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The Synergistic Roles of Green Openness and Economic Complexity in Environmental Sustainability of Europe's Largest Economy: Implications for Technology-intensive and Environmentally Friendly Products

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Abstract:

The degrowth approach posits the idea that sustainable development and economic expansion are mutually exclusive. Conversely, it is believed that international trade within a complex economic system can help distribute green products to simultaneously ensure economic expansion and sustainable development. For this reason, the dynamic ARDL simulations technique was adopted to analyze the German economy's data from 2000-2020 towards determining the specific and interactive ecological implications of international green openness and economic complexity in Europe's largest economy. We discovered that green openness and economic complexity each have desirable impacts on ecofootprint, and their interaction further confirms a strong ecological-enhancing synergistic effect. The presence of the EKC phenomenon was also upheld from the analysis while clean energy exerts a positive impact on Germany's environmental quality level. The study further posits that a faster shift into the manufacture of technology-intensive and environmentally friendly products is possible for nations that invest in strengthening their internal technological skills to curb ecological harm. It is therefore advocated that even if the manufacturing of green items is not optimally done domestically, the special opportunities presented by international trade in the distribution of green products should always be leveraged to foster environmental sustainability.

Keywords: Green openness; economic complexity; Germany economy; dynamic ARDL simulations technique; EKC.

1. Introduction

The environmental crisis of global warming and climate change has reached an all-time high threat level today. It is becoming obvious that the chaotic environmental challenges faced by our ecology are the consequence of the increasing carbon footprints (Agozie et al., 2022). The International Panel on Climate Change (IPCC) reports that pollutant emissions have increased substantially from the 1960s through 2010 till today. Thus, attempting to limit temperature increase below 2°C in line with pre-industrial levels requires more ambitious strategies from business as usual (IPCC, 2021). This assertion presents the overarching need to address the increasing environmental deterioration and global warming to avert the looming threats to human lives, property, and the natural ecology.

Ensuring sustainable environments already exists as a global phenomenon. Thus, recent natural occurrences, such as the record-breaking heat waves that baked India and Pakistan in 2022, the week-long monsoon rains that drove one-third of Pakistan underwater, affecting over 33 million households (WEF, 2022), rising temperatures above 104°F in the US for prolonged periods, have necessitated a greater need for environmental sustainability (WEF, 2022). These occurrences openly display the extent of damage caused by economic development activities to the environment. Hence, there is a need to hasten meeting the sustainable environment targets to safeguard the environment from further anthropogenic consequences (Musah et al., 2023; Agboola et al., 2022).

Largely, the global environmental targets are feasible only if policy and actions possess greater consideration for human activity that exacerbates environmental poor quality (Gyamfi et al., 2021; Can et al., 2021). This is because, unquestionably, socio-economic activities are at the helm of global environmental challenges (Howson & de Vries, 2022). Economic growth activities provide immense economic and environmental benefits to economies. Like trade openness, it facilitates the flow of goods, technology, and processes that have both positive and negative impacts on the environment (Wen et al., 2022).

However, from the degrowth strategy perspective, it is commonly argued that balancing economic growth with environmental quality is challenging (Hickel & Hallegatte, 2022). This is because ensuring environmental protection in place of economic growth could be viewed as counterproductive (Pollin, 2019). The post-pandemic economic era requires greater economic expansion to stabilize the global recession battled by many economies. However, greater economic expansion goals are more likely to exacerbate the environmental quality challenges. It is in light of this paradox that experts have argued

for green development and innovations to drive harmony between economic growth and environmental targets (Gyamfi et al., 2023; Onifade & Alola, 2022). Transitioning to green developmental strategies and mechanisms for economic growth is a policy-oriented goal that needs critical evaluation, mainly because of the financial obligation required and the unavailability and complexity of green technologies (Lin & Zhou, 2022). According to Shahbaz et al. (2022), achieving this transition is challenging for many economies, particularly developing economies. Thus, proposing a route to decomplicating this process is at the core of this current study's motivation.

Studies highlight trade openness and international trade activities as ways to diffuse green technologies and practices, so long as countries willingly open up to green development (Nchofoung & Asongu, 2022; Jiang, et al., 2022). However, available empirical assessments on the impact of international trade on green development and the environment suggest inconsistent findings. For instance, some scholars believe trade openness worsens pollution through increased economic engagements (Iorember, et al., 2021). Vale et al. (2018) present that trade openness introduces comparative advantages, technological differences, that account for variations in pollution levels. Others like Agozie et al. (2022) also found that trade openness expands cross-border economic activity in energy-efficient and pro-environment products and green financing. Thus, spreading green products and processes across economies through trade is likely to improve performance on sustainable environmental targets. Therefore, this study is further motivated to deepen the understanding of green trade openness and ecological development, giving the litany of mixed findings (Can et al., 2021).

While greater research and technological innovation are expected to drive economic complexities (Huang et al., 2022), economic complexities can become the gateway for greater openness to green products and technologies. Studies have established links between the economic complexity of countries and the structural transformations experienced. As countries transition from their reliance on primary production sectors to more sophisticated and tertiary sectors, economic complexity levels will increase with ensuing environmental impacts (Sun et al., 2022). For example, moving toward industrial production from primary economic activities may come with increased utilization of fossil energies that worsen carbon emissions. Therefore, understanding this nexus, while considering contextual differences is crucial to achieving environmental quality goals (Doğan, et al., 2022). Thus, this study is motivated to understand the effect of economic complexity, green innovation, and green openness on the environment.

In light of these motivations, this study makes some crucial contributions to existing works that will offer insights into dealing with the problems motivating it. Compared with prior studies, this current study assesses the effect of green openness using a green openness index. Prior studies performing similar assessments have largely relied on proxy indicators of green development such as environmentally adjusted multi-factor productivity and technological innovation (Cai et al., 2022; Can et al., 2021). For instance, Can et al. (2021) provided evidence that green openness (trade in environmentally friendly goods and technologies) improves environmental degradation. However, Can et al. (2021) employed a 40-item green openness index to assess the environmental impacts of green openness among the OECD states. Although this study introduced substantial novelty to understanding environmental quality from a green openness index context, it is also limited in a few ways. First, it compasses 40 green products, and the index was only tested between 2007 to 2017. To contribute to this, our study reviews and incorporates additional elements to the Green Openness Index, using new environmentally preferred products or goods, as well as considered from a major economy like Germany. This approach helps to offer a unit-specific assessment of the effect, as the initial assessment of OECD states fails to account for the nuances in individual states.

Moreover, most prior studies in energy economics and related fields have studied environmental pollution through the lens of CO₂ emissions or Sulphur (Du & Li, 2020). This study diverts attention to ecological footprints because ecological footprints have more preferred measures of the environment's capacity. In addition, ecological footprints compass both the ecological and biological capabilities of the environment, an aspect that emission indicators often overlook (Gupta et al., 2022). Findings herein provide more composite insights for policies that differ from evidence limited to carbon emissions only.

Similarly, in studies that have considered the phenomenon of trade openness and environmental quality, technological innovation has largely been considered via the per unit economic activity on the environment (Lee & Olasehinde-Williams, 2022). This current examination relies on the economic complexities linked with industrialization and economic development in an economy. Thus, providing potential insights relevant to industrialized economies. From a methodological perspective, this study also considers a robust second-generation econometric assessment technique. Specifically, it employs a dynamic ARDL simulation technique and covers homogeneity, homoscedasticity, and cross-sectional dependency across panels. Finally, most prior studies have also studied nation blocks and economic integration of nations such as the EU nations (Lee et al., 2022); OECD states (Mealy &

Teytelboym, 2022), BRICS (Sun et al., 2022), and E7 together with the G7 states (Doğan et al., 2022). Thus far, country-specific assessments are largely nonexistent. However, specific countries have made significant contributions to improving or deteriorating environmental quality. For instance, Germany which is Europe's largest economy, alone emitted about 805 million tons of greenhouse gases in 2021, suggesting a 4.5% increase in emissions from the previous year. Germany aims to reduce GHG emissions by at least 55% by 2030, however, the combination of various crises at an international level such as the COVID-19 pandemic, the worsening climate change situation, and the Russian-Ukraine war all pose diverse threats to Germany's green developmental objectives. Thus, these warrant the need for investigations into how individual countries can achieve sustainable development goals to impact global environmental targets.

2. Review of Related Studies

2.1. Trade and the Environment in Context

Several studies have extensively investigated the relationship between trade and ecological quality, focusing on a national or regional scale (Yussif et al. 2022; Dingru et al. 2023). For instance, a study by Al-Mulali et al. (2015) delved into the intricate interplay between economic development, CO2 emissions, and trade liberalization across MENA economies. The findings uncovered a substantial correlation between trade flow and carbon emissions, underscoring their interconnectedness. In another investigation by Hasanov, et al. (2018), particular attention was given to oil-exporting countries, aiming to explore the intricate dynamics linking CO2 emissions, and trade openness. The results revealed a positive impact from both GDP and imports, signifying their influence in contributing to higher CO2 emissions. Conversely, exports were found to have a negative effect on CO2 emissions, indicating a potential role in mitigating carbon output.

Additionally, a distinct study by Liddle, (2018) thoroughly analyzed the repercussions of international trade on CO2 emissions across 102 countries within the timeframe of 1990 to 2013. The study's outcomes disclosed that an upswing in GDP exhibited a positive association with increased CO2 emissions. Simultaneously, imports demonstrated a negative correlation with production-based greenhouse gas emissions, potentially suggesting a mechanism for curbing environmental impact. These analytical investigations shed light on the complex dynamics between international trade and

ecological quality, providing valuable insights into the intricate balance between economic growth, trade patterns, and environmental sustainability.

Comparatively, a study focusing on the G-7 economies Wang, et al. (2020) concludes that heightened trade leads to increased resource utilization, resulting in a decline in environmental quality. The process of trade liberalization further exacerbates the energy demand, leading to a subsequent upsurge in carbon emissions. Similarly, employing MMQR and FMOLS statistical techniques, another study [46] provides empirical evidence suggesting a negative correlation between clean energy, export diversification, and GHG emissions in Asian nations. These findings find support in the research conducted by Grossman and Krueger (1991).

In practical terms, the progression of industrialization and trade activities has yielded economic growth Pata et al. (2022). Furthermore, an investigation by Pan et al. (2019) explores the relationship between trade openness and savings in an economy, revealing that trade openness promotes savings. Moreover, the environmental impact of both industrialization and trade openness has been studied, underscoring the contribution of both factors to ecological contamination.

Other recent studies have considered this issue in the context of green technologies, green finance, green innovation, green investments, and green growth on environmental quality as shown in Table 1. Although, these studies exist, most of them generally aggregate green products with the entire global trade basket rather than creating the necessary distinction in line with the submission of Lee et al. (2022) and Can et al. (2022). Therefore, the conclusions that green trade in international trade baskets can mitigate ecological footprints need more examination.

Table 1. A list of available studies with major indicators

Authors	Period	Context	Green Indicator
Hao et al. (2021)	1991-2017	G7 states	Green Growth
Shen et al. (2021)	1995-2017	China	Green Investment
Li et al. (2021)	1995-2017	China	Green Investment
Paramati et al. (2020)	1991-2016	OECD	Green Technology
Wang & Zhu (2020)	2001-2017	China	Green Energy Technologies
Cheng et al. (2019)	2000-2013	BRICS	Environmental Patent
Wang et al. (2020)	1990-2017	G7 states	Ecological Innovation

2.2. The Environment and Economic Complexity in Context

The interest in relating economic complexity to the environment has recently risen considerably among researchers. Ahmad et al. (2021) for instance noted that the assessments of the role of economic complexity in CO₂ emissions among countries and country blocs have gained more ground. In the submissions by Rafique et al. (2022), economic complexity was viewed as those innovative transformations driving knowledge-based production across countries. Most studies have concluded positive links between economic complexity and environmental impacts. Rafique, et al. (2022) linked lower ecological footprints to economic complexity in the top 10 economically complex countries. In other instances, some scholars argue that the manufacturing of complex products will contribute to greater gains toward their carbon neutrality goals (Van Dam & Frenken, 2022). This is because it requires newer technologies with green capabilities to produce these complex products. Very recent evidence also finds that environmental quality improvements are linked with greater economic complexity, as such sophisticated export products do not compromise environmental quality (Fakher et al., 2023). Lee and Olasehinde-Williams (2022), argue that the productive structure of economies as considered in economic complexity directly impacts environmental quality. In their study, Lee and Olasehinde-Williams, assumed economic complexity to represent the technology component in the STIRPAT model, thus accounting for the structural developments from technology through economic complexity. Despite the positive evidence produced in several studies, other studies have also presented certain arguments opposed to the positive effect of economic complexity on the environment. For example, in a 55-country panel study performed by Dogan et al. (2019), it is found that while economic complexity lowers pollution among high-income nations, it rather worsened pollution levels among low and middle-income economies. Another study considering 118 countries studied economic complexity as a determinant of environmental performance and observed an inverted U-shaped association between these factors. In Balsalobre-Lorente et al., (2022), the authors studied the link between economic complexity and environmental quality in Portugal, Ireland, Italy, Greece, and Spain. The study observed the validation of the EKC and pollution haven hypotheses across these states. Khan et al., (2022) purport that economic complexity drives the EKC, thus, the turning point occurs at greater levels of pollution. Therefore, it can be concluded here that economic complexity exacerbates environmental poor quality in both short and middle-term durations in developing economies. Neagu (2021) argues that economic complexity presents new challenges to environmental quality while reviewing the dimensions of structural economic transformation in

economies. Lee et al. (2022) also observed the detrimental impacts of economic complexity on the environment from a study of 99 countries.

2.3 Literature Gap in the Context of the German Economy

Lessons learned from this review suggest few attempts exist on economic complexity and green trade, and even fewer on green trade openness within the contexts reviewed. Moreover, those studies that have examined the economic complexity, trade, and environment nexus, have evidenced mixed reports. Indicating the lack of consensus among scholars in the field. In addition, Understanding how trade patterns and policies impact the environment over extended periods can provide valuable insights for designing sustainable trade strategies. However, little consideration has been given to this effect dimension of trade on environmental quality in the literature. For example, more research is needed to explore the specific effects of green trade on ecological footprints, including the extent to which incorporating green products in international trade can mitigate environmental impacts.

Furthermore, the general focus of the greater proportion of studies has been on multiple states and nation blocs, and few examinations have sought country-specific evidence. We believe that to attain global sustainable goals, individual countries would first have to achieve their personal climate and environmental sustainability objectives to make any significant contributions to the global scene. Thus, this study seeks to bridge this gap, by initiating the study of a phenomenon that has received nascent attention so far from a country-specific context, specifically in the case of the German economy.

3. Methodology

3.1 Model Specification and Theoretical Underpinning

The increase in ecological degradation over the years has contributed to climate change and global warming, endangering the sustainability of the ecosystem (Bölük and Mert, 2014; Shayanmehr et al., 2020a; Alola & Onifade, 2022). This menace is caused by many macroeconomic factors of which green openness and economic complexity are no exception. Green trade could help in curbing environmental deterioration. While traditional environmental products like pollution control equipment offer solutions to a variety of environmental issues, environmentally preferable products like automobiles are less harmful to the environment than their traditional counterparts. Besides, low energy is required for the development of green products. This helps to advance ecological quality in the process. Green trade is also an effective way to create a green economy that could aid in achieving the carbon neutrality goals of nations. Openness to trade can impact environmental quality in three

key avenues, namely scale, composition, and technique effects. The scale effect occurs when the rise in production levels leads to a rise in ecological contamination. According to the composition effect, the structure of the industry affects how openly trade affects the environment. This could be advantageous or harmful depending on the environmental policy and resource availability of a nation. To the technique effect, rising income and technological development encourage environmentally friendly production, which reduces ecological pollution. We work with the Combined List of Environmental Goods (CLEG) comprising 255 diverse products to compute a green openness index for Germany as an extension of the framework in Can et al. (2021b). The green openness index (GOP) with respect to the CLEG (GOPCLEG) was calculated via the formula below;

$$GOPCLEG_{it} = \frac{GRNX_{it} + GRNM_{it}}{GDP_{it}} \quad (1)$$

Where GRNM denotes total green goods import's present values given the imports from the rest of the globe to a country i at a time t . On the other hand, GRNX signifies the present value of green commodity export by reporter country to the world i at time t , while the total value of manufactured commodities in the same country and time is demoted by GDP. The index ranges between zero (0) to a hundred (100) and is based on data availability on the OECD and World Bank websites. Moreover, the production capacity and the technological capability of an economy are interconnected because economic complexity assesses a nation's capacity to produce in terms of diversity and sophistication. Since economic complexity plays these roles efficiently, it can be viewed as the indicator of nations' resilience and production capacity. Economic complexity varies depending on the sophistication and diversity of countries' exports. On one hand, increasing product diversity and the complexity of the economy could lead to more pollution. Economic complexity can also improve ecological quality due to its potential to promote eco-friendly products and clean technology as well as its involvement in research and development activities. Furthermore, nations can increase ecological sustainability and minimize climate change by adopting major reforms in their energy sectors and putting in place efficient energy transition strategies. Fossil fuel combustion, which leads to the decomposition of hydrocarbons and subsequently air pollution, is the main source of dirty energies. Since increasing the use of energies from this source is unsustainable and detrimental to the ecology, there is a need to transition to clean energy sources. Clean energy sources like hydro, solar, wind, and electricity are ecologically friendly, as they curb the rate of pollutant emissions emanating from industries and households. Due to this, global economies are significantly improving their environments by replacing their dirty energy sources with clean ones. According to the EKC

hypothesis, the rise in economic growth leads to a rise in environmental degradation at the initial stages of growth. This effect is known as the scale effect which underpins the conventional assumption that economic progress and ecological contamination are mutually exclusive. However, at the highest level of economic expansion, structural variety in information-intensive businesses and services, along with the surge in environmental consciousness, regulation enforcement, and cutting-edge technology helps to promote environmental safety. Thus, economic growth and environmental pollution have an inverted U-shaped relationship. Finally, ecological footprint (EP) is a better measure of environmental sustainability because it covers all pollution in the ecosystem, unlike CO₂ emissions that have been expansively used. Ecological footprints encompass pollution from carbon, forest land, cropland, fishing areas, built-up lands, and grazing areas. The multidimensional nature of the indicator increases its suitability in reflecting the ecological performance state. Given the steps in Udemba et al. (2021), EP was used as a surrogate of environmental sustainability in Germany. Based on aforesaid theoretical framework, the following econometric model is developed to assess the synergistic influence of green trade and economic complexity on environmental sustainability in Germany.

$$EP_t = \beta_0 + \beta_1 ECI_t + \beta_2 GDP_t + \beta_3 GDP_t^2 + \beta_4 GOPCLEG_t + \beta_5 CE_t + \beta_6 (GOPCLEG * ECI)_t + u_t \quad (2)$$

Where ecological footprint (EP) is the response variable; economic complexity (ECI) and green trade (GOPCLEG) are the main predictors; and clean energy (CE) is a control variable to help minimize model specification bias. Income (GDP) and income squared (GDP²) are incorporated into the framework to test whether the EKC hypothesis holds for the country or not. Finally, the interactive term between GOPCLEG and ECI (GOPCLEG* ECI) is included in the model to examine the moderating effect of green trade and economic complexity on the ecological sustainability of the nation. According to Li et al. (2020), Musah (2022a), Tackie et al. (2022), and Chen et al. (2022) adopting log-linear specifications of the first equation as seen in the equation (3) offer valid and reliable outcomes than those that are not in their log forms (Shahbaz et al., 2012). This also enhances results explanations in terms of elasticity forms.

$$LEP_t = \beta_0 + \beta_1 LECI_t + \beta_2 LGDP_t + \beta_3 LGDP_t^2 + \beta_4 LGOPCLEG_t + \beta_5 LCE_t + \beta_6 L(GOPCLEG * ECI)_t + u_t \quad (3)$$

Where β_1, \dots, β_6 are the coefficients of LECI, LGDP, LnGDP², LGOPCLEG, and L(GOPCLEG* ECI) respectively; t is the study period; and u is the stochastic error term. We expect the coefficient

of ECI to be either positive $\left(\beta_1 = \frac{\partial LEP_t}{\partial LECI_t} > 0\right)$ or negative $\left(\beta_1 = \frac{\partial LEP_t}{\partial LECI_t} < 0\right)$ because the complexity-environmental nexus is arguably inconclusive. On one hand, economic complexity worsens ecological quality. For instance, Lee et al.'s (2022a) for 99 countries, while on the other hand, it advances ecological quality. For example, Wan et al. (2022) for India, and Dogan et al. (2021) for OECD nations. Also, since green products' trade increases energy efficiency and technological innovations, thereby lessening ecological damage, we project its elasticity coefficient to be negative $\left(\beta_4 = \frac{\partial LEP_t}{\partial LGOPCLEG_t} < 0\right)$ conforming to the stance of Lee et al. (2022b). Besides, clean energy has been viewed as the avenue for balancing economic progress and stimulating ecological quality. This has made its development a key priority in most nations, especially in the EU. Giving the beneficial effects of clean energy on the ecosystem, we expect its coefficient to be negative $\left(\beta_5 = \frac{\partial LEP_t}{\partial LCE_t} < 0\right)$. Besides, the EKC conjuncture is validated for Germany if β_2 is greater than zero $\left(\beta_2 = \frac{\partial LEP_t}{\partial LGDP_t} > 0\right)$ and β_3 is less than zero $\left(\beta_3 = \frac{\partial LEP_t}{\partial LGDP^2_t} < 0\right)$. The association between income and ecological deterioration is U-shaped if β_2 is less than zero $\left(\beta_2 = \frac{\partial LEP_t}{\partial LGDP_t} < 0\right)$ and β_3 is greater than zero $\left(\beta_3 = \frac{\partial LEP_t}{\partial LGDP^2_t} > 0\right)$. Moreover, if β_2 and β_3 are equal to zero $(\beta_2 = \beta_3 = 0)$, then, no tangible nexus exists between income and environmental contamination. Also, if $\beta_2 > 0, \beta_3 = 0$, it implies, ecological pollution rises as income grows; and if $\beta_2 < 0, \beta_3 = 0$, it means, a decrease in income will lead to a decrease in ecological pollution. It has finally been proven that both economic complexity and green trade influence ecological quality. If these two influence environmental sustainability, then their interaction could also impact ecological quality favorably or unfavorably. Hence, we project the coefficient of the interactive terms to be either positive $\left(\beta_6 = \frac{\partial LEP_t}{\partial L(GOPCLEG*ECI)_t} > 0\right)$ or negative $\left(\beta_6 = \frac{\partial LEP_t}{\partial L(GOPCLEG*ECI)_t} < 0\right)$. Further information on the series is displayed in Table 2.

Table 2: The Variables in view

Variables/Proxies	Given Acronyms	Details of Measurement	Obtained From
Ecological footprint	EP	Ecological footprint per capita that involves carbon footprint and additional components	Global Footprint Network
Economic Complexity Index	ECI	The productive composition appearance of countries as obtained by the aggregation of information on the variety of commodities exports.	OECD Database
Per capital Income	GDP	it is proxied by the gross domestic product per capita (2015 Constant USD)	WDI
Square of Per capital Income	GDP ²	it is proxied by the gross domestic product per capita (15 Constant USD)	WDI
Access to Clean energy	CE	% of total final energy consumption	BP
Green Openness	GOPCLEG	Index	Authors computations
Interaction term	GOPCLEG* ECI	Green openness*Economic complexity index	Authors computations
WDI (World Bank Development Indicator) and BP (British Petroleum)			

Source: authors' compilation

3.2 Econometric Strategies

Understanding the unit root properties of series is critical as a prerequisite to the choice of appropriate econometric methods to be employed in a study. Hence, to begin with, certain unit root tests like augmented Dickey and Fuller WA (1979) (ADF), Phillips and Perron (1988) (PP), and Kwiatkowski, Phillips, Schmidt, and Shin (1992) (KPSS) approaches were carried out on the listed variables. The ADF test can be computed in three different ways. The following are the various scenarios of the test equations;

No trend

$$\Delta Z_t = \theta Z_{t-1} + a_1 Z_{t-1} + a_2 Z_{t-2} + \dots + a_p Z_{t-p} + a_t \quad (4)$$

With intercept

$$\Delta Z_t = a_0 + \theta Z_{t-1} + a_1 Z_{t-1} + a_2 Z_{t-2} + \dots + a_p Z_{t-p} + a_t \quad (5)$$

Intercept and trend

$$\Delta Z_t = a_0 + \theta Z_{t-1} + yt + a_1 Z_{t-1} + a_2 Z_{t-2} + \dots + a_p Z_{t-p} + a_t \quad (6)$$

Where p denotes the lags determined by minimizing the AIC or the SIC. The null and alternative hypotheses of the above cases are stated as;

$$H_0: \theta = 0 \quad (8)$$

$$H_1: \theta < 0 \quad (9)$$

For all three scenarios, the null hypothesis is that the data requires differentiation to make it stationary. The alternative hypothesis under the first two equations is that the data is stationary and requires no differentiation. But in the last case (intercept and trend), the data exhibit trend stationarity and warrants analysis via a time trend in the model. The PP test extends Phillips' (1987) research to scenarios in which the specification includes both a drift and a linear trend. These extensions are crucial for real-world applications where a nonzero drift is frequently present. The test's asymptotic approaches are based on the functional weak convergence theory. The limit distributions of the new test statistics created are reported by Fuller (1976) and are given as functionals of standard Brownian motion. This means that although the PP test allows for considerably more extensive time series parameters, it may still be utilized with existing tabulations. The test investigates the null hypothesis of the unit root condition in contrast to an alternative stance of no unit root in the studied series. The KPSS test, on the other hand, employs a parameterization that logically represents both stationary and nonstationary variables and naturally results in the test of a stationary hypothesis. This test selects a components representation in which the time series under consideration is expressed as the sum of a deterministic trend, a random walk, and a stationary error. The null hypothesis of trend stationary corresponds to the hypothesis that the variance of the random walk equals zero. The one-sided LM statistic for the trend stationary hypothesis is the same as the locally best invariant with additional assumptions that the random walk is normal and that the stationary error is normal white noise. Likewise, running a test to determine whether the series possessed a cointegration association or otherwise is equally worthwhile before exploring the likely elasticities of the determinants. Hence, as a second step, the ARDL bound test of Pesaran (2001) was corroborated with the critical values and appropriate p-values of Kripfganz and Schneider (2020) while assessing the cointegration features of the series. As compared to some other tests for cointegration, the bound test is advantageous because it is vigorous to series with integration order $I(0)$, $I(1)$, or both. The appropriate model for the bound test in the study was specified in equation (4) following Pesaran (2001) and other vast applications in the literature (Göktuğ Kaya et al. 2022; Taiwo et al. 2022; Ay et al. 2020).

$$\begin{aligned}
\Delta LEP_t = & \varphi_0 + \varphi_1 LEP_{t-1} + \varphi_2 LECI_{t-1} + \varphi_3 LGDP_{t-1} + \varphi_4 LGDP^2_{t-1} + \varphi_5 LGOPCLEG_{t-1} + \varphi_6 LCE_{t-1} \\
& + \varphi_7 L(GOPCLEG * ECI)_{t-1} + \sum_{i=1}^p \beta_{1i} \Delta LEP_{t-1} \\
& + \sum_{i=1}^q \beta_{2i} \Delta LECI_{t-1} \\
& + \sum_{i=1}^q \beta_{3i} \Delta LGDP_{t-1} + \sum_{i=1}^q \beta_{4i} \Delta LGDP^2_{t-1} + \sum_{i=1}^q \beta_{5i} \Delta LGOPCLEG_{t-1} + \sum_{i=1}^q \beta_{6i} \Delta LCE_{t-1} + \\
& + \sum_{i=1}^q \beta_{7i} \Delta L(GOPCLEG * ECI)_{t-1} + u_t
\end{aligned} \tag{10}$$

In the specification of model (4), φ_0 and Δ represent the constant and change operator respectively while the parameters φ and β will be evaluated at the lags selected via the AIC are represented by $t - 1$ in line with the specified null and alternative hypothesis in equation 4a and equation 4b accordingly.

$$H_0: \varphi_{1i} = \varphi_{2i} = \varphi_{3i} = \varphi_{4i} = \varphi_{5i} = 0 \tag{10a}$$

$$H_1: \varphi_{1i} \neq \varphi_{2i} \neq \varphi_{3i} \neq \varphi_{4i} \neq \varphi_{5i} \neq 0, \text{ for } i = 1, \dots, 5 \tag{10b}$$

The rule of thumb is that cointegration holds if F-statistic exceeds the upper bound value, otherwise (if it is lesser than the lower bound), the series are not cointegrated. However, if the value lies within the two bounds (upper and lower), then there is inconclusiveness in the final decision. Additionally, the Bayer and Hanck (2013) cointegration test was also employed for robustness checks. This test is advantageous because it incorporates four different tests in its computation as seen in equation (11) equation (12) where PEG, PJOH, PBO, and the PBDM stand for the significance levels of the Engle and Granger (1987) method, the Johansen (1991) technique, Boswijk (1995) method, and the Banerjee et al. (1998) approach in that order.

$$EG - JOH = -2[\ln(PEG) + \ln(PJOH)] \tag{11}$$

$$EG - JOH - BO - BDM = -2[\ln(PEG) + \ln(PJOH) + \ln(PBO) + \ln(PBDM)] \tag{12}$$

In the aftermath of the cointegration confirmation, the elasticities of the regressors were then assessed using the Dynamic ARDL regression estimator of Jordan and Philips (2018). This advanced method

of the traditional ARDL gives more benefits to this work considering its distinct properties. Firstly, assuming that the influence of all other regressors is held constant, the DARDL method can accurately estimate and produce graph plots for the corresponding impacts of a certain regressor on the regressand for both its positive and negative dimensions (Musah et al. 2022b). Secondly, DARDL still produces valid outcomes within series with I(0), I(1) popularly known as mixed order of integration (Sarkodie et al. 2019). Before the application of the method, the level relationship confirmation is necessary, and variables are not expected to go beyond the first order of integration (Jordan and Philips, 2018). The parameter estimations are carried out based on about five thousand simulations following equation (13) (Amin and Dogan, 2021).

$$\Delta(y)_t = \alpha_0 + \theta_0(y)_{t-1} + \theta_1(x_1)_{t-1} + \dots + \theta_k(x_k)_{t-1} + \sum_{i=1}^p (\alpha_i)\Delta(y)_{t-i} + \sum_{j=0}^{q_1} \beta_{1,j}\Delta(x_1)_{t-j} + \dots + \sum_{j=0}^{q_k} \beta_{k,j}\Delta(x_k)_{t-j} + u_t \quad (13)$$

In the above specification, the constant term is denoted by α_0 while the one-year lag of the series is represented by t-1. Also, the change in the regressand is epitomized by $\Delta(y)$ while the lags of the explained variable and regressors are captured by p and q in that order. Finally, the change operator is Δ and the stochastic error component is u . Based on the above specification, the following DARDL model was formulated for our study;

$$\begin{aligned} \Delta LEP_t = & \alpha_0 + \theta_0 LEP_{t-1} + \theta_1 LECI_{t-1} + \theta_2 LGDP_{t-1} + \theta_3 LGDP^2_{t-1} + \\ & \theta_4 LGOPCLEG_{t-1} + \theta_5 LCE_{t-1} + \theta_6 L(GOPCLEG * ECI)_{t-1} + \alpha_i \Delta LEP_{t-1} + \beta_1 \Delta LECI_t + \\ & \beta_2 \Delta LGDP_t + \beta_3 \Delta LGDP^2_{t-1} + \beta_4 \Delta LGOPCLEG_t + \beta_5 \Delta LCE_t + \beta_6 \Delta L(GOPCLEG * ECI)_t + u_t \end{aligned} \quad (14)$$

In equation (14), β_1, \dots, β_6 are the parameter for short-run influence while $\theta_1, \dots, \theta_6$ are the parameter for long-run influence. Also, the constant term for the period t is α_0 and the error term is u given that the change indicator is Δ . To examine the robustness of the DARDL results, the conventional ARDL approach was also checked. Although the approach has some shortfalls, it is however also suitable for within I(0) and I(1) integration like in the case of DARDL technique (Khan et al., 2020; Musah, 2022b; Çevik et al. 2020). The technique can also handle small- or short-time datasets (Haug, 2002), and allows for the selection of different lags for regressors and regressands (Abbasi and Adedoyin, 2021). Following Pesaran and Shin (1995), the ensuing ARDL model was formulated to determine the long-run coefficients of the predictors in equation (15).

$$\begin{aligned}
LEP_t = & \alpha_0 + \sum_{i=1}^p \sigma_{1i} LEP_{t-1} \\
& + \sum_{i=1}^q \sigma_{2i} LECI_{t-1} + \sum_{i=1}^q \sigma_{3i} LGDP_{t-1} + \sum_{i=1}^q \sigma_{4i} LGDP^2_{t-1} + \sum_{i=1}^q \sigma_{5i} LGOPCLEG_{t-1} \\
& + \sum_{i=1}^q \sigma_{6i} LCE_{t-1} + \sum_{i=1}^q \sigma_{7i} L(GOPCLEG * ECI)_{t-1} + u_t
\end{aligned} \tag{15}$$

Where σ denotes the long-run variabilities. The short-run coefficients were also explored via the ensuing specifications as follows.

$$\begin{aligned}
LEP_t = & \alpha_0 + \sum_{i=1}^p \sigma_{1i} \Delta LEP_{t-1} \\
& + \sum_{i=1}^q \sigma_{2i} \Delta LECI_{t-1} + \sum_{i=1}^q \sigma_{3i} \Delta LGDP_{t-1} + \sum_{i=1}^q \sigma_{4i} \Delta LGDP^2_{t-1} \\
& + \sum_{i=1}^q \sigma_{5i} \Delta LGOPCLEG_{t-1} + \sum_{i=1}^q \sigma_{6i} \Delta LCE_{t-1} \\
& + \sum_{i=1}^q \sigma_{7i} \Delta L(GOPCLEG * ECI)_{t-1} + \phi ECT_{t-1} + u_t
\end{aligned} \tag{16}$$

In model (16) above, the short-run variance is denoted by σ while the error correction term that is lagged and its parameter are represented by ECT_{t-1} and ϕ correspondingly. The ECT_{t-1} parameter captures correction speed to the expected equilibrium state from the state of disequilibrium and its value has to be significantly negative and expected to be below one (Khan et al., 2020). It was worthwhile conducting some diagnostic tests on the results. Therefore, the Ramsey Reset test, the Jarque-Bera test, ARCH test, Breusch-Pagan-Godfrey test, and the Breusch-Godfrey test were performed to confirm whether the results were robust or not. As indicated by Musah et al. (2022a), regression techniques do not point to causalities between indicators. Therefore, as a final step, the Engle and Granger (1987) test was adopted since we are dealing with time series in this study (Li et

al., 2022b; Hakan et al. 2022). Following Musah (2022a), the ensuing error correction models were formulated to explore the causalities between the variables;

$$\begin{aligned}
\Delta LEP_t = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LEP_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LECI_{t-j} + \sum_{j=1}^q \varphi_{1,3j} \Delta LGDP_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LGDP^2_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LCE_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{17}$$

$$\begin{aligned}
\Delta LECI_t = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LECI_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LEP_{t-j} + \sum_{j=1}^q \varphi_{1,3j} \Delta LGDP_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LGDP^2_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LCE_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{18}$$

$$\begin{aligned}
\Delta LGDP_t = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LGDP_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LECI_{t-j} + \sum_{j=1}^q \varphi_{1,3j} \Delta LEP_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LGDP^2_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LCE_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{19}$$

$$\begin{aligned}
\Delta LGDP^2 = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LGDP^2 + \sum_{j=1}^q \varphi_{1,2j} \Delta LGDP_{t-j} + \sum_{j=1}^q \varphi_{1,3j} \Delta LECl_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LEP_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LCE_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{20}$$

$$\begin{aligned}
\Delta LGOPCLEG_{t-j} = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LGDP^2 + \sum_{j=1}^q \varphi_{1,3j} \Delta LGDP_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LECl_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LEP_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LCE_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{21}$$

$$\begin{aligned}
\Delta LCE_{t-j} = & \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta LCE_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,3j} \Delta LGDP^2 \\
& + \sum_{j=1}^q \varphi_{1,4j} \Delta LGDP_{t-j} + \sum_{j=1}^q \varphi_{1,5j} \Delta LECl_{t-j} + \sum_{j=1}^q \varphi_{1,6j} \Delta LEP_{t-j} \\
& + \sum_{j=1}^q \varphi_{1,7j} \Delta L(GOPCLEG * ECI)_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned} \tag{22}$$

$$\begin{aligned}
& \Delta(LGOPCLEG * ECI)_{t-j} \\
&= \omega_1 + \sum_{j=1}^q \varphi_{1,1j} \Delta(LGOPCLEG * ECI)_{t-j} + \sum_{j=1}^q \varphi_{1,2j} \Delta LCE_{t-j} \\
&+ \sum_{j=1}^q \varphi_{1,3j} \Delta LGOPCLEG_{t-j} + \sum_{j=1}^q \varphi_{1,4j} \Delta LGDP^2 + \sum_{j=1}^q \varphi_{1,5j} \Delta LGDP_{t-j} \\
&+ \sum_{j=1}^q \varphi_{1,6j} \Delta LECI_{t-j} + \sum_{j=1}^q \varphi_{1,7j} \Delta LEP_{t-j} + \phi_1 ECT_{t-1} + \mu_{1t}
\end{aligned}$$

(23)

In the above equations, φ represents the parameters of the predictors while ω indicates the intercepts. Also, the lagged error correction term alongside its parameter are symbolized by ECT_{t-1} and ϕ respectively, while q denotes the lags selected through the AIC. Moreover, $t = 1, \dots, T$ represents the study period, while μ is the residual term. Finally, Δ denotes the difference operator.

4. Result and Discussion

4.1 Analysis of the Descriptive Statistics

The empirical findings of the study were dealt with in this section beginning with the summary statistics and the correlation coefficient examination. From table 3, which shows the basic measurement of the coefficients under study it was observed that all the understudy variables confirmed a negatively skewed for the analysis span. Moreover, in respect of the dataset's peaks, as indicated by Kurtosis, all factors have light tails except for economic complexity. Again, the VIF shows that there is no multicollinearity among the selected coefficients. For the correlation analysis, it is observed that all the variables (economic complexity, income, green trade, green energy, and LGOPCLEG*LECI) are negatively correlated with the dependent variable ecological footprint.

Table 3. Basic statistics and correlation matrix analysis

	LEP	LECI	LGDP	LGOPCLEG	LCE	LGOPCLEG*LECI
Mean	9.5960	0.1617	10.5479	1.4478	2.3128	0.7535
Median	9.4963	0.6402	10.6342	1.8181	2.3480	1.1904
Maximum	17.9767	0.7191	10.7330	2.0152	2.6776	1.3547
Minimum	0.0129	-1.4848	10.1702	0.2432	1.6929	-0.7079
Std. Dev.	7.3919	0.8478	0.1868	0.6771	0.3027	0.7443

Skewness	-0.0952	-1.2088	-1.0288	-0.8837	-0.3447	-0.9637
Kurtosis	1.1772	2.5448	2.4770	2.0733	1.9287	2.1800
VIF	-	0.0391	0.0005	0.0090	0.0303	0.0354
Correlation						
LEP	1.00					
LECI	-0.2127a	1.00				
LGDP	-0.2215a	0.9440b	1.00			
LGOPCLEG	-0.2256a	0.9499a	0.9303b	1.00		
LCE	-0.1989c	0.3933c	0.6449a	0.4579b	1.00	
LGOPCLEG*LECI	-0.2070a	0.9687a	0.9086a	0.9816a	0.3707c	1.00

Note: ^a, and ^b stand for the significance at 1%, and 5% levels, respectively.

Next, the stationarity characteristics of the factors being examined were investigated using the ADF unit root technique, the PP unit root technique, and the KPSS confirmatory non-unit root analysis, as detailed in Table 4. After accounting for the initial discrepancy, all stationarity tests including KPSS confirmatory analyses agree on stationarity after $I(1)$. Thus, the analysis dataset authorizations the test of $I(1)$ and not $I(2)$. Therefore, it is crucial to examine the long-run features. First of all, the lag length criterion was investigated to ensure that an optimum model was selected, i.e. the most parsimonious model. For this study, it was discovered that lag two serves the analysis best judging by the Akaike information criterion (AIC), which is consistent with the investigation layout as presented in Table 5. As can be seen in Table 6 and Table 7, we apply the ARDL bounds technique and the novel combined cointegration Bayer and Hanck (2013) for our long-run assessment. The results of all the tests indicate that, across the time range examined, the analyzed factors were in a state of long-run equilibrium.

Table 4. Unit root test.

Variable	ADF test		PP test		KPSS test	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LEP	-0.7104	-6.0634a	-2.8823a	-61.4411a	-0.0114	13.1455a
LECI	-0.8732	-4.1772a	-0.9418	-4.1765a	0.0180	4.2394a

LGDP	-0.5897	-4.6635a	-0.6449	-4.6635a	-0.0015	5.0486a
LGOPCLEG	-0.7378	-4.6076a	-0.7264	-4.6063a	-0.0111	5.5199a
LCE	-0.6735	-4.6505a	-0.6827	-4.6456a	0.0723	9.9572a
LGOPCLEG*LECI	-0.9130	-3.9261a	-0.9206	-3.9032a	0.0001	4.9706a

Notes: ^a, ^b and ^c define significance level of 1%, 5%, and 10%, respectively. The probability of KPSS test and the obtained critical values were based on Kwiatkowski et al. (1992).

Table 5. Deciding the Lag criteria for the (ARDL) model.

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	5.8126	NA	4.11e-08	0.0197	0.3179	0.0701
1	103.9283	123.935z	7.39e-11	-6.5187	-4.4310	-6.1654
2	179.0100	47.4200	6.08e-12z	-10.6326z	-6.7554z	-9.9764z

Table 6. The Results for Bounds test.

The F-statistics	significance	For Lower Bound I(0)	For Upper Bound I(1)	The Long-run connection
8.6915	10%	2.26	3.35	Confirmed
	5%	2.62	3.79	
	2.5%	2.96	4.18	
	1%	3.41	4.68	

Table 7: Co-integration test (Bayer-Hanck, 2013) findings

Fisher Type	Check Statistics	CV@1%	CV@5%	CV@10%	Outcome
EG-JOH	22.0561a	12.8044	10.0236	8.6404	Co-integrated
EG-J-BO-BDM	22.0766a	115.0258	8.0163	6.4470	Co-integrated

Note: a implies that the outcome are significant at the 1% level

4.2 Dynamic (ARDL) Simulation Outcomes

The presentations in Table 8 show the simultaneous highlights of the short and long-run dynamics of the roles of the connection between income and its squared components, economic complexity, green trade, green energy, and LGOPCLEG*LECI on ecological footprint of the German economy as initially represented in the baseline regression model. Firstly, from the analysis, the EKC is confirmed in the present investigation. The study's analysis shows that a percentage increase in economic growth will enhance pollution by 0.9437% while a look at its higher (square) value, pollution will reduce by 0.1843% in the long run. In essence, there has been a continued emphasis on economic growth over ecological protection that is initially triggering environmental damages in the European largest economy which were latter cushioned with increased income rise thereby supporting the EKC's validity for the German economy. The outcomes support the arguments made for the hypothesis by Musah et al. (2022) and Agboola et al. (2022) when they analyze the Ghanaian and Turkish economies. For the short-run analysis, the hypothesis validity was consistent. This finding casts doubt on the feasibility of separating ecological integrity from the rate of economic expansion. The outcomes do not contradict our expectations since, at the early stage of growth, the average economic policies are targeted at increasing economic growth, production expansion, and increased job creation. Particularly, ecological considerations do not find a good place on the discussion list when a country's standard of living must be improved at all costs. It is also assumed that after a certain amount of income is reached, the general public's attitude toward the environment will change (Altuntaş et al. 2022; Ilham et al. 2021; Sarpong et al 2023; Gyamfi & Adebayo 2023). To put it in a more elaborate perspective in the submission of Lee et al.'s (2022), people would begin to develop a greater interest in environmental viability unlike the initial rigorous push for growth as seen in most economies at the early stages (Onifade, 2022; Gyamfi et al 2023a, Musah et al 2023, Ofori et al 2023). This proves that after a particular economic level is achieved, people become more concerned about protecting the environment.

Moreover, the findings demonstrate a negative association between complexity and ecological footprint in Germany. We can observe from the analysis that a 1% rise in economic complexity (assuming a zero green openness) results in a 0.5238% reduction in ecological footprint in the long run while in the short run, economic complexity increases emission by 1.5270%. This suggests that the ecological footprint is negatively impacted by economic complexity. This confirms the findings of Agozie et al. (2022) and Lee et al (2022), which found that more complex and technologically advanced

countries also have higher environmental effectiveness. Economic complexity has the potential to serve as a crucial metric for devising roadways and evaluation strategies that foster sustainable and environmentally responsible growth cycles, as exemplified by the "European Green Deal". Additionally, it can aid in evaluating sophisticated specialization plans and sectoral relocation strategies for economic activities that are linked to improved ecological efficiency and reduced ecological footprint (Dogan et al 2021: Adedoyin et al 2023: Gyamfi et al 2023b). Another justification for the adverse impact of ECI on ecological footprint is that an elevation in ECI results in a rise in the demand for cleaner and renewable energy in Germany. The empirical results of the ECI concerning Germany are noteworthy, as they suggest that the productive structure has a significant impact on renewable energy policies. Consequently, the increased utilization of renewable energy sources leads to a reduction in emission levels. The finding from the ECI is both encouraging and precise.

As for green trade, the findings also demonstrate an inverse relation between green trade and ecological footprint in Germany. It was observed that a 1% rise in green trade in the long run (assuming a zero economic complexity) would result in a significant 0.1493% reduction in ecological footprint while it would lead to a 0.8190% insignificant reduction in footprint for the short run case. This finding makes sense, considering the widespread agreement that eco-friendly products are a key factor determining ecosystem health. Ecologically responsible products are tied to global trade. As a result of international trade, countries can source a wide range of environmentally friendly products from other economies as well as produce and sell their own. On the other hand, with this stipulation nations can expand their trade while preserving their natural resources. This analytical result shows that increased commerce in environmentally friendly products (as defined by the green openness index) can aid in slowing down environmental deterioration. This confirms the results of Lee et al. (2022), who apply the concept of green openness to the EU economy, and the findings of Paramati et al. (2021), who utilize environmental patents as a reference for green indices in OECD nations.

However, in both short and long-run cases, it is confirmed that green energy helps the environment by reducing the ecological footprint in Europe's largest economy. This suggests that Germany's ecological footprint is decreasing as a result of the country's increased use of clean energy. Clean energy can be beneficial to the environment and a supportive argument can be seen in the work of Ayobamiji et al (2022) for Columbia, Miao et al (2022) for newly industrialized countries, Bozkaya et al. (2022) for Nordic countries, and Kartal et al (2023) for the US economy. The outcome

demonstrates the idea that the utilization of renewable energy sources enhances environmental health. The countries of the European Union which Germany is a major stakeholder have made major investments in renewable energy, which have paid off. Because of this, they are on schedule to complete the SDGs by the 2030 deadline. Moreover, this conclusion is justifiable as countries pursuing economic growth via the adoption of cleaner and renewable energy sources are more inclined to collaborate with those countries opting for environmentally sustainable technologies. Therefore, increased economic development, particularly in the energy sector of these nations, can aid their respective governments in mitigating their ecological impact. Nonetheless, the adverse impact of renewable energy on the ecological footprint suggests that the nation under examination is making strides toward attaining the sustainable development objectives established by the United Nations (UN) by integrating and enhancing renewable energy technologies.

In addition, the study demonstrates that the connection regarding green openness as well as economic complexity is adverse. From this, we infer that the more complex a country is, the more negatively green openness affects its ecological footprint. Because of the increased complexity of the economy, the influences of expansions in trade on the natural environment may be both obvious and immediate. This outcome lends credence to our claim that economies pursuing traditional growth methods but lacking the technological sophistication and economic complexity necessary to implement green growth strategies may get access to green resources through green-certified trade. In a similar vein, trade liberalization might provide incentives for companies to follow stricter pollution laws. The export sector of a country is particularly vulnerable to the environmental criteria set by major importers at the early stages of economic integration into the global economy. As a result of the ripple effect of implementing the necessary changes up the supply chain to meet these criteria, more environmentally friendly production practices and technology are promoted (Lee et al 2022; Sarpong et al 2023b). The error adjustment aspect (ECT) characterizes the rate of adaptation, and it was valued to be negatively useful (significant), thus suggesting a lasting linkage between the factors under investigation. The predicted value of ECT is -0.8183, which means that 81.83% of the disequilibrium will be corrected in the long run.

Table 8. Findings of ARDL simulations model.

Variables	Coefficients	Stand. Error	Prob.
-----------	--------------	--------------	-------

Cons.	-0.5477b	33.5125	0.0309
LECI	-0.5238b	4.5853	0.0451
Δ LECI	1.5270	9.2818	0.1459
LGDP	0.9437b	23.31488	0.0260
Δ LGDP	0.9984b	40.8239	0.0218
LGDP ²	-0.1843c	0.1614	0.821
Δ LGDP ²	-0.0591	2.0504	0.1773
LGOPCLEG	-0.1493c	5.5745	0.0708
Δ LGOPCLEG	-0.8190	8.5625	0.1949
LCE	-0.7282a	5.6284	0.0036
Δ LCE	-0.6911b	9.9208	0.0029
LGOPCLEG*LECI	-0.1807b	6.1562	0.0235
Δ LGOPCLEG*LECI	-0.4222b	11.1859	0.0234
ECT(-1)	-0.8183a	0.1174	0.0000
R2	0.9439		
Adj. R2	0.9031		
F-Sat.	23.1378a		0.0000
Simulation	5000		
Diagnostics techniques			
B-G LM technique	1.6100		0.2525
B-P-G technique	1.1045		0.4275

ARCH technique	0.6729		0.4234
RESET technique	0.7234		0.3950
J-B technique	2.0177		0.3646

^a, ^b and ^c denote significance at 1%, 5% and 10% level, respectively.

4.3. Diagnostic Checks

Going by Table 8, we can say that the foundation model is fit, as it satisfies all diagnostic checks (such as the serial correlation test, ARCH check, heteroscedasticity check, and model specification test). As a result, our adjusted model can be used to guide policymaking. The blue lines in Figure 6 are for the CUSUM and CUSUMsq graphs. The graphs are presented to show that the model is structurally stable given that the lines are inside the acceptable 5% threshold. This buttresses the reliability of the assessed model. Using dynamic ARDL simulations, we can automatically depict the predicted effects of a genuine regressor modification on the regressand, while keeping all other determinant factors fixed. This analysis shows how ecological footprint levels in Germany change when various independent variables are increased or decreased by 10%. The link between income and the pressure on the ecological environment is depicted in the impulse response graph of Figure 1. The situation in Germany always worsens whenever economic growth increases or decreases by 10% in the short term. However, the ecological impact brought on by accelerated economic growth is becoming increasingly obvious as time passes. Conversely, for every 10% cut in income level, ecological footprint levels decline, and the ecosystem heals itself. The degradation of the environment cannot be stopped with just a 10% cut in economic development.

Figure 1: Income and Ecological Footprint

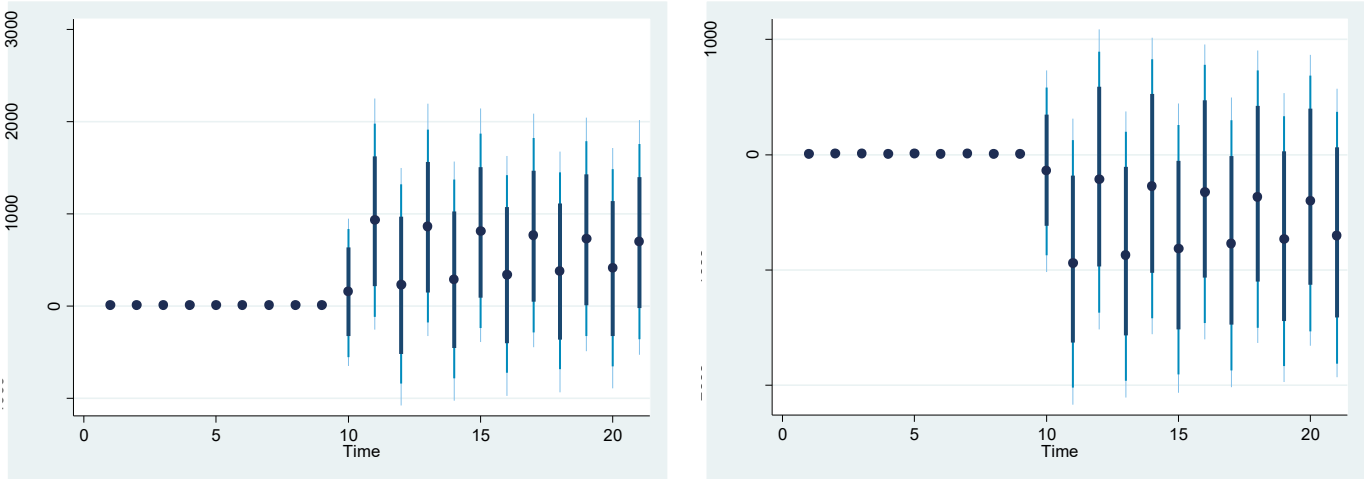


Figure 1 indicates that there is a $\pm 10\%$ response in Germany’s pollutants level to the influence of income. The dots denote the predicted assessment, while the deep blue to light blue lines designates the 75%, 90%, and 95% confidence intervals, correspondingly.

As crucial as economic complexity is to Germany’s economy, it inevitably has negative effects on the country's natural resources. For every 10% change in complexity, ecological destruction increases or decreases in the short run (Figure 2), but an increase in complexity is worse for the ecology in the long run. Undoubtedly, income is responsible for the ongoing ecological crisis in Germany. Therefore, regulators should carefully monitor complexity level in Germany’s economy to enhance the ecosystem's long-term health.

Figure 2. Economic complexity and ecological footprint

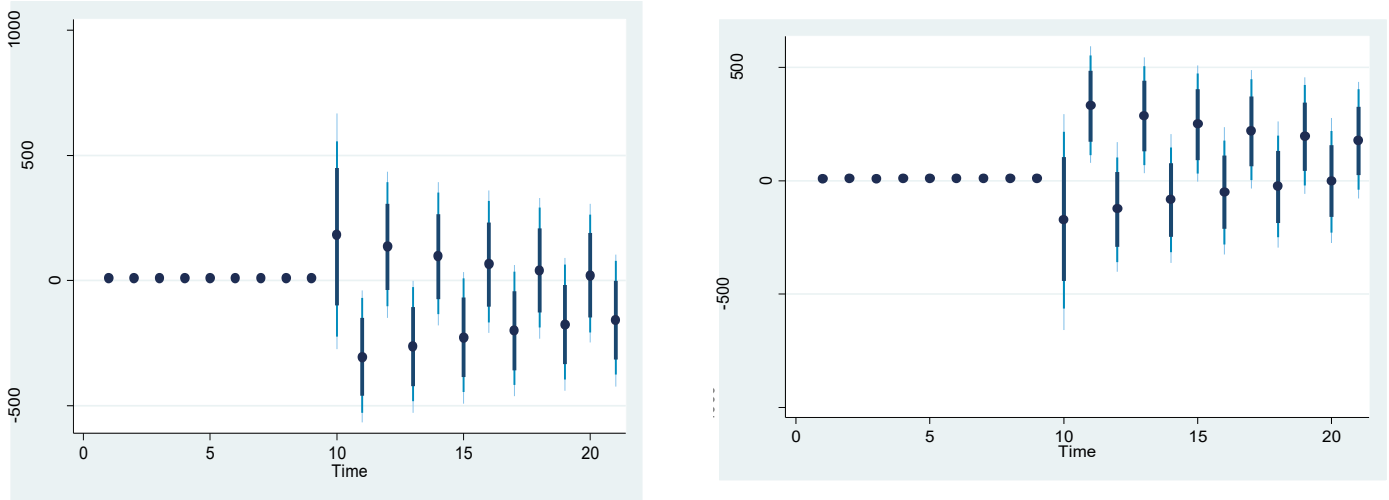


Figure 2 indicates a $\pm 10\%$ response in Germany's pollutants level to complexity and its influence. The dots denote the suggested prediction, while the deep blue up to the light blue lines designate the 75%, 90%, and 95% confidence intervals, correspondingly.

Variations in clean energy, both positive and negative, will induce alterations in ecological footprint levels, as seen in Figure 3. Whether green energy grows or shrinks by 10%, it is evident that this will have a noticeable impact on ecological quality in the near future. In contrast, growing amounts of ecological depletion can trigger environmental improvement following every 10% rise in clean energy adoption. Each 10% decline in clean energy to the horizon enhances ecological integrity, but this is still insufficient to fully increase carbon pollution and produce an unhealthy society.

Figure 3. clean energy and ecological footprint.

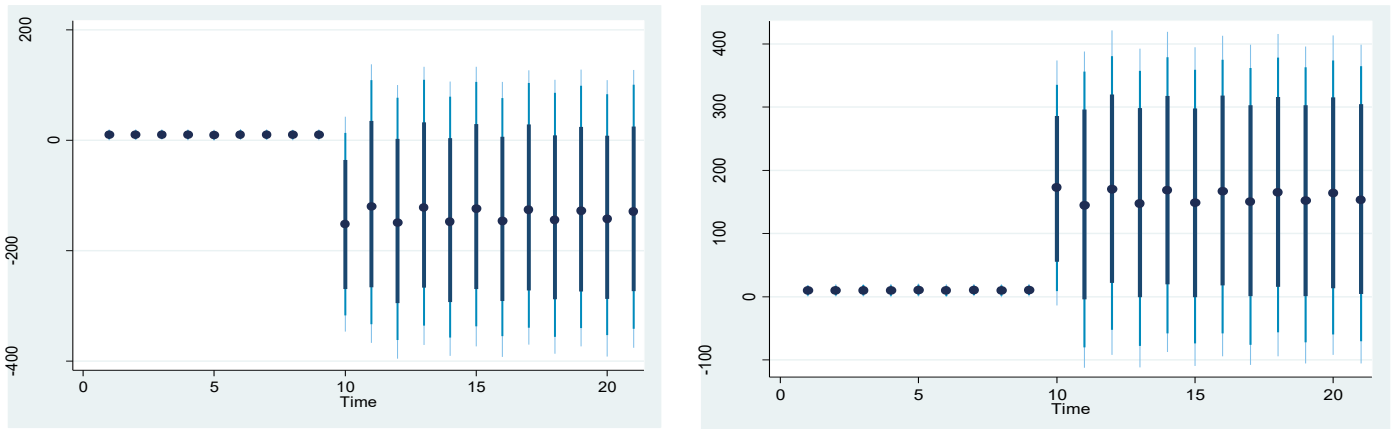


Figure 3 indicates a $\pm 10\%$ response in Germany's pollutants level to clean energy and its influence. The dots denote the predicted assessment, while the deep blue to light blue lines designates the 75%, 90%, and 95% confidence intervals, correspondingly.

Figure 4 displays the impulse response graph of Germany's green openness and ecological footprint. The green openness graph demonstrates that an increase of 10% in green trade has a significant negative effect on both the immediate and distant future state of the ecology. But in the long and short run, a 10% cut would have a negative effect on pollution levels. This suggests that increased trade in Germany has a negative impact on ecological integrity. Thus, Germany should monitor the shift toward adding technology and renewable energy to trade to preserve ecological sustainability.

Figure 4. Green openness and ecological footprint.

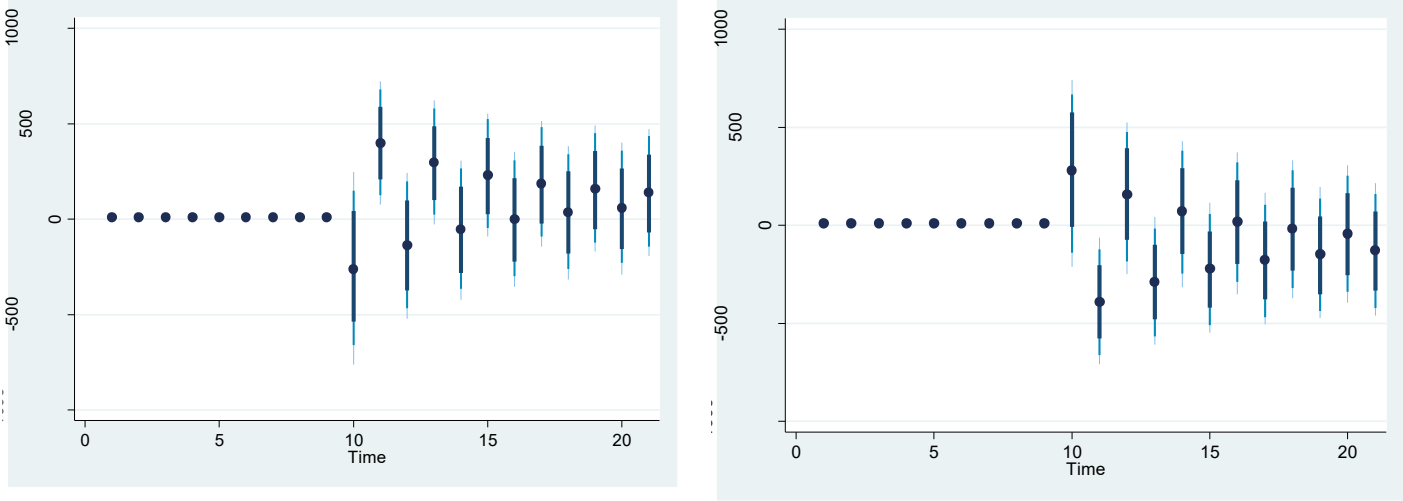


Figure 4 indicates a $\pm 10\%$ response in Germany's pollutants level to Green openness and its influence. The dots denote the predicted assessment, while the deep blue to light blue lines designates the 75%, 90%, and 95% confidence intervals, correspondingly.

The relationship between LGOPCLEG*LECI, as well as ecological footprint, is depicted in Figure 5's impulse response graph. The situation in Germany always worsens whenever the interaction between green openness and economic complexity increases by 10%. However, the ecological impact brought on by accelerated LGOPCLEG*LECI is becoming increasingly obvious as time passes. Conversely, for every 10% cut in the interaction between green openness and economic complexity, pollution levels decline, and the ecosystem heals itself.

Figure 5. LGOPCLEG*LECI and ecological footprint.

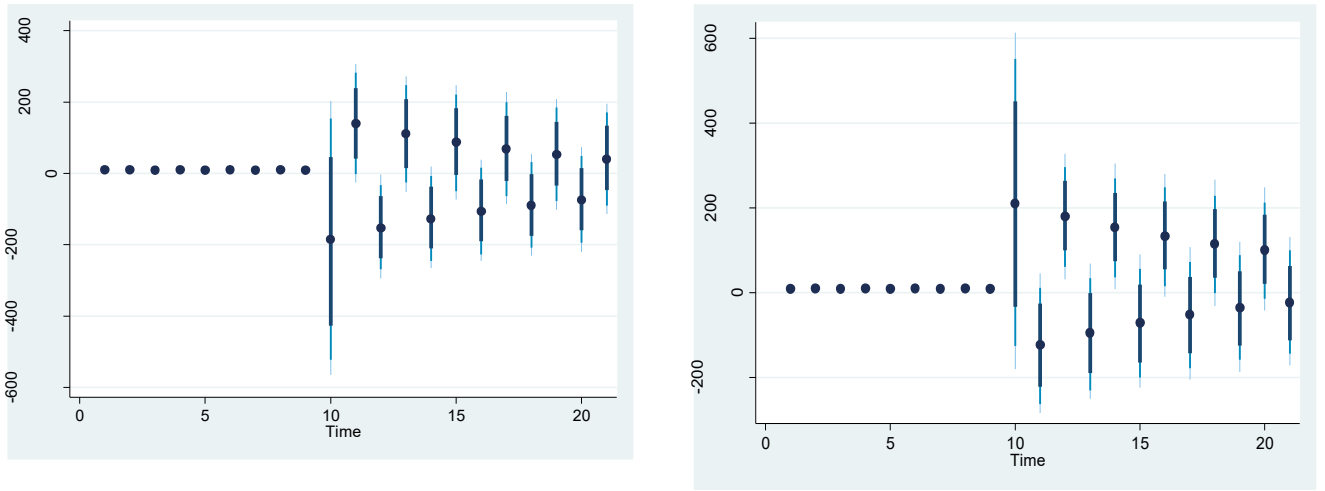
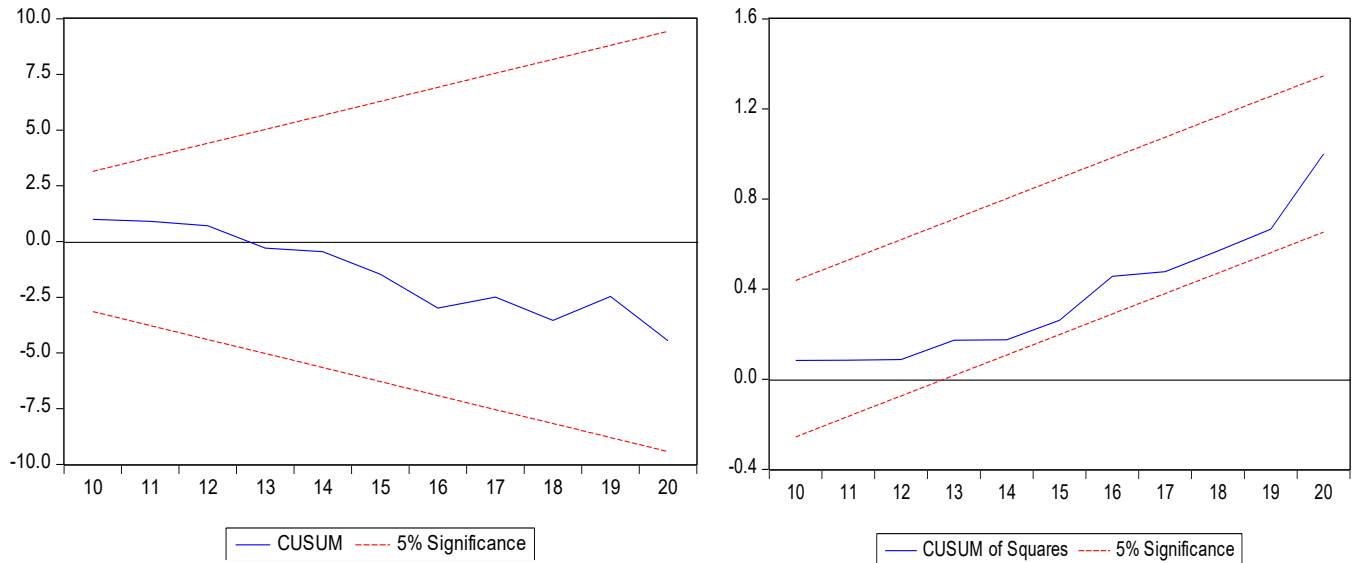


Figure 5 indicates a $\pm 10\%$ response in Germany’s pollutants level to the interaction between green openness and economic complexity and its influence. The dots denote the predicted assessment, while the deep blue to light blue lines designates the 75%, 90%, and 95% confidence intervals, correspondingly.

Figure 6. CUSUM & CUSUM (square) technique.



5. Conclusion and Policy Recommendations

The need to pay more attention to green goods and their potential ecological benefits as a crucial aspect of attaining environmental sustainability has become more pertinent given the global struggle for carbon neutrality. Although the positive roles of green trading have been alluded to in some studies, however, less attention has been given to their roles, especially from the angle of the green commerce-ecosystem nexus. The trade openness index is used to measure the global trade basket in these analyses. Nevertheless, products that are harmful to the ecosystem (not green) are also included in the index. Therefore, to understand the significance of green commodities in achieving carbon neutrality goals, we set out to investigate the environmental impact on the German economy from the years 2000 to 2020. To do this, it is necessary to disentangle the eco-friendly items from the rest of the market. To begin our research, we used the OECD CLEG basket of 255 items to compute an index we term the "Green Openness Index."

Moreover, we built an empirical model to test the EKC hypothesis in light of the analysis that followed the establishment of a long-run connection in the sample series. The dynamic effects of the predictors on the response variable were investigated using the dynamic ARDL simulations method, and the results showed that green openness enhanced ecological benefits in Germany in both the long and short run through the reduction of ecological footprints. The inverted U-Shaped which confirms the presence of EKC was also obtained from the analysis base on income and its square's impact on ecological footprint. However, economic complexity, clean energy as well as LGOPCLEG*LECI were all found to have a favorable impact on Germany's environment.

Giving these results, it is believed that the German economy can leverage these findings to further advance its potential of achieving sustainable development targets, especially from a better ecological perspective. Based on the findings, not only does increasing economic complexity enhance ecological efficiency, but it also improves the ecological quality of international green trade. This is possible since green global commerce helps countries obtain environmentally friendly goods that they cannot economically manufacture on their own. Besides, a country's export sector will become more aware of the sustainability criteria that are put in place by main stakeholders in the global commerce system as the country becomes more integrated into the international system. So, we recommend that the German authority should further enhance the integration of the economy into the global value chain

to encourage more green manufacturing practices and further boost the creation of more eco-friendly goods.

Based on the desirable ecological benefits of green trade as seen from the findings, it's recommended that the German authorities devise an effective policy framework to further boost and sustain green manufacturing. Germany is already a well-known industrial hub in Europe and, by extension, among the leading industrial powers globally. Nevertheless, there is a need to put in place more policy frameworks to boost the share of green commodities in the overall manufacturing outputs. This action is very important for the largest EU economy on two different fronts. Firstly, this will go a long way in facilitating the growing momentum as part of the necessary inputs for sustainable production & consumption, and supportive steps for the required climate actions as stipulated in SDGs 12 & 13 respectively. Secondly, devising adequate policy frameworks to boost and sustain green manufacturing will also help to increase trade in environmentally friendly products.

Some concrete steps that can be taken include supporting green innovative manufacturers with carefully designed subsidy packages and other financial incentives. The authorities can also encourage green manufacturing by providing tax incentives such as implementing minimal or zero duties on the import of needed materials for green manufacturing. Furthermore, considering the beneficial ecological aspect of economic complexity, it is recommended that the German authorities should further develop policy frameworks to facilitate green openness through increased investments in information technology and general environmental education. This is a necessary step towards enhancing a better penetration of information on available opportunities in green businesses for all stakeholders.

To achieve environmental goals in terms of ecological prosperity, authorities must announce a long-term, comprehensive strategy to increase green product trading. The abolition of import tariffs and other forms of restrictions (non-tariff) on eco-friendly goods will be a laudable idea. Green trade negotiations between trading partners could be essential in preventing further environmental damage. The removal of barriers to import would help to rapidly boost consumer surplus on cost-effective green products. Increasing the green trade basket under a liberal economic strategy can assist in improving ecological integrity and move us closer to carbon neutrality.

Limitations and Direction for Future studies

Although the current study provides insightful information on the understudied theme, the study is not without its limitations. The generalization of the overall findings within the context of the German economy in this study to other countries could be potentially misleading given the possibility of country-specific differences. However, this posits a good basis for future studies to examine other economies within or beyond the current framework for a broader comparative analysis.

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