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Greening the Economy: How Forest-Product Trade and Bioenergy Shape the Framework for Green Growth

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Abstract: Green growth aims to foster economic development while ensuring environmental sustainability by optimizing resource use and reducing pollution. Despite growing attention, the nexus between forest trade, bioenergy, and green growth remains underexplored. Therefore, the main aim of this study is to investigate the impact of forest trade and bioenergy on green growth. To that end, we apply cross-sectional autoregressive distributed lag (CS-ARDL) using 33 global economies. The findings of the CS-ARDL show that forest trade helps enhance green growth both in the short- and long run. However, bioenergy significantly boosts green growth only in the long run, while the short-run estimate of bioenergy is insignificant. The estimates of the regional analysis signify that forest trade and bioenergy enhance green growth in both developed and developing economies only in the long run. Policymakers in both developed and emerging economies should focus on boosting forestry trade and promoting bioenergy production to stimulate green growth.

Keywords: forest-product trade; green growth; bioenergy

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1. Introduction

The rapid increase in global temperatures and its harmful effects on human life have made sustainable development a key focus of international debates [1]. In order to combat climate change, several nations are searching for methods and procedures to reduce carbon emissions, a major factor behind ecological degradation and climate change. According to the OECD [2], two international conventions, the Paris Agreement and the 2030 Sustainable Development Agenda, have played a vital role in fostering efforts to improve the ecosystem. The OECD [2] further underlined the significance of the Agenda 2030 for all emerging and advanced economies. Although several nations committed to devising their economic and environmental policies in line with Agenda 2030 and the Paris Agreement, there are notable differences in how these nations pursue ecologically sustainable economic growth.

Given the multifaceted nature of environmental concerns and the failure of a one-size-fits-all approach in resolving these concerns in this era of growing economic activity, we need to find the determinants that contribute to green growth [3]. Green growth analyzes whether economic development is moving toward a greener economy by using natural capital better, and the green growth indicator of the OECD is used to monitor the country's transition to a green and clean economy [4]. In order to achieve the green growth objectives, it is necessary to utilize natural resources sustainably during economic activities. The primary motive of the green economy is to decouple economic growth and environmental degradation while promoting human well-being and reducing intergenerational inequality.

Energy is the most important factor fostering the economic performance of a nation. However, energy is primarily derived from fossil fuels, causing several ecological issues, such as natural resource consumption and rising carbon footprints [5]. The solution to all these ecological concerns is to replace fossil-fuel-driven energy sources with clean and green ones, also known as renewable energy. Bioenergy is seen as a low-carbon, clean energy source, gaining popularity as renewable energy becomes more important [6]. Consequently, policy experts all around the globe are now making a rigorous effort to boost bioenergy production and to make it an integral part of energy mixes worldwide. Bioenergy can contribute to green solutions, as it has the ability to fulfill energy demand without releasing too much carbon during production and consumption activities, which in turn fosters economic and environmental objectives side by side. Moreover, bioenergy also significantly absorbs waste and promotes more efficient land utilization, facilitating the transition to green economic growth [7].

Since forests preserve the equilibrium of the ecosystem, environmental and economic sustainability largely depends on the area under forest cover. Forests reduce the detrimental environmental impacts of economic expansion as they absorb excessive carbon emissions [8]. In recent times, urbanization, agriculture, and socioeconomic issues have hurt the amount of forest cover worldwide, which has worsened the state of the ecosystem [9]. One detrimental factor for forests that has been overlooked is the forest trade. Since the beginning of the twenty-first century, several theoretical discussions have been going on, liberalizing trade regarding forest products. For instance, the "Fourth Ministerial Conference of the WTO" was held in Doha in November 2001, which initiated a new round of talks known as the New Round. The primary focus of this so-called New Round was to liberalize forest trade products by adopting a zero-for-zero tariff structure [10]. Despite the importance of forest trade, its role in achieving green growth has not been discussed extensively. Forest trade can hurt environmental sustainability, as it has the potential to upset the natural balance and resource availability [11]. In contrast, it is also believed that a well-managed forest trade helps foster the sustainability of the ecosystem and boosts regional and national economies [12]. In this respect, the Forest Stewardship Council (FSC) has provided extensive guidelines that are crucial for eco-friendly and sustainable forest management. The guidelines provided by the FSC are vital in promoting forest trade without endangering forests, as they encourage efficient methods of harvesting wood. Hence, the relationship between forest trade and green growth depends on how forest management is carried out.

The theoretical arguments confirm that bioenergy and forest trade impact green growth; however, empirical evidence is unavailable to support these claims. A major part of the contemporary literature on green growth has examined its role in achieving environmental sustainability; recently, some researchers have also estimated the determinants of green growth [13,14]. Nevertheless, no empirical study has estimated the effect of forest trade and bioenergy on green growth. Therefore, a significant gap exists in the green growth literature. Through this study, we intend to close this gap. The main aim of this study is to investigate the nexus between forest trade, bioenergy, and green growth. This study is novel in the following aspects. The study's first novel aspect is its selection of green growth indicators developed by the OECD, which account for both environmental and economic aspects. The second novel aspect of this analysis is the inclusion of bioenergy and forest trade in the green growth function. Thus, the study sheds light on the crucial information on the role of bioenergy and forest trade in fostering green growth. Third, this analysis extends the green growth literature theoretically and empirically, thus providing a foundation for future studies in the same context. The fourth novel aspect of the analysis is the application of the CS-ARDL and PMG-ARDL methods. This study also provides a comparative analysis of developed and developing countries. Figures 1 and 2 report the largest global shares of forest product exports and bioenergy. Lastly, policymakers can utilize the outcomes to design policies to foster green growth.

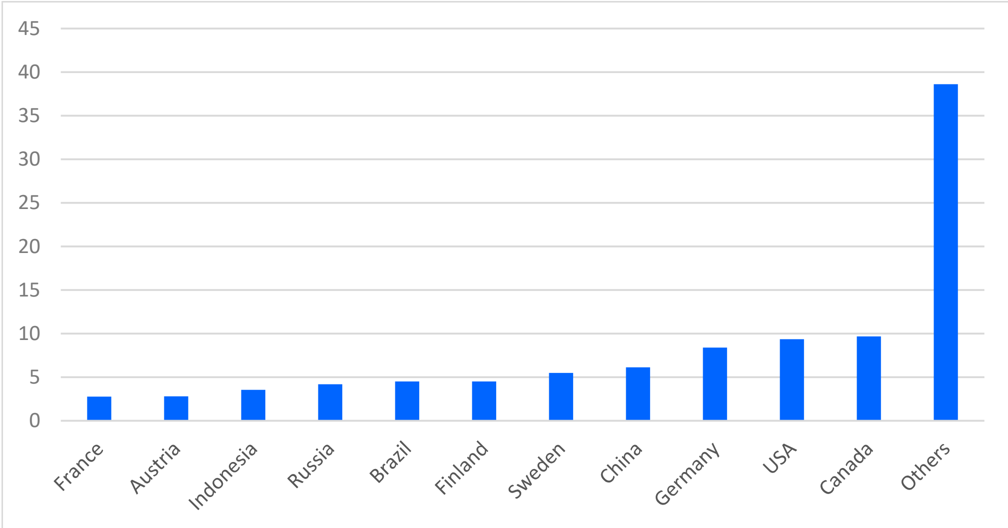

Figure 1. Global share of forest exports (%). Source: authors' calculation based on FAO, 2023 dataset.

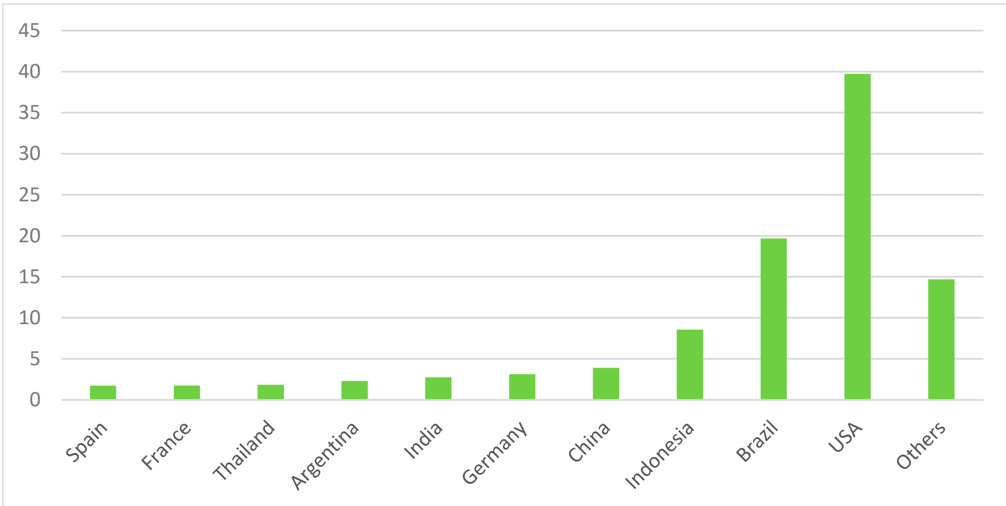

Figure 2. Global share of biofuel production (%). Source: authors' calculation based on EIA, 2023 dataset.

2. Literature Review

Green growth refers to sustainable green economic growth (EG) that is socially inclusive and minimizes the detrimental effect of production activities on the environment [15]. Some other studies document that green growth aims to curb carbon emissions and encourage the development of eco-friendly products [16]. In the present era, forest- and bioenergy have become increasingly significant in the quest of green growth. Bioenergy plays a crucial role in the global transition to sustainable energy. This is crucial for achieving climate targets and fostering a low-carbon economy. Studies such as those by Kumar et al. [17] argued that bioenergy production leads to deforestation and a loss of biodiversity, which causes a detrimental impact on green growth. Research by Eisentraut and Brown [18] described that bioenergy revitalized rural economies by providing new income sources and reducing energy costs for local communities.

Many empirical studies have documented that bioenergy favors EG and enhances environmental quality. Firbank [19] documented the significant role of bioenergy cropping in reducing global GHG emissions for environmental benefit. However, the study also highlighted the positive and negative influence of biofuel crops and bioenergy cultivation on biodiversity. Demirbas and Demirbas [20] highlighted that bioenergy, as a form of renewable energy, has the potential to lower GHG emissions. Moreover, substituting fossil fuels' energy consumption with biomass energy consumption results in an enhancement of the overall environmental quality. Ollikainen [21] discussed the importance of bioenergy consumption for environmental sustainability. Qin et al. [22] reported that bioenergy consumption is a favorable solution to China's environment, food, and energy trilemma. Wu et al. [23] described that bioenergy plays a crucial role in defending the environment and enhances energy security.

Ale et al. [24] stated that the increasing demand for bioenergy has led to an upsurge in agricultural land productivity and shifted land use into biofuel production, thus exerting significant effects on the environment. Similarly, Busu [25] reported bioenergy's positive effect on Romania's sustainable EG. Pathak and Das [26] argued that bioenergy production provides social and economic benefits in addition to the climate and energy goals. Alsaleh and Abdul-Rahim [27] explored the impact of bioenergy industry on economic outgrowth of EU-28 regions. The findings report an increasing impact of bioenergy on EG. Panoutsou et al. [28] highlighted that bioenergy contributes significantly to reducing carbon footprints. Moreover, bioenergy stimulates rural development and creates employment opportunities, thus contributing to social factors and EG. Romero et al. [29] estimated biofuel energy's impact on developing countries' regional economies. The study demonstrated that the proper utilization of the biofuel sector potential can promote energy transition, employment, and production.

Forest trade is another critical factor influencing green growth. Forests play a significant role in carbon sequestration, biodiversity conservation, and ecological balance. Moreover, forest-product trade can drive EG. The literature presents mixed findings on the impact of forest trade on EG and the environment. Gulbrandsen and Humphreys [30] reported that forest-product trade contributes to both the economic and environmental goals of sustainable development. Barbier et al. [31] demonstrated that forest trade contributes to EG if it is accompanied by policies that promote sustainable forest management, reforestation, and biodiversity protection. Stenberg and Siriwardana [32] found that unilateral forest-product trade openness positively affected EG. Hao et al. [33] explored the effect of forest resources on EG using data from thirty provinces of China. The findings affirm positive effects on China's efforts to balance EG, leading to less use of forest resources. Sheppard et al. [34] pointed out that sustainable forest management practices promote EG by ensuring that forest resources are used efficiently. Most recently, Mi et al. [12] explored the impact of forest trade and rural bioenergy on environment using data for twenty-three economies. The study found the negative impact of forest-product trade and rural bioenergy on CO_2 emissions, contributing to environmental sustainability. The literature review concluded that prior studies have examined the bioenergy and forest impacts on economic and environmental sustainability. However, there is a need for empirical research that examines the short- and long-run impacts of the trade of bioenergy and forest products on green growth.

3. Theoretical Framework and Econometric Model

International trade is well acknowledged for its contribution to fostering economic progress. Governments and nations can enjoy several benefits from participating in international trade. International trade enables consumers to access diverse goods and services, allows corporations to benefit from technical advancements from other regions, enables entrepreneurs to market their products globally, and enhances resource efficiency [35]. Theoretically, the idea of comparative advantage drives international trade, and it can benefit all stakeholders [36]. Nevertheless, it is evident that global trade liberalization can have consequences for green economic growth, especially in emerging nations with less strict environmental rules. In light of the pollution haven hypothesis, international trade can prove detrimental for green growth, implying that less stringent environmental laws might lure polluted entrepreneurs to increase their production and the resulting pollution [37]. This might lead to the concentration of pollution-intensive activities in certain locations. As a result, there is a debate about whether trade liberalization without implementing strong environmental regulation is beneficial for green economic growth, as it leads to an escalation in pollution. Conversely, the pollution halo hypothesis posits that trade liberalization may facilitate the exchange of environmentally friendly technology between advanced and emerging countries, decreasing carbon emissions and promoting green growth [38]. In the context of forest trade, the pollution heaven hypothesis states that forest trade blocks green growth if not performed under sustainable forest management practices and strict environmental regulations. Though, the pollution halo hypothesis posits that forest trade can promote green growth if forest trade is managed sustainably. Popova et al. [39] reported that the trade of agricultural products plays a favorable role in sustainable development. In support, Mikhno et al. [40] noted that environmental trade policy positively impacts the green economy.

Energy is widely acknowledged as an essential element of the manufacturing process in all businesses, since it plays a crucial role in increasing EG [41,42]. The main cause of environmental deterioration is the growing dependence on traditional energy sources, which leads to increased carbon footprints. Energy consumption is widely recognized as the main factor causing the decline in environmental quality. As a result, authorities are making efforts to minimize energy consumption, regulate emissions, and reduce reliance on energy sources derived from fossil fuels by encouraging their efficient use [43]. Moreover, raising the share of renewable energy within the overall energy mix is a viable strategy for achieving these goals. Biomass, as an abundant and sustainable energy resource, promotes both economic and environmental sustainability [44]. Therefore, based on the theoretical framework, we have made the following green investment model:

$$\mathrm{GG_{it}} = \delta_0 + \delta_1\mathrm{FT_{it}} + \delta_2\mathrm{BE_{it}} + \delta_3\mathrm{ET_{it}} + \delta_4\mathrm{PS_{it}} + \delta_5\mathrm{HC_{it}} + \delta_6\mathrm{FDI_{it}} + \mathrm{e_{it}} \quad (1)$$

The subscripts i = 1, 2, . . ., 33 represent global countries, while t = 1, 2, . . ., T corresponds to the years from 2000 to 2022. GG signifies green growth that depends on forest trade (FT), bioenergy (BE), environmental technology (ET), political stability (PS), foreign direct investment (FDI), and human capital (HC), respectively. Forest trade and bioenergy are expected to have a positive effect on GG. Forest-product trade enhances green growth by promoting the sustainable use of forest resources while contributing to economic development, as bioenergy production enhances green growth by driving the transition to green economy. Moreover, bioenergy helps reduce greenhouse gas emissions, essential for promoting GG.

4. Econometric Methods

4.1. Cross-Sectional Dependence and Slope Heterogeneity

In order to identify significant connections within a panel analysis, cross-sectional dependence (CSD) tests are used to avert biased parameter estimates. While estimating panel analysis, CSD tests are essential diagnostic tools that enhance the reliability of model specifications, estimation techniques, and statistical results. Due to the growing financial and economic interconnection seen in several situations, CSD is important [45]. For confirmation of the CSD, we employ the Pesaran's [46] CSD.

$$CSD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right)} \quad (2)$$

Moreover, the slope homogeneity test is conducted as presented by Pesaran and Yamagata [47]. The null hypothesis shows slope homogeneity, and the alternative hypothesis shows slope heterogeneity.

4.2. Panel Unit Root

The CIPS unit root test is an advanced variant of the IPS unit root test used in this research to identify whether a series contains a unit root [48]. This approach is effective in panel analysis, advantageous for a large number of panel observations, and addresses the limitations of cross-sectional dependency. Thus, CIPS surpass its first-generation counterparts, as first-generation tests fail to account for CSD, while checking the stationary properties of the variables. The unit root test is essential for assessing the credibility and accuracy of data, guiding appropriate data transformations and modeling, mitigating erroneous outcomes, and enhancing the quality of economic forecasts and conclusions [49]. To obtain CIPS, we apply the following equation:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{it-1} + \gamma_i \overline{Y}_{t-1} + \varphi \Delta \overline{Y}_t + \varepsilon_{it} \tag{3}$$

where $\overline{Y_t}$ represents the cross-sectional averages. The mean value helps reduce the contemporaneous correlation among Y_{it}. Where the cross-sectional averages are highlighted by $\overline{Y_t}$, which is used to lower the contemporaneous correlation among Y_{it}. In Equation (3), we can extract the null and alternative hypothesis: H0: $\beta_i = 0$ for all i is the null hypothesis, and H1: $\beta_i < 0$ for some i is the alternative hypothesis. The CIPS test is represented by the following equation, designed by Pesaran [48]:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T) \tag{4}$$

4.3. Westerlund Cointegration Test

The research used the Westerlund [50] cointegration methodology, which resembles time-series cointegration but imposes some limitations and offers superior error correction. It facilitates the long-term equilibrium of several variables and tolerates structural breaks; however, it is vulnerable to lag duration. This test provides two types of statistics: group (G_τ, G_α) and panel (P_τ, P_α) statistics. Sharif et al. [51] stated that the thumb role of accepting cointegration between the variables is that one-group and one-panel statistics must be significant. The formula is articulated as follows:

$$G_\tau = N^{-1} \sum_{i=1}^{N} \frac{\theta_i}{SE(\theta_i)} \tag{5}$$

$$G_\alpha = N^{-1} \sum_{i=1}^{N} \frac{T\theta_i}{\theta_i(1)} \tag{6}$$

$$P_\tau = \frac{\theta_i}{SE(\theta_i)} \tag{7}$$

$$P_\alpha = T\theta_i \tag{8}$$

4.4. CS-ARDL

This study utilizes the panel data that vary across time (*t*) and countries (*i*). This type of data is considered superior to time series and cross-sections. Since the panel is a combination of time series and cross-sections, it offers more observations, variability, and information. Panel data are a special type of data; hence, they require special estimation techniques. First-generation estimation techniques, such as fixed effect, random effect, 2SLS, and GMM, do not address CSD and heterogeneity. In contrast, if both the number of (*t*) and (*i*) are large, as in our case, where the number of years is 23 and the number of countries is 33, we should employ the panel cointegration techniques, such as FMOLS, CS-ARDL, and DCCE. This research utilizes the framework Chudik and Pesaran [52] established, an advanced econometric method known as the CS-ARDL model. We choose CS-ARDL because it can accommodate the variables with I(0) and I(1), while other techniques do not have this quality. Another reason for selecting the CS-ARDL is its ability to offer short-and long-run estimates simultaneously, and this quality is missing in other approaches. Further, the CS-ARDL can also control the issues of CSD and endogeneity, which allows it to provide robust estimates. To ensure robustness, we use the PMG-ARDL, which provides both short-term and long-term results and accommodates a combination of I(0) and I(1) variables in the framework. Below, we will discuss the advantages and limitations of the CS-ARDL in detail.

The CS-ARDL demonstrates superiority over other methodologies in several aspects. The simultaneous generation of short-term and long-term estimations is the most distinctive characteristic of this approach [53]. Secondly, macro variables exhibit integration at I(0) and I(1), while the majority of panel regression methodologies need I(1); nonetheless, the CS-ARDL may accommodate variables with differing orders of integration [54]. Consequently, it outperforms all other methodologies in the study of macroeconomic series and omits pre-unit-root testing from the first evaluation. Ultimately, the CS-ARDL represents an enhanced iteration of the ARDL and belongs to the category of dynamic common correlated estimators. The CS-ARDL approach offers robust estimates by including lagged values of cross-sectional mean and outcome variables, thereby addressing CSD and endogeneity issues [55]. Moreover, mean group estimations may be conducted even when the slope coefficients exhibit variability. Ultimately, this method is dependable even with few samples. However, the results are sensitive to the lag length; thus, we need to be careful while adopting the lag length. The equation representing the CS-ARDL framework is expressed as follows:

$$\Delta GG_{it} = 6_i + \kappa_i \left(GG_{it-1} - Y_i Z_{it-1} - \eta_{1i} \overline{GG}_{t-1} - \eta_{2i} \overline{Z}_{t-1} \right) + \sum_{j=1}^{p-1} \delta_{ij} \Delta GG_{it-j} + \sum_{j=0}^{q-1} \lambda_{ij} \Delta Z_{it-j} + \partial_{1i} \Delta \overline{GG}_t + \partial_{2i} \Delta \overline{Z}_t + e_{it} \quad (9)$$

where the green growth (ΔGG_{it}) is the outcome variable, while Z_{it} represents the regressors in the long run. The PMG-ARDL methodology proposed by Pesaran et al. [56] has been used to assess robustness. This technique is characterized by its acceptability for varied coefficients for each nation and data aggregation from diverse units. Thus, the approach simultaneously depends on data that fluctuates between cross-sectional and time series, mitigating the problem of autocorrelation in the residuals. This method also accommodates variables with varying integration orders, such as I(0) and I(1). An additional benefit of this method is that it provides simultaneous short-term and long-term outcomes. Figure 3 outlines the steps of the econometric approach.

Figure 3. Steps of econometric methodology. Source: authors' calculation.

5. Data and Descriptive Analysis

This study explores the impact of forest product trade and bioenergy on green growth using 33 global economies from 2000 to 2022. The dependent variable, green growth (GG), is measured as pollution-adjusted GDP growth, sourced from the OECD. The mean score of GG is recorded as 2.873, ranging from −22.40 to 22.30. Bioenergy (BE) is measured as biofuels production in quad Btu. The data for bioenergy come from the EIA, with a low average value of 0.066 quad Btu, but varies significantly from 0.000 to 1.707. Forest trade (FT) data are sourced from the FAO. They are measured through total forest trade (1000 USD), averaging 15.45 with a variation between 12.43 and 18.09. Following green growth literature, we have chosen a few control variables, such as environmental technology, political stability, human capital, and FDI. Environmental technology helps in green growth by promoting efficient resource use and reducing environmental harm [57]. Prior literature documents the positive effect of environmental technology on GG [58]. Environmental technology (ET) is measured by total environment-related patents and the data are obtained from the OECD. The mean score of ET is 6.020, ranging from 1.386 to 12.54. Political stability is chosen, as it is considered as a significant determinant of green growth and green investment. A stable government attracts more investments in green economy [59]. The political stability (PS) data series is obtained from the WDI and is measured by the estimate of political stability and the absence of violence and terrorism. Political stability data range from −2.376 to 1.759, with an average of 0.447. Human capital is also considered essential for enhancing green growth. As documented in the human capital theory, well-educated and skilled workers are more capable of managing new technologies and reducing environmental damage, which all contribute to sustainable green growth [60]. Human capital (HC) is measured by school enrollment at the secondary level in gross percent. The data series is collected from the WDI, which shows a mean of 4.624 ranging from 1.887 to 5.356. Lastly, following the pollution halo hypothesis, FDI is included as a control variable, as it supports green growth by facilitating the transfer of green technology and capital to host economies [61]. The net inflows of FDI measure FDI as a percentage of GDP, sourced from the WDI. The FDI series has a mean of 1.063, ranging from −6.524 to 4.668. A detailed description of variables and sources are given in Table 1. The panel dataset contains some missing values in the original data. Therefore, following Gao et al. [62], the missing data are determined using the extrapolation method.

Table 1. Variables description and sources.

Variable	Definitions	Sources	Mean	Std. Dev.	Min	Max
Green growth (GG)	Pollution-adjusted GDP growth (%)	OECD	2.873	3.542	−22.40	22.30
Bioenergy (BE)	Biofuels production (quad Btu)	EIA	0.066	0.222	0.000	1.707
Forest trade (FT)	Total forest goods trade (1000 USD)	FAO	15.45	1.264	12.43	18.09
Environmental technology (ET)	Environment-related technologies (total patents)	OECD	6.020	2.224	1.386	12.54
Political stability (PS)	Political stability and absence of violence/terrorism: estimate	WDI	0.447	0.749	−2.376	1.759
Human capital (HC)	School enrollment, secondary (% gross)	WDI	4.624	0.285	1.887	5.356
Foreign direct investment (FDI)	FDI, net inflows (% of GDP)	WDI	1.063	1.151	−6.524	4.668

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets.

The VIF test is used to assess the presence of multicollinearity among the variables. Table 2 reports the outcome of VIF test. VIF values under 5 indicate low multicollinearity, which is generally acceptable. However, VIF values ranging from 5 to 10 suggest moderate multicollinearity, while values above 10 confirm the absence of serious multicollinearity issues [63]. In our case, all the VIF scores are below 5, confirming the absence of a serious multicollinearity issue. ET has the highest VIF of 2.70, indicating a low level of multicollinearity, with a 1/VIF value of 0.370. Similarly, FT shows a VIF of 2.64 and a 1/VIF of 0.379. PS, BE, HC, and FDI exhibit lower VIF values, ranging from 1.15 to 1.29, with corresponding 1/VIF values between 0.775 and 0.868, indicating low multicollinearity. The VIF values close to 1 suggest that these control variables are largely independent of each other. The mean VIF across all variables is 1.70, suggesting that multicollinearity is generally low in the model.

Table 2. VIF test.

Variable	VIF	1/VIF
ET	2.70	0.370
FT	2.64	0.379
PS	1.29	0.775
BE	1.26	0.796
HC	1.16	0.862
FDI	1.15	0.868
Mean VIF	1.70	

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets.

6. Empirical Results and Discussion

Before estimating the regression, it is essential to conduct key preliminary analyses. In Table 3, the estimates of CSD test are significant at the 1% level, confirming strong CSD across all variables. In the next step, we have confirmed the slope homogeneity among variables. Table 4 outlines the results of the homogeneity test. All the variables are found to be statistically significant, which confirms the rejection of null for slope homogeneity. Thus, these findings confirm the strong evidence of slope heterogeneity for all variables, indicating that the relationships between the variables differ across the cross-sections in the model. The presence of CSD and heterogeneity suggests the second-generation unit root tests. Thus, our study has used CIPS test; the results are in Table 5. The CIPS test results reveal a mixed integration order. Specifically, GG, PS, and FDI are stationary at I(0), whereas BE, FT, ET, and HC are non-stationary at I(0) but achieve stationarity at I(1). In the last step, we assessed the presence of a LR equilibrium relationship among the variables with the help of the Westerlund cointegration test. In Table 6, the Westerlund cointegration test results indicate that the G_τ, P_τ, and P_α statistics are all highly significant, suggesting strong evidence of cointegration. The G_α statistic is significant at the 10% level. Overall, these results indicate the existence of a LR cointegrating relationship.

Table 7 reports the PMG-ARDL and CS-ARDL results. BE has a significant and positive effect on GG in both models in the LR, but the effect remains insignificant in the SR. The LR estimates are 0.830 in the CS-ARDL and 0.687 in the PMG-ARDL. It indicates that a 1% upsurge in BE would lead to 0.830% rise in GG in the CS-ARDL and 0.687% in PMG-ARDL. First, we note that bioenergy has a favorable relationship with GG. This outcome matches our initial forecasts. This finding is backed by Kiehbadroudinezhad et al. [64], who demonstrated that bioenergy enhances GG. A possible reason for this is that bioenergy contributes to GG by enhancing energy security and rural development. The study of Du et al. [65] described that bioenergy plays a crucial role in reducing environmental pressures by lowering carbon emissions that increase GG. Moreover, bioenergy promotes sustainable agricultural practices, which further support GG. The study of Magne et al. (2024) [66] supported our results and infers that modern bioenergy has the potential to achieve multiple SDGs in the South American region. The IEA [67] report supports our arguments and findings, indicating that bioenergy has contributed to local economic development while reducing reliance on imported fossil fuels in developing economies. The implementation of bioenergy in many African countries is marvelous, because it provides basic welfare and economic activity, as it meets more than 90% of household energy needs [68]. EIA [69] statistics show that global bioenergy production has had substantial growth over the past two decades, from 0.421 quad Btu in 2000 to 4.295 quad Btu in 2022. This development has positively impacted global green growth.

Table 3. CSD test.

	GG	BE	FT	ET	PS	HC	FDI
Pesaran's test	23.53 ***	6.102 ***	55.48 ***	21.17 ***	11.19 ***	19.34 ***	7.866 ***
Prob.	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Off-diagonal elements	0.340	0.461	0.631	0.414	0.363	0.426	0.213

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets. Note: *** $p < 0.01$.

Table 4. Homogeneity test.

	GG	BE	FT	ET	PS	HC	FDI
$\hat{\Delta}$	6.923 ***	6.837 ***	14.34 ***	9.720 ***	10.99 ***	10.52 ***	5.787 ***
$\hat{\Delta}_{adj}$	8.761 ***	8.652 ***	18.15 ***	12.30 ***	13.90 ***	13.31 ***	7.323 **

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets. Note: *** $p < 0.01$, ** $p < 0.05$.

Table 5. CIPS test.

	I(0)	I(1)
GG	−2.031 ***	
BE	−1.031	−3.665 ***
FT	−1.606	−5.019 ***
ET	−1.161	−3.649 ***
PS	−2.402 ***	
HC	−1.515	−4.103 ***
FDI	−3.430 ***	

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets. Note: *** $p < 0.01$.

Table 6. Westerlund cointegration test.

Statistic	Value	z-Value	*p*-Value
G_τ	−2.174 ***	4.344	0.000
G_α	−7.081 *	1.320	0.093
P_τ	−9.937 ***	3.427	0.000
P_α	−5.286 ***	3.267	0.001

Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets. Note: *** $p < 0.01$, * $p < 0.1$.

Table 7. CS-ARDL and PMG-ARDL estimates.

	CS-ARDL	PMG-ARDL
Long run		
BE	0.830 ***	0.687 **
	(0.308)	(0.348)
FT	1.064 ***	1.426 ***
	(0.407)	(0.253)
ET	1.555 *	1.072 ***
	(0.927)	(0.181)
PS	1.818 **	1.445 ***
	(0.871)	(0.326)
HC	2.762 **	2.939 ***
	(1.296)	(0.730)
FDI	0.513	0.545
	(0.484)	(0.378)

Table 7. *Cont.*

	CS-ARDL	PMG-ARDL
Short run		
BE	0.779	0.670
	(0.705)	(0.595)
FT	0.745 *	1.313 *
	(0.422)	(0.702)
ET	1.390	0.308
	(0.998)	(0.607)
PS	2.808 **	2.942 ***
	(1.339)	(0.944)
HC	1.443	1.110
	(1.598)	(1.663)
FDI	0.561	0.369
	(0.420)	(0.233)
C		27.26 ***
		(2.922)
ECM(-1)	−0.661 ***	−0.514 ***
	(0.065)	(0.053)
Observations	759	759
Number of countries	33	33

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets.

FT shows a significant and positive effect on GG in both models in the LR and SR. The LR (SR) estimates are 1.064 (0.745) in the CS-ARDL and 1.426 (1.313) in the PMG-ARDL. This indicates that a 1% upsurge in FT would lead to a 1.064% rise in GG in the CS-ARDL and a 1.426% upsurge in the PMG-ARDL in the LR. Meanwhile, a 1% upsurge in FT is associated with a 0.745% upsurge in GG in the CS-ARDL and a 0.313% rise in the PMG-ARDL in the SR. This finding is rather clear institutionally, because forest goods are made from wood and other resources produced by forests. Aside from its positive effects on the environment, sustainable forest trade also enhances living conditions in the surrounding areas, creates jobs, and encourages the growth of society equitably and reasonably. Mi et al. [12] provide support for these empirical findings. Fair-trade practices and certification schemes provide incentives for protecting and using natural resources, which ensure the ethical procurement of forest products. Fair-trade policies and certification programs are crucial in ensuring that timber goods are produced based on sustainable practices because they provide financial incentives for sustainable usage and conservation. Since timber products are regarded as green goods, trading in them may have a major positive influence on reducing the detrimental effect of trade. Green technology and practices may be adopted quickly with proper legislation and international collaboration, leading to higher innovation, more employment, and rapid economic development in encouraging the trade of green commodities. Chen et al. [70] supports the forest trade outcome by pointing out that trading in green goods enhances environmental sustainability. Conversely, the research study by Sasaki [71] noted the positive influence of timber production on ecological quality. The study by Khan and Magda [72] contends that a nation's involvement in international trade increases its likelihood of encountering adverse environmental effects that impede sustainable development goals. FAO [73] statistics indicate that forest trade increased from 298.8 million USD (in thousands) in 2000 to 637.9 million USD (in thousands) in 2022. This development in forest trade has a favorable impact on green growth.

In the LR, ET exhibits a significant and positive impact on GG in both models, with LR estimates of 1.555 in the CS-ARDL and 1.072 in the PMG-ARDL. This indicates that a 1% upsurge in ET would lead to a 1.555% rise in GG in the CS-ARDL and a 1.072% upsurge in the PMG-ARDL. However, the effect of ET on GG is insignificant in the SR. PS demonstrates a significant and positive influence on GG in both the LR and SR across the models. In the CS-ARDL, the LR (SR) estimates are 1.818 (2.808), while in the PMG-ARDL, these estimates are 1.445 (2.942). This reveals that a 1% upsurge in PS would result in a 1.818% upsurge in GG in the CS-ARDL and a 1.445% rise in the PMG-ARDL in the LR. Similarly, in the SR, a 1% upsurge in PS results in a 2.808% upsurge in GG in the CS-ARDL and a 2.942% rise in the PMG-ARDL. HC exhibits a significant and positive influence on GG in the LR in both models, with estimates of 2.762 in the CS-ARDL and 2.939 in the PMG-ARDL. This means that a 1% upsurge in HC would result in a 2.762% rise in GG in the CS-ARDL model and a 2.939% upsurge in the PMG-ARDL. However, in the SR, the effect of ET on GG is found to be insignificant. Although FDI positively influences GG in both models in the LR and SR, the estimates are statistically insignificant. In the CS-ARDL, the ECM(−1) coefficient is −0.661, while in the PMG-ARDL, the ECM(−1) coefficient is −0.514. These negative and significant coefficients indicate that any SR deviations from the LR equilibrium will be corrected at rates of 66.1% in the CS-ARDL and 51.4% in the PMG-ARDL, implying a steady adjustment process to equilibrium over time. Figure 4 shows a summary of the results.

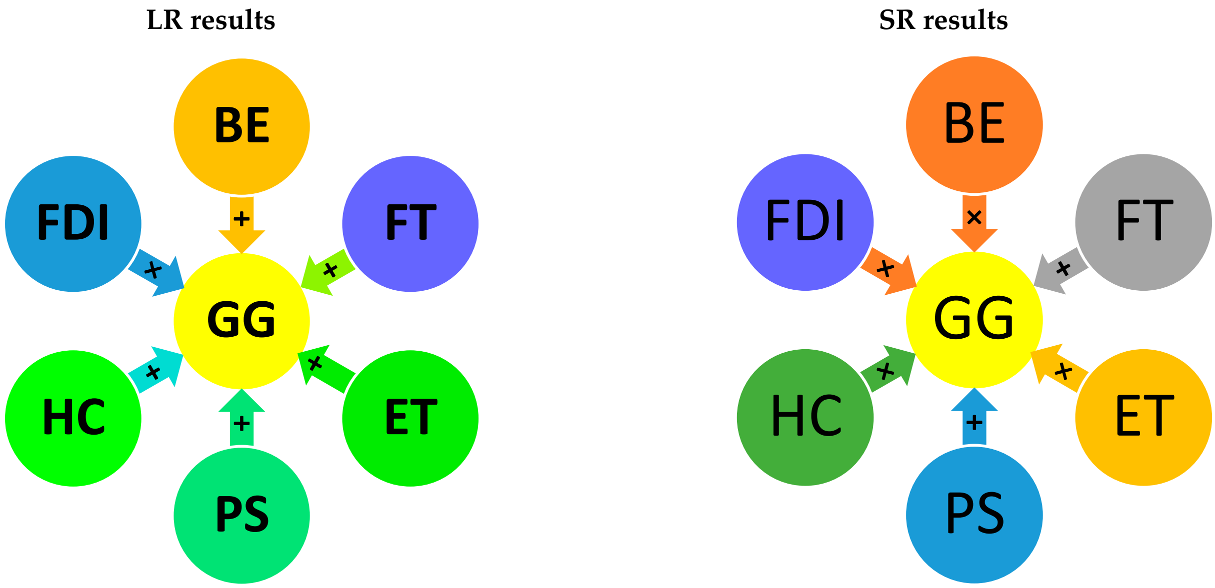

Figure 4. Results summary. Note: +: positive effect; ×: No effect. Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets.

Group-Wise Estimates

Table 8 presents the CS-ARDL and PMG-ARDL estimates for developed and developing countries. The estimated coefficients of BE and FT are statistically significant and positive across all four regression models in the LR, indicating that bioenergy production and forest trade are significant factors that play a crucial role in encouraging green growth in both developed and developing economies. However, both variables report statistically insignificant effect on GG in the SR in all four regression models. According to the CS-ARDL, a 1% upsurge in BE leads to a 0.912% boost in GG in developed economies and a 0.671% upsurge in developing economies over the LR. Similarly, in the PMG-ARDL, a 1% rise in BE enhances GG by 0.771% in developed economies and 0.476% in developing economies over the LR. The results depict that the effect of BE on GG is more substantial in developed economies. In the CS-ARDL, a 1% upsurge in FT results in a 0.927% rise in GG for developed economies and a 1.107% rise for developing economies. Likewise, the PMG-ARDL shows that a 1% upsurge in FT boosts GG by 1.467% in developed economies and 2.716% in developing economies in the LR. These findings reveal that FT has a stronger impact on GG in developing nations than in developed nations.

ET reports a significantly positive effect on GG only in developed economies in the LR and SR across CS-ARDL and PMG-ARDL. The estimated coefficients indicate that a 1% improvement in ET would enhance GG by 1.216% (0.396%) in the LR and 1.836% (1.139%) in the SR in the CS-ARDL (PMG-ARDL) regressions in the developed countries. The estimates of PS are significant and positive across all four regression models in the LR, but remain statistically insignificant across all models in the SR. According to the CS-ARDL, a 1% rise in PS leads to a 2.443% upsurge in GG in developed economies and a 2.159% upsurge in developing economies in the LR. Similarly, in the PMG-ARDL, a 1% upsurge in PS enhances GG by 1.593% in developed economies and 2.389% in developing economies in the LR. The impact of HC on GG is found significantly positive in developed and developing economies in the LR only in the PMG-ARDL. The estimates show that a 1% upsurge in HC would enhance GG by 2.377% in the developed economies and 2.091% in the developing economies in the LR. The SR estimates of HC are found to be insignificant in our analysis. FDI is significantly and positively connected with GG only in developed economies across both CS-ARDL and PMG-ARDL in the LR and SR. The estimated coefficients indicate that a 1% rise in FDI would enhance GG by 1.164% (0.565%) in the LR and 0.890% (0.529%) in the SR in the CS-ARDL (PMG-ARDL) in the developed countries. In developed economies, the ECM coefficient is −0.671 (−0.585) in the CS-ARDL (PMG-ARDL), both significant at the 1% level, indicating a strong adjustment speed toward LR equilibrium following SR shocks. Similarly, for developing economies, the ECM coefficients are −0.749 (−0.528) in the CS-ARDL (PMG-ARDL), also significant at the 1% level. These results suggest that developing economies exhibit a slightly faster adjustment process in the CS-ARDL model compared to developed economies, while both groups show significant convergence in both models.

Table 8. Group-wise estimates.

	Developed Economies		**Developing Economies**	
	CS-ARDL	**PMG-ARDL**	**CS-ARDL**	**PMG-ARDL**
Long run				
BE	0.912 ***	0.771 *	0.671 *	0.476 *
	(0.200)	(0.446)	(0.400)	(0.250)
FT	0.927 *	1.467 ***	1.107 **	2.716 ***
	(0.537)	(0.244)	(0.504)	(1.039)
ET	1.216 ***	0.396 **	0.847	0.765
	(0.381)	(0.175)	(0.866)	(0.476)
PS	2.443 **	1.593 ***	2.159 **	2.389 *
	(1.068)	(0.317)	(0.942)	(1.375)
HC	1.180	2.377 ***	1.209	2.091 *
	(1.809)	(0.726)	(1.101)	(1.121)
FDI	1.164 **	0.565 ***	0.232	0.526
	(0.528)	(0.075)	(1.512)	(0.721)
Short run				
D(BE)	0.109	0.429	0.654	0.504
	(0.802)	(0.563)	(0.627)	(0.529)
D(FT)	0.123	0.553	0.392	0.485
	(0.617)	(0.754)	(0.943)	(0.773)
D(ET)	1.836 **	1.139 *	1.671	1.329
	(0.772)	(0.584)	(1.605)	(1.395)
D(PS)	1.276	1.031	1.865	1.028
	(1.761)	(1.175)	(2.086)	(1.340)
D(HC)	0.380	0.199	−0.443	0.287
	(0.809)	(0.533)	(0.511)	(0.658)
D(FDI)	0.890 **	0.529 **	−0.223	−0.067
	(0.432)	(0.227)	(1.105)	(0.575)
C		33.24 ***		10.36 ***
		(3.485)		(2.181)
ECM(−1)	−0.671 ***	−0.585 ***	−0.749 ***	−0.528 ***
	(0.083)	(0.059)	(0.102)	(0.124)

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: authors' calculation based on OECD, 2023, EIA, 2023, FAO, 2023, and World Bank, 2023 datasets.

7. Conclusions

The conventional economic framework is detrimental to environmental sustainability, as it prioritizes economic growth over ecological goals. To counter this situation, the concept of GG arises, which simultaneously focuses on economic and environmental goals by decoupling economic growth and carbon footprints. Due to its advantages, the popularity of GG has significantly increased over the past few decades, and policymakers and empirics are striving to find the determinants of GG. In this regard, the role of bioenergy and forest trade has never been estimated before, leaving a visible gap in the GG literature. The main objective of this analysis is to investigate the impact of bioenergy and forest trade on GG. We apply CS-ARDL, a novel approach that can estimate the short and LR connection between forest trade, bioenergy, and GG. The findings of the CS-ARDL model highlight that bioenergy significantly boosts GG only in the LR, while the short-run estimate of bioenergy is insignificant. However, the forest trade helps enhance GG both in the short and LR. In addition, environmental technologies, political stability, and human capital significantly exacerbate GG in the LR, while only political stability positively impacts GG in the short run. The estimates of the regional analysis signify that bioenergy, forest trade, and political stability enhance GG in both developed and developing economies in the LR only. In contrast, environmental technologies and foreign direct investment only foster GG in the LR in developed economies. The short-run regional estimates are mostly insignificant.

7.1. Policy Implications

The outcomes of this analysis have significant policy suggestions for policymakers. First, bioenergy has a positive impact on GG. This suggests policymakers should enhance their investment in bioenergy sources and increase their share in the total energy mix. Since rural regions are the ideal places for generating bioenergy sources, increasing research and development activities regarding generating alternative energy sources in rural regions should be a viable policy option for fostering bioenergy generation. Moreover, research and development spending on bioenergy can also lead to the development of second-generation bioenergy resources made from non-food-based biomass sources. The second-generation bioenergy sources are less detrimental to the ecosystem and help decouple economic activities and carbon emissions. The government should also spread the knowledge regarding the benefits of bioenergy and how to control its adverse impact on the ecosystem. Fostering public–private investment could significantly boost the production of bioenergy. In addition, the government should provide financial incentives, such as subsidies and tax rebates, for investment in big bioenergy power plants, which would significantly reduce the risks attached to such investments. Second, forest trade also promotes GG. Consequently, policymakers in both developed and developing economies should augment the proportion of forest trade within overall trade. Nevertheless, policymakers should consider a more careful approach as forest wood is the main driver of forest trade. Thus, it is suggested that the government should support the sustainable utilization of forests by designing policies that endorse green forest management methods. This will guarantee that forest trade is supported by products produced from sustainably managed sources. Government officials must compel forest merchants to engage in “reforestation and afforestation” initiatives to safeguard forest cover and ecosystem. Additionally, to maximize the tangible advantages of the forest trade for indigenous people, raise their quality of life, and guarantee the preservation of forest resources, policy formulation should be carried out by keeping the promotion of fair trading standards in mind.

Most of the advanced economies are working within the guidelines of the sustainable forestry initiative (SFI) and the forest stewardship council (FSC), ensuring that most forest products in these economies are sourced from sustainably managed forests. As a result of these techniques, the total deforestation rate in the advanced economies has significantly decreased, hence promoting biodiversity and increasing the global market for forest products. Consequently, policymakers must design policies in accordance with SFI and FSC, which promote sustainable management practices and facilitate green growth. Likewise, developing economies have achieved notable advancements in forest certification under the umbrella of SFI and FSC. Urbanization and industrialization are increasing in developing economies, placing more strain on the nation's forest resources and necessitating the formulation of sustainable forest management rules. Hence, policymakers in developing economies following the footprint of the advanced economies should focus on sustainable forest management within the framework of SFI and FSC. Developing economies should also focus on urban forests. Moreover, both developed and developing economies should increase the production of second-generation biofuels that are less detrimental to the ecosystem and contribute to green growth. Investing more in the R&D in second-generation biofuels should be the way forward for both advanced and emerging economies.

7.2. Limitations and New Directions

Indeed, this study has made some useful contributions to the existing body of knowledge. Since asymmetry is the common trait of most of the macro series, using linear modeling may lead to wrong and biased outcomes. Therefore, future studies are suggested to estimate the nexus between forest trade, bioenergy, and GG using non-linear modeling. Moreover, the study utilizes the green index developed by OECD while ignoring other indicators such as sustainable development and GDP by WDI. Estimating the impact of bioenergy and forest trade on different indicators of GG can add more value to analysis. Lastly, a global analysis of the nexus between bioenergy, forest trade, and GG can increase the applicability of the results across different economies in diverse socioeconomic environments, such as low-income, middle-income, and high-income environments. Thus, future studies should conduct a global analysis.

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