and enforcement of environmental tax laws is imperative, with the objective of penalizing activities that yield adverse environmental consequences while concurrently advocating for sustainable alternatives. The policies above possess the capacity to stimulate the extensive integration of environmentally sustainable energy sources and the execution of sustainable operational strategies by individuals and organizations alike.

Empirical studies with secondary data may not have certain limitations, and the present study does as well. The importance of study findings may limit their impact on the following grounds. First, the influence of data quality and availability on the study's results is not to be underestimated. Inaccurate data can introduce bias and error, while incomplete data can lead to gaps in understanding. Moreover, outdated or limited data can restrict the study's ability to provide insights that reflect the most current and relevant trends in the fields of ICT, innovation, eco-taxes, and clean energy, which are critical components of sustainable ecological practices. Addressing these data-related limitations is essential for ensuring the validity and robustness of the study's conclusions. Second, the study's policy recommendations provide a valuable foundation for addressing ecological sustainability. However, to enhance their effectiveness, it would be beneficial to conduct a more thorough analysis that considers various aspects that are sometimes overlooked during the early stages of policy development.

Author Contributions: Y.W.: conceptualization, investigation, writing—review and editing; M.Q.: conceptualization, investigation, data curation, validation, writing—review and editing; S.K.: conceptualization, investigation, validation, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This paper was supported by the Institute of Advanced Research (IAR) at the United International University (UIU). Research grant IAR-2023-PUB-051.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are openly available in [WDI]. This data can be found in the following location: [https://databank.worldbank.org/source/world-development-indicators, accessed on 10 July 2023].

Acknowledgments: The successful completion of this manuscript owes a debt of gratitude to the invaluable contributions of three esteemed reviewers and a dedicated academic editor. Their insightful comments, meticulous evaluations, and constructive feedback have significantly enriched the quality and depth of this work.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

DSUR	Dynamic Seemingly Unrelated Regression
CUP-FM	continuously updated and fully modified
CUP-BC	continuously updated bias-corrected
CADF	cross-sectional augmented Dickey–Fuller
ICT	information and communication technology
ED	environmental degradation
EF	ecological footprint
GTI	green technological innovation
GF	green finance
ET	environmental tax
CEC	clean energy consumption
RE	renewable energy
AMG	augmented mean group
CS-ARDL	cross-sectional autoregressive distributed lagged
CO_2	carbon dioxide

References

1. Lee, P.-C.; Huang, C.-Y.; Huang, M.-H.; Hsu, M.-J. The Behavioral Intention of Hospitals to Promote Sustainable Development of Green Healthcare from the Perspective of Organizational Stakeholders during the COVID-19 Epidemic: A Case Study of Hospitals in Taiwan. *Sustainability* **2023**, *15*, 4521. [CrossRef]
2. Xie, Y.; Cao, Y.; Li, X. The importance of trade policy uncertainty to energy consumption in a changing world. *Financ. Res. Lett.* **2023**, *52*, 103566. [CrossRef]
3. Su, J.; Wang, W.; Tang, S. The spatial spillover effect of ICT development level on regional CO_2 emissions. *Sci. Rep.* **2023**, *13*, 7690. [CrossRef] [PubMed]
4. Alola, A.A.; Alola, U.V.; Akdag, S.; Yildirim, H. The role of economic freedom and clean energy in environmental sustainability: Implication for the G-20 economies. *Environ. Sci. Pollut. Res.* **2022**, *29*, 36608–36615. [CrossRef] [PubMed]
5. Kazemian, S.; Djajadikerta, H.G.; Said, J.; Roni, S.M.; Trireksani, T.; Alam, M.M. Corporate governance, market orientation and performance of Iran's upscale hotels. *Tour. Hosp. Res.* **2021**, *21*, 344–357. [CrossRef]
6. Rahman, M.M. Environmental degradation: The role of electricity consumption, economic growth and globalisation. *J. Environ. Manag.* **2020**, *253*, 109742. [CrossRef] [PubMed]
7. Manisalidis, I.; Stavropoulou, E.; Stavropoulos, A.; Bezirtzoglou, E. Environmental and Health Impacts of Air Pollution: A Review. *Front. Public Health* **2020**, *8*, 14. [CrossRef]
8. Fang, G.; Chen, G.; Yang, K.; Yin, W.; Tian, L. Can green tax policy promote China's energy transformation?— A nonlinear analysis from production and consumption perspectives. *Energy* **2023**, *269*, 126818. [CrossRef]
9. Aydin, C.; Esen, Ö.; Aydin, R. Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach. *Ecol. Indic.* **2019**, *98*, 543–555. [CrossRef]
10. Solarin, S.A.; Nathaniel, S.P.; Bekun, F.V.; Okunola, A.M.; Alhassan, A. Towards achieving environmental sustainability: Environmental quality versus economic growth in a developing economy on ecological footprint via dynamic simulations of ARDL. *Environ. Sci. Pollut. Res.* **2021**, *28*, 17942–17959. [CrossRef]
11. Ju, S.; Andriamahery, A.; Qamruzzaman, M.; Kor, S. Effects of financial development, FDI and good governance on environmental degradation in the Arab nation: Dose technological innovation matters? *Front. Environ. Sci.* **2023**, *11*, 1094976. [CrossRef]
12. Uddin, M.M.M. What are the dynamic links between agriculture and manufacturing growth and environmental degradation? Evidence from different panel income countries. *Environ. Sustain. Indic.* **2020**, *7*, 100041. [CrossRef]
13. Larson, B.A. Changing the economics of environmental degradation in Madagascar: Lessons from the national environmental action plan process. *World Dev.* **1994**, *22*, 671–689. [CrossRef]
14. Rani, T.; Wang, F.; Rauf, F.; ul Ain, Q.; Ali, H. Linking personal remittance and fossil fuels energy consumption to environmental degradation: Evidence from all SAARC countries. *Environ. Dev. Sustain.* **2023**, *25*, 8447–8468. [CrossRef]
15. Chau, K.Y.; Lin, C.-H.; Tufail, B.; Tran, T.K.; Van, L.; Nguyen, T.T.H. Impact of eco-innovation and sustainable tourism growth on the environmental degradation: The case of China. *Econ. Res. Ekon. Istraživanja* **2023**, *36*, 2150258. [CrossRef]
16. Wang, C.; Cardon, P.W.; Liu, J.; Madni, G.R. Social and economic factors responsible for environmental performance: A global analysis. *PLoS ONE* **2020**, *15*, e0237597. [CrossRef]
17. Rakshit, B.; Neog, Y. Do macroeconomic uncertainty and financial development cause environmental degradation? Evidence from an emerging economy. *Int. J. Soc. Econ.* **2021**, *48*, 1264–1289. [CrossRef]
18. Wang, F.; Wu, M. How does trade policy uncertainty affect China's economy and energy? *J. Environ. Manag.* **2023**, *330*, 117198. [CrossRef]
19. Qamruzzaman, M. Does Environmental Degradation-Led Remittances Flow? Nexus between Environmental Degradation, Uncertainty, Financial Inclusion and Remittances Inflows in India and China. *Int. J. Energy Econ. Policy* **2023**, *13*, 9–26. [CrossRef]
20. Yi, S.; Raghutla, C.; Chittedi, K.R.; Fareed, Z. How economic policy uncertainty and financial development contribute to renewable energy consumption? The importance of economic globalization. *Renew. Energy* **2023**, *202*, 1357–1367. [CrossRef]
21. Farooq, F.; Faheem, M.; Nousheen, A. Economic Policy Uncertainty, Renewable Energy Consumption and Environmental Sustainability in China. *Pak. J. Humanit. Soc. Sci.* **2023**, *11*, 1978–1993. [CrossRef]
22. Shrinkhal, R. Chapter 22-Economics, Technology, and Environmental Protection: A Critical Analysis of Phytomanagement. In *Phytomanagement of Polluted Sites*; Pandey, V.C., Bauddh, K., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 569–580.
23. Numan, U.; Ma, B.; Sadiq, M.; Bedru, H.D.; Jiang, C. The role of green finance in mitigating environmental degradation: Empirical evidence and policy implications from complex economies. *J. Clean. Prod.* **2023**, *400*, 136693. [CrossRef]
24. Adebayo, T.S.; Ullah, S. Formulating sustainable development policies for China within the framework of socioeconomic conditions and government stability. *Environ. Pollut.* **2023**, *328*, 121673. [CrossRef]
25. Balsalobre-Lorente, D.; Abbas, J.; He, C.; Pilař, L.; Shah, S.A.R. Tourism, urbanization and natural resources rents matter for environmental sustainability: The leading role of AI and ICT on sustainable development goals in the digital era. *Resour. Policy* **2023**, *82*, 103445. [CrossRef]
26. Chaabouni, S.; Saidi, K. The dynamic links between carbon dioxide (CO_2) emissions, health spending and GDP growth: A case study for 51 countries. *Environ. Res.* **2017**, *158*, 137–144. [CrossRef]
27. Carrión-Flores, C.E.; Innes, R. Environmental innovation and environmental performance. *J. Environ. Econ. Manag.* **2010**, *59*, 27–42. [CrossRef]

28. Danish; Ulucak, R. Analyzing energy innovation-emissions nexus in China: A novel dynamic simulation method. *Energy* **2022**, *244*, 123010. [CrossRef]
29. Semieniuk, G.; Campiglio, E.; Mercure, J.F.; Volz, U.; Edwards, N.R. Low-carbon transition risks for finance. *Wiley Interdiscip. Rev. Clim. Chang.* **2021**, *12*, e678. [CrossRef]
30. Petrović, P.; Lobanov, M.M. The impact of R&D expenditures on CO_2 emissions: Evidence from sixteen OECD countries. *J. Clean. Prod.* **2020**, *248*, 119187.
31. Rafindadi, A.A.; Ozturk, I. Impacts of renewable energy consumption on the German economic growth: Evidence from combined cointegration test. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1130–1141. [CrossRef]
32. Zhang, K.Q.; Chen, H.H.; Tang, L.Z.; Qiao, S. Green Finance, Innovation and the Energy-Environment-Climate Nexus. *Front. Environ. Sci.* **2022**, *10*. [CrossRef]
33. Triki, R.; Kahouli, B.; Tissaoui, K.; Tlili, H. Assessing the Link between Environmental Quality, Green Finance, Health Expenditure, Renewable Energy, and Technology Innovation. *Sustainability* **2023**, *15*, 4286. [CrossRef]
34. Mngumi, F.; Shaorong, S.; Shair, F.; Waqas, M. Does green finance mitigate the effects of climate variability: Role of renewable energy investment and infrastructure. *Environ. Sci. Pollut. Res.* **2022**, *29*, 59287–59299. [CrossRef]
35. Xue, C.; Shahbaz, M.; Ahmed, Z.; Ahmad, M.; Sinha, A. Clean energy consumption, economic growth, and environmental sustainability: What is the role of economic policy uncertainty? *Renew. Energy* **2022**, *184*, 899–907. [CrossRef]
36. Chen, M.; Jiandong, W.; Saleem, H. The role of environmental taxes and stringent environmental policies in attaining the environmental quality: Evidence from OECD and non-OECD countries. *Front. Environ. Sci.* **2022**, *10*, 972354. [CrossRef]
37. Heine, D.; Black, S. Benefits beyond Climate: Environmental Tax Reform. In *Fiscal Policies for Development and Climate Action*; International Bank for Reconstruction and Development/The World Bank: Washington, DC, USA, 2019; pp. 1–63. [CrossRef]
38. Wang, Z.; Zhu, N.; Wang, J.; Hu, Y.; Nkana, M. The impact of environmental taxes on economic benefits and technology innovation input of heavily polluting industries in China. *Front. Environ. Sci.* **2022**, *10*, 959939. [CrossRef]
39. Achuo, E.D.; Miamo, C.W.; Nchofoung, T.N. Energy consumption and environmental sustainability: What lessons for posterity? *Energy Rep.* **2022**, *8*, 12491–12502. [CrossRef]
40. Nan, Y.; Sun, R.; Mei, H.; Yue, S.; Yuliang, L. Does renewable energy consumption reduce energy ecological footprint: Evidence from China. *Environ. Res. Ecol.* **2023**, *2*, 015003. [CrossRef]
41. Chien, F.; Anwar, A.; Hsu, C.-C.; Sharif, A.; Razzaq, A.; Sinha, A. The role of information and communication technology in encountering environmental degradation: Proposing an SDG framework for the BRICS countries. *Technol. Soc.* **2021**, *65*, 101587. [CrossRef]
42. Bieser, J.C.T.; Hilty, L.M. Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review. *Sustainability* **2018**, *10*, 2662. [CrossRef]
43. Bostrom, R.P.; Gupta, S.; Thomas, D. A Meta-Theory for Understanding Information Systems within Sociotechnical Systems. *J. Manag. Inf. Syst.* **2009**, *26*, 17–47. [CrossRef]
44. Ozkan, O.; Khan, N.; Ahmed, M. Impact of green technological innovations on environmental quality for Turkey: Evidence from the novel dynamic ARDL simulation model. *Environ. Sci. Pollut. Res.* **2023**, *30*, 72207–72223. [CrossRef]
45. Ahmad, M.; Kuldasheva, Z.; Nasriddinov, F.; Balbaa, M.E.; Fahlevi, M. Is achieving environmental sustainability dependent on information communication technology and globalization? Evidence from selected OECD countries. *Environ. Technol. Innov.* **2023**, *31*, 103178. [CrossRef]
46. Ling, G.; Razzaq, A.; Guo, Y.; Fatima, T.; Shahzad, F. Asymmetric and time-varying linkages between carbon emissions, globalization, natural resources and financial development in China. *Environ. Dev. Sustain.* **2022**, *24*, 6702–6730. [CrossRef]
47. Lam, V.T.; Phan, T.T.H.; Mai, N.H.; Huy, P.Q.; Ngo, T.Q. Dynamic association of green financial innovation, eco-financing, carbon tax, economic openness, and sustainable energy transition in Vietnam: Fresh evidence using DARDL approach. *Econ. Res. Ekon. Istraživanja* **2023**, *36*, 2199416. [CrossRef]
48. Jiang, Y.; Sharif, A.; Anwar, A.; The Cong, P.; Lelchumanan, B.; Thi Yen, V.; Thi Thuy Vinh, N. Does green growth in E-7 countries depend on economic policy uncertainty, institutional quality, and renewable energy? Evidence from quantile-based regression. *Geosci. Front.* **2023**, *14*, 101652. [CrossRef]
49. Gong, Q.; Ying, L.; Dai, J. Green finance and energy natural resources nexus with economic performance: A novel evidence from China. *Resour. Policy* **2023**, *84*, 103765. [CrossRef]
50. Aydin, M.; Degirmenci, T.; Gurdal, T.; Yavuz, H. The role of green innovation in achieving environmental sustainability in European Union countries: Testing the environmental Kuznets curve hypothesis. *Gondwana Res.* **2023**, *118*, 105–116. [CrossRef]
51. Aydin, M.; Bozatli, O. The effects of green innovation, environmental taxes, and financial development on renewable energy consumption in OECD countries. *Energy* **2023**, *280*, 128105. [CrossRef]
52. Ahmad, M.; Ahmed, Z.; Bai, Y.; Qiao, G.; Popp, J.; Oláh, J. Financial Inclusion, Technological Innovations, and Environmental Quality: Analyzing the Role of Green Openness. *Front. Environ. Sci.* **2022**, *10*, 851263. [CrossRef]
53. Zhai, X.; An, Y. The relationship between technological innovation and green transformation efficiency in China: An empirical analysis using spatial panel data. *Technol. Soc.* **2021**, *64*, 101498. [CrossRef]
54. Zhan, Y.; Wang, Y.; Zhong, Y. Effects of green finance and financial innovation on environmental quality: New empirical evidence from China. *Econ. Res. Ekon. Istraživanja* **2023**, *36*, 2164034. [CrossRef]

55. Sun, Y.; Bao, Q.; Taghizadeh-Hesary, F. Green finance, renewable energy development, and climate change: Evidence from regions of China. *Humanit. Soc. Sci. Commun.* **2023**, *10*, 107. [CrossRef]
56. Koseoglu, A.; Yucel, A.G.; Ulucak, R. Green innovation and ecological footprint relationship for a sustainable development: Evidence from top 20 green innovator countries. *Sustain. Dev.* **2022**, *30*, 976–988. [CrossRef]
57. Khan, I.; Han, L.; Zhong, R.; Bibi, R.; Khan, H. Income inequality, economic growth, renewable energy usage, and environmental degradation in the Belt and Road initiative countries: Dynamic panel estimation. *Environ. Sci. Pollut. Res.* **2023**, *30*, 57142–57154. [CrossRef]
58. Huo, W.; Zaman, B.U.; Zulfiqar, M.; Kocak, E.; Shehzad, K. How do environmental technologies affect environmental degradation? Analyzing the direct and indirect impact of financial innovations and economic globalization. *Environ. Technol. Innov.* **2023**, *29*, 102973. [CrossRef]
59. Ng, C.-F.; Yii, K.-J.; Lau, L.-S.; Go, Y.-H. Unemployment rate, clean energy, and ecological footprint in OECD countries. *Environ. Sci. Pollut. Res.* **2023**, *30*, 42863–42872. [CrossRef]
60. Zhang, S.; Chen, K. Green finance and ecological footprints: Natural resources perspective of China's growing economy. *Resour. Policy* **2023**, *85*, 103898. [CrossRef]
61. Qadri, S.U.; Shi, X.; ur Rahman, S.; Anees, A.; Ali, M.S.E.; Brancu, L.; Nayel, A.N. Green finance and foreign direct investment–environmental sustainability nexuses in emerging countries: New insights from the environmental Kuznets curve. *Front. Environ. Sci.* **2023**, *11*. [CrossRef]
62. Gu, X.; Alamri, A.M.; Ahmad, M.; Alsagr, N.; Zhong, X.; Wu, T. Natural resources extraction and green finance: Dutch disease and COP27 targets for OECD countries. *Resour. Policy* **2023**, *81*, 103404. [CrossRef]
63. Feng, H.; Yang, F. Does environmental psychology matter: Role of green finance and government spending for sustainable development. *Environ. Sci. Pollut. Res.* **2023**, *30*, 39946–39960. [CrossRef] [PubMed]
64. Alharbi, S.S.; Al Mamun, M.; Boubaker, S.; Rizvi, S.K.A. Green finance and renewable energy: A worldwide evidence. *Energy Econ.* **2023**, *118*, 106499. [CrossRef]
65. Yuan, H.; Feng, Y.; Lee, C.-C.; Cen, Y. How does manufacturing agglomeration affect green economic efficiency? *Energy Econ.* **2020**, *92*, 104944. [CrossRef]
66. Xu, J.; Moslehpour, M.; Tran, T.K.; Dinh, K.C.; Ngo, T.Q.; Huy, P.Q. The role of institutional quality, renewable energy development and trade openness in green finance: Empirical evidence from South Asian countries. *Renew. Energy* **2023**, *207*, 687–692. [CrossRef]
67. Tran, T.; Do, H.; Vu, T.; Do, N. The factors affecting green investment for sustainable development. *Decis. Sci. Lett.* **2020**, *9*, 365–386. [CrossRef]
68. Katircioğlu, S.; Katircioğlu, S. Testing the role of urban development in the conventional Environmental Kuznets Curve: Evidence from Turkey. *Appl. Econ. Lett.* **2018**, *25*, 741–746. [CrossRef]
69. Shen, Y.; Su, Z.-W.; Malik, M.Y.; Umar, M.; Khan, Z.; Khan, M. Does green investment, financial development and natural resources rent limit carbon emissions? A provincial panel analysis of China. *Sci. Total Environ.* **2021**, *755*, 142538. [CrossRef]
70. Esen, Ö.; Yıldırım, D.Ç.; Yıldırım, S. Pollute less or tax more? Asymmetries in the EU environmental taxes—Ecological balance nexus. *Environ. Impact Assess. Rev.* **2021**, *91*, 106662. [CrossRef]
71. Bosquet, B. Environmental tax reform: Does it work? A survey of the empirical evidence. *Ecol. Econ.* **2000**, *34*, 19–32. [CrossRef]
72. Hsu, C.-C.; Zhang, Y.; Ch, P.; Aqdas, R.; Chupradit, S.; Nawaz, A. A step towards sustainable environment in China: The role of eco-innovation renewable energy and environmental taxes. *J. Environ. Manag.* **2021**, *299*, 113609. [CrossRef]
73. Telatar, O.M.; Birinci, N. The effects of environmental tax on Ecological Footprint and Carbon dioxide emissions: A nonlinear cointegration analysis on Turkey. *Environ. Sci. Pollut. Res.* **2022**, *29*, 44335–44347. [CrossRef] [PubMed]
74. Sarıgül, S.S.; Topçu, A.B. The impact of environmental taxes on carbon dioxide emissions in Turkey. *Int. J. Bus. Econ. Stud.* **2021**, *3*, 43–54.
75. Shahbaz, M.; Topcu, B.A.; Sarıgül, S.S.; Vo, X.V. The effect of financial development on renewable energy demand: The case of developing countries. *Renew. Energy* **2021**, *178*, 1370–1380. [CrossRef]
76. Akkaya, Ş.; Hepsag, A. Does fuel tax decrease carbon dioxide emissions in Turkey? evidence from an asymmetric nonlinear cointegration test and error correction model. *Environ. Sci. Pollut. Res.* **2021**, *28*, 35094–35101. [CrossRef]
77. Muposhi, A.; Mpinganjira, M.; Wait, M. Efficacy of plastic shopping bag tax as a governance tool: Lessons for South Africa from Irish and Danish success stories. *Acta Commer.* **2021**, *21*. [CrossRef]
78. Bashir, M.F.; Ma, B.; Komal, B.; Bashir, M.A. Analysis of environmental taxes publications: A bibliometric and systematic literature review. *Environ. Sci. Pollut. Res.* **2021**, *28*, 20700–20716. [CrossRef]
79. Wolde-Rufael, Y.; Mulat-Weldemeskel, E. Do environmental taxes and environmental stringency policies reduce CO_2 emissions? Evidence from 7 emerging economies. *Environ. Sci. Pollut. Res.* **2021**, *28*, 22392–22408. [CrossRef]
80. Dissanayake, H.; Perera, N.; Abeykoon, S.; Samson, D.; Jayathilaka, R.; Jayasinghe, M.; Yapa, S. Nexus between carbon emissions, energy consumption, and economic growth: Evidence from global economies. *PLoS ONE* **2023**, *18*, e0287579. [CrossRef]
81. Li, R.; Wang, X.; Wang, Q. Does renewable energy reduce ecological footprint at the expense of economic growth? An empirical analysis of 120 countries. *J. Clean. Prod.* **2022**, *346*, 131207. [CrossRef]
82. Su, S.; Qamruzzaman, M.; Karim, S. Charting a Sustainable Future: The Impact of Economic Policy, Environmental Taxation, Innovation, and Natural Resources on Clean Energy Consumption. *Sustainability* **2023**, *15*, 13585. [CrossRef]

83. Sharma, R.; Sinha, A.; Kautish, P. Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. *J. Clean. Prod.* **2021**, *285*, 124867. [CrossRef]
84. Brainerd, C.J.; Reyna, V.F. Fuzzy-Trace Theory and Lifespan Cognitive Development. *Dev. Rev.* **2015**, *38*, 89–121. [CrossRef] [PubMed]
85. Binh An, N.; Kuo, Y.-L.; Mabrouk, F.; Sanyal, S.; Muda, I.; Hishan, S.S.; Abdulrehman, N. Ecological innovation for environmental sustainability and human capital development: The role of environmental regulations and renewable energy in advanced economies. *Econ. Res. Ekon. Istraživanja* **2023**, *36*, 243–263. [CrossRef]
86. Westerlund, J. Testing for Error Correction in Panel Data. *Oxf. Bull. Econ. Stat.* **2007**, *69*, 709–748. [CrossRef]
87. Bai, J.; Kao, C. Chapter 1 On the Estimation and Inference of a Panel Cointegration Model with Cross-Sectional Dependence. In *Contributions to Economic Analysis*; Baltagi, B.H., Ed.; Elsevier: Amsterdam, The Netherlands, 2006; Volume 274, pp. 3–30.
88. Pedroni, P. Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the ppp hypothesis. *Econom. Theory* **2004**, *20*, 597–625. [CrossRef]
89. Kao, C. Spurious regression and residual-based tests for cointegration in panel data. *J. Econ.* **1999**, *90*, 1–44. [CrossRef]
90. Saleem, H.; Khan, M.B.; Mahdavian, S.M. The role of green growth, green financing, and eco-friendly technology in achieving environmental quality: Evidence from selected Asian economies. *Environ. Sci. Pollut. Res.* **2022**, *29*, 57720–57739. [CrossRef]
91. Li, L.; Li, G.; Ozturk, I.; Ullah, S. Green innovation and environmental sustainability: Do clean energy investment and education matter? *Energy Environ.* **2022**, *34*, 2705–2720. [CrossRef]
92. Zhang, W.; Zhu, Z.; Liu, X.; Cheng, J. Can green finance improve carbon emission efficiency? *Environ. Sci. Pollut. Res.* **2022**, *29*, 68976–68989. [CrossRef]
93. Magazzino, C. Ecological footprint, electricity consumption, and economic growth in China: Geopolitical risk and natural resources governance. *Empir. Econ.* **2023**. [CrossRef]
94. Dumitrescu, E.-I.; Hurlin, C. Testing for Granger non-causality in heterogeneous panels. *Econ. Model.* **2012**, *29*, 1450–1460. [CrossRef]
95. Balsalobre-Lorente, D.; Topaloglu, E.E.; Nur, T.; Evcimen, C. Exploring the linkage between financial development and ecological footprint in APEC countries: A novel view under corruption perception and environmental policy stringency. *J. Clean. Prod.* **2023**, *414*, 137686. [CrossRef]
96. Sarpong, K.A.; Xu, W.; Gyamfi, B.A.; Ofori, E.K. Can environmental taxes and green-energy offer carbon-free E7 economies? An empirical analysis in the framework of COP-26. *Environ. Sci. Pollut. Res.* **2023**, *30*, 51726–51739. [CrossRef] [PubMed]
97. Yan, H.; Qamruzzaman, M.; Kor, S. Nexus between Green Investment, Fiscal Policy, Environmental Tax, Energy Price, Natural Resources, and Clean Energy—A Step towards Sustainable Development by Fostering Clean Energy Inclusion. *Sustainability* **2023**, *15*, 13591. [CrossRef]
98. Wang, Y.; Qamruzzaman, M.; Serfraz, A.; Theivanayaki, M. Does Financial Deepening Foster Clean Energy Sustainability over Conventional Ones? Examining the Nexus between Financial Deepening, Urbanization, Institutional Quality, and Energy Consumption in China. *Sustainability* **2023**, *15*, 8026. [CrossRef]
99. Liu, C.; Wu, S.S. Green finance, sustainability disclosure and economic implications. *Fulbright Rev. Econ. Policy* **2023**, *3*, 1–24. [CrossRef]
100. Agrawal, R.; Agrawal, S.; Samadhiya, A.; Kumar, A.; Luthra, S.; Jain, V. Adoption of green finance and green innovation for achieving circularity: An exploratory review and future directions. *Geosci. Front.* **2023**, 101669. [CrossRef]
101. Tamura, H.; Hotehama, M.; Tomiyarna, S.; Hatono, I. On environmental tax for total emission control of carbon dioxide. *IFAC Proc. Vol.* **1999**, *32*, 5782–5787. [CrossRef]