

Article

Does Green Transition Hurt the Poor? Evidence from Developing Countries

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Abstract

This study examines whether the green transition alleviates or exacerbates poverty in developing countries, utilizing a dynamic panel dataset of 74 developing economies from 2000 to 2022. The paper investigates four key dimensions of the green transition: ecological footprints, green finance (proxied by public investment in renewable energy), renewable energy production, and renewable energy consumption. The findings reveal a compelling “green transition paradox”. While renewable energy production, green finance, and economic growth contribute significantly to poverty reduction, renewable energy consumption is adversely associated with higher poverty levels. This suggests that, in the absence of sufficient supply capacity and robust institutional support, the demand-side transition toward renewable energy may impose short-term economic burdens on vulnerable populations. Furthermore, ecological footprint exhibits a poverty-reducing effect, underscoring the reliance on resource-intensive economic expansion in developing economies, albeit with potential long-term environmental trade-offs. The results remain robust across alternative model specifications and exhibit heterogeneous across income and regional groups. The study contributes to the extant literature by disentangling the supply and demand mechanisms of renewable energy, thereby highlighting the complex distributional consequences of green transition policies. Ultimately, the policy implications emphasize the critical need to align renewable energy expansion with social protection, skill development, and inclusive financial frameworks to ensure that green transformation fosters both environmental sustainability and poverty alleviation.

Keywords: poverty; sustainable development goal; green finance; renewable energy; ecological footprint; green transition



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1. Introduction

The persistence of extreme poverty and the intensification of climate change represent two of the most pressing global challenges in the 21st century. Despite significant progress in recent decades, the goal of eradicating extreme poverty by 2030, as outlined in the United Nations Sustainable Development Goals (SDGs), remains increasingly difficult to achieve. Recent global crises, including the COVID-19 pandemic, geopolitical tensions, and energy price shocks, have further slowed poverty reduction efforts and disproportionately affected vulnerable populations. At the same time, the urgent need to mitigate climate

change has accelerated the transition toward low-carbon and environmentally sustainable economic systems.

The transition to a green economy is widely regarded as a key pathway to achieving sustainable development. By promoting renewable energy, reducing environmental degradation, and encouraging green investment, this transformation is expected to generate long-term economic, social, and environmental benefits. However, the short-term distributional effects of green transition policies remain ambiguous, particularly in developing countries, since many trade-offs from primary steps of transition may impact its long-term effectiveness. Requirements on infrastructure for green development and high risk of investment in this field could lead to burden of investment costs in short term, exacerbating energy price and inequality which make the poor become poorer [1,2]. Structural changes in energy systems, production processes, and labor markets may create adjustment costs that disproportionately affect low-income groups. According to Zeb, Ullah [3], not all green transition could ensure for sustainability, especially when it does not provide enough green investment to adapt with structure change. The rising living costs and environmental degradation from rapid growth in the short term can push vulnerable groups into temporary impoverishment. Without social safety nets, livelihood protection policies, and rigorous social impact assessment standards, the costs of green transition tend to fall heavily on the most vulnerable groups, creating ambiguity and distributive inequalities in developing countries. Therefore, despite the growing attention devoted to green transition, an important question remains unresolved: Does green transition alleviate or exacerbate poverty?

A growing body of empirical literature highlights the complex relationship between green transition and poverty. It remains profoundly fragmented, yielding multidimensional and contradictory findings [4,5]. On the one hand, proponents of the win-win scenario assert that renewable energy development and green finance contribute to poverty alleviation [6–9] especially the expansion of RE production fostering job creation, enhancing energy autonomy, and directly reduce poverty rates [10,11]. Conversely, the trade-off perspective raises stringent warnings regarding transition cost barriers, wherein the mandatory shift toward RE consumption acts as a regressive tax that depletes the constrained budgets of low-income households. This inadvertently exacerbates the impoverishment risk and economic vulnerability of the poor in the short term [1,12,13]. These mixed findings point to the potential existence of a “green transition paradox,” whereby policies aimed at enhancing environmental sustainability may unintentionally harm vulnerable populations if not properly designed. However, existing empirical studies predominantly focus on renewable energy consumption, frequently overlooking renewable energy production (REpro) as a distinct driver of poverty alleviation. Moreover, there is a notable dearth of research integrating both the supply and demand sides within a unified estimation framework. Consequently, previous estimations often fail to capture this energy transition paradox, potentially leading to misguided policy implications. It is given that REpro reflects macro-level energy capacity while consumption captures micro-level demand [14]. The issue of unilaterally by either separating the boundaries between macroeconomic production and microeconomic consumption, or amalgamating them into a single proxy variable could led to ambiguous conclusions that obscure the true distributional impacts of the energy system on poverty [4,15]. By explicitly disentangling these two opposing mechanisms, this research not only demystifies the decarbonization paradox but also provides critical empirical foundations for formulating Just Transition policies, ensuring that ecological conservation efforts do not come at the expense of the poor.

One important limitation of the existing literature is the tendency to treat green transition as a homogeneous process, often measured using a single indicator such as REcons or

green finance. Actually, green transition is a broad and multidimensional process encompassing structural changes in energy systems, technological innovation, financial markets, environmental governance, and sustainable production and consumption. This study does not attempt to capture every dimension of the green transition. Instead, it focuses on four core pillars that directly reflect the environmental and financial mechanisms underpinning the transition in developing countries, namely green finance, renewable energy production, renewable energy consumption, and ecological footprint. At first, green finance represents the financial mechanism supporting environmentally sustainable investments. Second, REpro reflects the supply side transformation of the energy system. Third, REcons captures the demand-side adoption of clean energy. Finally, ecological footprint is incorporated as an integrated indicator measuring the environmental effectiveness of the transition by accounting for the ecological pressure generated by human activities. Therefore, this study defines green transition as the combined process through which financial resources facilitate renewable energy development and improve environmental sustainability, ultimately influencing poverty outcomes in developing countries. These four dimensions are selected because they jointly represent the major channels through which countries mobilize green investment, expand clean energy supply and demand, and improve environmental sustainability. Therefore, throughout this study, the term green transition refers specifically to these four interconnected dimensions rather than the broader concept.

This study addresses research gaps mainly from the empirical and conceptual design. Specifically, instead of relying on a composite green transition index or a single proxy, this study decomposes green transition into four interconnected dimensions representing financial, energy supply, energy demand, and environmental sustainability. The study demonstrates that the poverty implications of green transition depend on interactions among these dimensions rather than individual green policies. Furthermore, it distinguishes between the supply and demand sides of renewable energy, an aspect that has received limited attention in the existing literature. This approach allows for the identification of a “green transition paradox,” whereby REcons may increase poverty while REpro contributes to its reduction, allowing for a more nuanced understanding of how different stages of the transition affect poverty outcomes. In addressing the traps of growth-pollution and green transition cost creating short term burden to the poor, this research raises three questions: (1) Does multidimensional green transition alleviate or exacerbate poverty in developing countries? (2) Amidst the paradox of rising emissions and the burden of green transition costs, what is the divergent impact of REpro and REcons on poverty reduction goals? (3) And is there a trade-off between ecological sustainability and poverty reduction during the transition process? These questions will be addressed by utilizing a two-step System GMM approach for 74 developing economies.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature. Section 3 presents the data and methodology. Section 4 discusses the empirical results. Section 5 concludes with policy implications.

2. Theoretical Section: Green Transition and Poverty

The relationship between the green transition and poverty has become a central topic in the context of sustainable development, reflecting the growing recognition that environmental and socio-economic objectives are deeply interconnected. While the transition toward a low-carbon economy is essential for mitigating climate change and ensuring long-term sustainability, its short-term implications for poverty reduction remain highly debated, particularly in developing countries. These economies are often characterized by structural constraints, including limited fiscal space, weak institutional capacity, and

high dependence on traditional energy sources, which may amplify the distributional consequences of green transition policies [7,16,17].

From a theoretical perspective, the impact of the green transition on poverty operates through several interrelated channels, primarily involving income and employment effects, price dynamics, and structural transformation processes. On the one hand, the expansion of environmentally sustainable sectors can stimulate economic activity, promote technological innovation, and generate employment opportunities, thereby contributing to poverty reduction [18–20]. Investments in renewable energy infrastructure, in particular, is associated with job creation, increased productivity, and improved energy security, all of which can enhance household welfare and reduce vulnerability.

On the other hand, the transition toward cleaner energy systems may impose significant short-term adjustment costs. One of the most important transmission mechanisms in this regard is the price channel. The adoption of renewable energy technologies often involves high initial capital costs, especially in developing economies where technological diffusion is limited and financial markets are underdeveloped. As a result, the transition may lead to higher energy prices, particularly in contexts where fossil fuel subsidies are reduced or eliminated [21,22]. Given that low-income households allocate a larger share of their income to energy consumption, such increases can disproportionately affect vulnerable groups and potentially exacerbate poverty and inequality.

In addition to price effects, the green transition also entails structural transformation processes that may have uneven distributional consequences. The reallocation of resources from traditional, carbon-intensive sectors toward greener industries can lead to job losses in the short run, particularly among low-skilled workers who face barriers to transitioning into new sectors. In the absence of adequate labor market policies and skill development programs, these adjustment costs may outweigh the potential long-term benefits of the transition, thereby increasing poverty in the short term [23,24].

Despite the growing body of empirical literature, an important limitation remains the tendency to treat the green transition, and renewable energy in particular, as a homogeneous process. Most existing studies rely on aggregate indicators, such as total REcons or composite indices of green development, without distinguishing between different dimensions of the transition [9,17,25–27]. However, this aggregation may obscure important heterogeneities and lead to inconsistent or even contradictory findings.

In this regard, a crucial distinction can be made between the supply side and the demand side of renewable energy. REpro reflects the expansion of energy supply capacity and is closely linked to investment, industrial development, and technological progress. By increasing domestic energy production, countries can reduce their dependence on imports, stabilize energy supply, and foster economic growth, all of which are conducive to poverty reduction [28–30]. Furthermore, large-scale renewable energy projects often generate employment opportunities and stimulate local economies, reinforcing their positive socio-economic effects.

In contrast, REcons captures the extent to which renewable sources are integrated into the overall energy mix. While this shift is essential for achieving environmental objectives, it may also generate short-term economic pressures if not supported by sufficient supply capacity and cost-reducing mechanisms. In particular, the transition toward REcons may lead to higher energy costs, reduced affordability, and unequal access to energy services, especially in developing countries with limited infrastructure [31,32]. Pereira, Marques [33] investigating for 15 EU economies during 2005–2015 reflects that the increase in energy cost from energy transition leads to disadvantage of poor households. The research of Adom, Amuakwa-Mensah [1] confirm this when mention that the requirements of high investment on innovation technology and infrastructure of RE leading to a pressure to increase energy

price while energy is inelasticity product, the poor encounters with more difficulties due to lowering their spending on education, healthcare, and foods for maintaining energy consumption; income inequality make the situation become even worse to the poor. As a result, the effects of REcons on poverty may differ significantly from those of renewable energy production.

This distinction provides the basis for identifying a potential “green transition paradox.” While several studies document the poverty-reducing effects of renewable energy development and green investment [6,34], others highlight the adverse socio-economic consequences associated with the transition, particularly in its early stages [21,23]. By failing to differentiate between the supply and demand dimensions of renewable energy, the existing literature may overlook the coexistence of these opposing effects. Consequently, a more disaggregated approach is needed to capture the complexity of the relationship between green transition and poverty.

Another critical factor shaping the outcomes of the green transition is the role of green finance. Initially, green finance was understood in a narrow sense as capital flows invested in environmental protection projects, such as renewable energy or waste management [27]. The scope of this concept has expanded significantly overtime. In a modern approach, green finance is defined as a system of financial activities, which include capital mobilization, allocation, and management, that support sustainable development goals, particularly reducing carbon emissions, adapting to climate change, and protecting ecosystems. This concept is not limited to individual financial instruments, but also encompasses the entire financial system, including banks, capital markets, insurance, and international financial institutions [35]. By mobilizing financial resources toward environmentally sustainable investments, green finance facilitates the development of renewable energy infrastructure and accelerates the adoption of clean technologies [36–38]. Due to the scarcity of green finance data in developing countries since this financial market is underdeveloped and opaque, the majority of existing research has predominantly concentrated on developed economies. Furthermore, green technological innovations require substantial initial capital and are characterized by high risks and long payback periods, making them inherently less attractive to private investors. Consequently, public investment plays an indispensable catalytic role as a seed fund, stimulating subsequent private sector participation during the primary stages of the transition [11,27]. Unlike private investment, which is primarily driven by financial returns, public investment in renewable energy simultaneously targets broad social security objectives. Therefore, utilizing public investment in renewable energy as a proxy for green finance in developing countries is theoretically justified, positing that it contributes to poverty reduction by mitigating long-term energy costs, expanding access to modern energy services, and generating robust employment opportunities. Moreover, green finance can alleviate the adverse distributional effects of the transition by underpinning inclusive policy frameworks, such as targeted subsidies and skill development programs [23,39,40].

However, the effectiveness of green finance depends critically on the broader institutional and economic context. In countries with weak governance structures or inefficient financial systems, green investments may not reach the most vulnerable populations, limiting their poverty-reducing impact. Furthermore, the benefits of green finance may take time to materialize, reinforcing the importance of considering both short-term and long-term effects when analyzing the relationship between green transition and poverty.

The ecological footprint is incorporated into the analysis to capture the environmental pressure associated with economic activity. In the context of developing countries, a higher ecological footprint is often linked to increased industrialization and resource utilization, which may contribute to economic growth and poverty reduction in the short

term [34,41,42]. However, this relationship also reflects a fundamental trade-off between economic development and environmental sustainability. Numerous studies have confirmed for the impact of environmental degradation on poverty, the EF is still not widely used as CO₂ emission on this driven role of poverty even though it is considered as a more precise way to describe multidimension aspects of environmental degradation. Contradict results are also found for the impact of this environmental degradation factor on poverty alleviation. Xu, Wang [8] confirms the negative impact of carbon emission on poverty reduction in 30 provinces of China period 2010–2021; whereas, Jin, Fu [21] proves that it is a positive effect. From another perspective, Yu and Liu [43] show the impact of environmental degradation on poverty is non-linear and mention that it turns into a reversed impact when estimation changes from short run to long run. In addition, poverty is also proved to be positive correlation with EF by many studies [44–47]. While resource-intensive growth can improve living standards, it may also lead to environmental degradation and long-term risks that undermine sustainable development [27,48]. This suggests that the relationship between ecological footprint and poverty is likely to be context-dependent and potentially non-linear.

An additional explanation for the mixed empirical evidence in the literature lies in differences in institutional quality, market development, and the stage of economic transition. In economies with well-developed financial systems and strong governance, the benefits of the green transition are more likely to be broadly distributed, enhancing its poverty-reducing effects. In contrast, in countries with weaker institutional frameworks, the transition may exacerbate existing inequalities, as the costs are borne disproportionately by vulnerable groups while the benefits are unevenly distributed.

Moreover, the timing of the transition plays a crucial role. In the early stages, renewable energy technologies are often associated with high costs and limited scalability, which may increase energy prices and reduce affordability. Over time, however, technological progress, economies of scale, and policy support tend to reduce costs and improve accessibility, thereby strengthening the poverty-reducing potential of renewable energy. This dynamic perspective helps reconcile the conflicting findings in the literature and underscores the importance of distinguishing between short-term and long-term effects.

Finally, the broader macroeconomic environment plays a key role in shaping poverty dynamics. Economic growth remains a fundamental driver of poverty reduction, although its effectiveness depends on inclusiveness and the distribution of income gains [49,50]. Remittances are another important factor, providing a stable source of income for households and contributing to poverty alleviation [51,52]. In contrast, inflation can have adverse effects by eroding purchasing power, particularly among low-income households [16,53,54]. Urbanization and trade openness may also influence poverty outcomes, depending on their ability to generate employment opportunities and improve access to markets and services [55–58].

Taken together, these considerations highlight that the relationship between green transition and poverty is complex, multidimensional, and context-dependent. Building on this framework and addressing the limitations of the existing literature, this study develops a set of testable hypotheses that explicitly distinguish between renewable energy production, renewable energy consumption, green finance, and ecological footprint, thereby providing a more nuanced understanding of the distributional effects of the green transition.

3. Data and Methodology

3.1. Data and Variables

This study uses a balanced panel dataset of 74 developing countries over the period 2000–2022. The selection of countries is based on data availability and consistency across all variables included in the analysis.

The dependent variable is poverty, proxied by the poverty headcount ratio at \$3.65 per day (2017 PPP), which captures the proportion of the population living below the international extreme poverty line. The key explanatory variables reflect different dimensions of the green transition. First, ecological footprint is used as an indicator of environmental pressure and resource use, capturing the extent to which economic activities rely on natural resources. Second, green finance is proxied by public investment in renewable energy, reflecting the role of financial resources allocated to environmentally sustainable projects. Third, REpro represents the supply side of the energy transition, measured as renewable sources. Fourth, REcons captures the demand side, reflecting the extent to which renewable energy is used within the overall energy mix.

In addition to the main variables of interest, the model includes several control variables that are commonly associated with poverty dynamics. Economic growth is measured by GDP per capita, reflecting overall economic performance. Remittances are included as a source of external income that may alleviate poverty. Inflation captures macroeconomic instability and its impact on purchasing power. Urbanization reflects structural transformation processes, while trade openness accounts for integration into the global economy.

All variables are transformed into natural logarithms where appropriate to reduce skewness and allow for elasticity-based interpretation of the estimated coefficients.

The dataset consists of variables drawn from internationally recognized sources, including the World Bank’s World Development Indicators (WDI), the Global Footprint Network, and energy-related databases, ensuring a high degree of consistency, reliability, and cross-country comparability (Table 1).

Table 1. Variables and data sources.

Indicators	Variables	Unit	Source
Poverty headcount ratio at \$3.65/day (2017 PPP, %)	POV	Percentage	SDG report of SDSN dashboards.sdginde.org
Total Ecological Footprint	lnEF	Global Ha per person	Footprintnetwork.org
Green finance (public investment on renewable energies)	lnGF	in 2021 million USD	IRENA
Green energy consumption (share of RE in total energy consumption)	lnREcons	percentage	WDI
Green energy production (renewable electricity capacity)	lnREpro	MW	IRENA
Economic growth (GDP growth rate)	GDPgr	Percentage	WDI
Remittances (percentage of GDP)	lnREMIT	Percentage	WDI
Inflation rate (by GDP deflator)	INFLAT	Percentage	WDI
Urbanization (URBAN growth rate)	lnURBAN	percentage	WDI
TRADE openness (total TRADE divided by GDP)	lnTRADE	Percentage	WDI

Table 2 presents the descriptive statistics of the variables used in the analysis. The results indicate substantial variation across countries, particularly in poverty levels and renewable energy indicators, reflecting the heterogeneity of the sample.

Table 2. Descriptive statistic of research indicators.

Variables	Observation	Mean	Std. Dev.	Min	Max
POV	1702	32.6413	26.5193	0.1150	99.5720
lnEF	1680	0.5277	0.5289	−0.8172	2.0497
lnGF	1490	2.0743	3.2834	−11.3460	9.3899
lnREcons	1642	3.2198	1.3002	−2.3026	4.5602
lnREpro	1671	6.7539	2.2941	−3.9120	13.9606
GDPgr	1693	4.2797	4.1639	−36.6582	18.3332
lnREMIT	1656	0.8134	1.6590	−10.4520	3.9858
INFLAT	1698	7.8805	10.5732	−30.1997	150.0007
lnURBAN	1642	0.9160	0.6060	−4.6411	2.5472
lnTRADE	1696	4.1474	0.4552	2.7120	5.3955

The number of observations for green finance is relatively smaller compared to other variables, reflecting data limitations in developing countries. While some missing values are present, the panel remains sufficiently balanced to support reliable econometric estimation. All relevant variables are transformed into natural logarithms to reduce skewness and ensure comparability across different measurement scales. It should be noted that negative values observed after the logarithmic transformation do not indicate negative quantities, but rather reflect values below one in their original scale. This is particularly relevant for variables such as green finance, ecological footprint, renewable energy indicators, remittances, and urbanization. In contrast, variables expressed in percentage terms, such as GDP growth and inflation, are not log-transformed, which explains their wider range of variation. Overall, the descriptive statistics suggest that the dataset is suitable for panel data analysis and captures significant cross-country heterogeneity.

3.2. Model Specification and Estimation Strategy

To examine the relationship between the green transition and poverty, the study applies a dynamic panel data model. The inclusion of the lagged dependent variable allows for capturing the persistence of poverty over time, reflecting structural and institutional factors that evolve gradually.

The baseline empirical specification is expressed as Equation (1):

$$POV_{it} = \beta_0 + \beta_1 EF_{it} + \beta_2 GF_{it} + \beta_3 REcons_{it} + \beta_4 REpro_{it} + \sum_k \beta_k Control_{kit} + \mu_{it} + \varepsilon_{it} \quad (1)$$

where POV_{it} denotes poverty in country (i) at time (t), EF represents ecological footprint, GF denotes green finance, REpro is renewable energy production, REcons is renewable energy consumption, and Control is a vector of control variables including GDP per capita, remittances, inflation, urbanization, and trade openness. The terms μ_{it} and γ_{it} capture unobserved country-specific effects, while ε_{it} and u_{it} are the idiosyncratic error terms.

Estimating the aforementioned model using standard panel techniques may yield biased and inconsistent results due to several inherent econometric challenges. First, the inclusion of the lagged dependent variable introduces dynamic panel bias. Second, potential endogeneity arises from reverse causality and omitted variable bias; for instance, while green finance and renewable energy influence poverty, poverty levels concurrently dictate investment decisions and energy consumption patterns. The persistence of poverty, coupled with its bidirectional interaction with macroeconomic factors, introduces a layer

of complexity indicating that the long-term impacts of these factors cannot be adequately captured through static approaches.

To address these endogeneity concerns, this study employs the two-step System GMM estimator. This approach is particularly suitable for dynamic panels characterized by a large number of cross-sectional units (N) and a relatively short time dimension (T). By integrating equations in first differences and levels, and utilizing lagged values as internal instruments, the System GMM effectively controls for unobserved country-specific heterogeneity. Specifically, applying the GMM estimator with the “collapse” and “robust” options not only mitigates the risk of instrument proliferation, thereby ensuring the validity of the Hansen test, but also adequately addresses the heteroskedasticity and autocorrelation prevalent in macroeconomic panel data. This rigorous approach ensures the unbiasedness, consistency, and efficiency of the estimated coefficients.

In the System GMM estimation, the lagged dependent variable, green finance, REpro and REcons are treated as endogenous because reverse causality with poverty cannot be excluded. The remaining control variables (economic growth, ecological footprints, remittances, inflation, urbanization and trade openness) are treated as predetermined variables. Endogenous variables are instrumented using their own lagged values from the second lag onward in the differenced equation, while lagged first differences are used as instruments in the level equation. The instrument matrix is collapsed to limit the number of instruments and avoid instrument proliferation. The validity of the instruments is assessed using standard diagnostic tests.

To ensure the reliability of the estimation results, several diagnostic tests are conducted. The Arellano–Bond test for serial correlation is used to verify the absence of second-order autocorrelation in the differenced residuals. The Hansen test of overidentifying restrictions is employed to assess the validity of the instruments used in the System GMM estimation. A failure to reject the null hypothesis of the Hansen test indicates that the instruments are valid, while the absence of second-order serial correlation supports the consistency of the estimator. Additionally, the number of instruments is carefully controlled to avoid instrument proliferation, which may weaken the power of the Hansen test.

To verify the stability of the results, several robustness checks are performed. These include alternative model specifications, exclusion of potential outliers, and sub-sample analyses based on income levels and geographical regions. Such analyses allow for examining whether the relationship between the green transition and poverty varies across different country groups and economic contexts.

Overall, this methodological framework ensures that the empirical analysis provides reliable and robust estimates of the impact of green transition variables on poverty dynamics.

4. Empirical Findings and Discussions

This section presents the empirical findings of the study. It begins with panel unit root tests, followed by baseline estimations using static panel models. The analysis then proceeds to dynamic estimation using the System GMM approach, which provides more reliable results by addressing endogeneity, autocorrelation, and heteroskedasticity. Finally, the results are interpreted to highlight the economic implications of the green transition for poverty rate.

4.1. Panel Unit Root Tests and Preliminary Diagnostics

Panel unit root tests based on the Im–Pesaran–Shin (IPS) procedure indicate that most variables are stationary at levels, while the remaining variables become stationary after first differencing (see Appendix A). The null hypothesis of a unit root is rejected at

conventional significance levels for all variables, confirming that the dataset is suitable for panel estimation and does not suffer from spurious regression issues.

Preliminary diagnostic tests are conducted for the baseline OLS estimations. The variance inflation factor (VIF) test indicates the absence of serious multicollinearity among the explanatory variables. However, the Wooldridge test reveals the presence of autocorrelation, and the White test confirms heteroskedasticity (see Appendices A–C). These findings suggest that OLS estimates may be inefficient, requiring more advanced panel estimation techniques.

To control for unobserved heterogeneity across countries and over time, both Fixed Effects (FEM) and Random Effects (REM) models are estimated. The Hausman test indicates that the Fixed Effects specification is preferred, implying that country-specific effects are correlated with the regressors (see Appendix D). Nevertheless, both FEM and REM continue to exhibit autocorrelation and heteroskedasticity issues. Although the GLS estimator improves efficiency by addressing these problems, it does not fully resolve potential endogeneity.

Further analysis using IV-2SLS suggests the presence of endogenous relationships, particularly due to the persistence of poverty and its interaction with macroeconomic variables. This motivates the use of a dynamic panel framework. Therefore, the System GMM estimator is employed as the most appropriate approach to simultaneously address endogeneity, serial correlation, and heteroskedasticity.

4.2. Baseline Panel Regression Results

Table 3 reports the results from OLS, FEM, REM, and GLS estimations for poverty (POV). Overall, the results show that most explanatory variables are statistically significant at the 1% level, while trade openness (TRADE) displays weaker and less consistent significance across specifications.

Table 3. Baseline and panel regressions for poverty (POV).

Variables	OLS POV	FEM POV	REM POV	GLS POV
lnEF	−18.9162 ***	−14.8407 ***	−16.4855 ***	−11.2702 ***
lnGF	−0.3911 ***	−0.3925 ***	−0.4214 ***	−0.0676 **
lnREcons	6.4128 ***	14.8891 ***	11.9940 ***	7.3830 ***
lnREpro	−2.5510 ***	−5.8238 ***	−5.2914 ***	−3.3191 ***
GDPgr	0.4569 ***	0.1264 ***	0.1529 ***	0.0045
lnREMIT	−4.0885 ***	−1.0427 ***	−1.4106 ***	−1.8035 ***
INFLAT	0.1847 ***	0.0344	0.0503 **	0.0125
lnURBAN	12.1622 ***	4.0612 ***	4.5196 ***	6.4844 ***
lnTRADE	−2.6944 ***	−1.1159	−1.5387	−1.9457 ***
_cons	39.2572 ***	33.0992 ***	40.5378 ***	39.4007 ***
Observation	1316	1316	1316	1316
Fstat	348.39	166.72		
Wald stat			1533.05	2667.85
R ²	0.706	0.5635	0.5926	
Adj R ²	0.7039			
Root MSE	14.21			

Note: ** $p < 0.05$, *** $p < 0.01$.

The estimated coefficients exhibit consistent signs across models, reinforcing the robustness of the baseline relationships. Ecological footprint (EF), green finance (GF), and REpro are negatively associated with poverty, indicating their role in supporting income generation and poverty reduction. In contrast, REcons shows a positive and statistically significant effect on poverty, suggesting that it may exacerbate poverty in the short term.

However, given the presence of econometric issues identified in the diagnostic tests, these baseline results should be interpreted with caution. This justifies the transition to a dynamic panel estimation framework.

4.3. Dynamic Panel Estimation: System GMM Results

Table 4 present the results of the System GMM estimations for poverty (POV). A key result is the strong persistence of poverty indicated by the large coefficient of the lagged values (above 0.8 in most specifications) which is significant at 1 percent. This confirms the existence of substantial temporal inertia in poverty dynamics.

Table 4. Robustness of SGMM for factors impact poverty rate (POV).

Variables	GMM POV365	GMM POV365	GMM POV365	GMM POV365	GMM POV365	GMM POV215	GMM POV215
L. pov365	0.8590 ***	0.8610 ***	0.8708 ***	0.8228 ***	0.8131 ***		
L. pov215						0.8635 ***	0.8329 ***
lnEF	−2.9099 **	−3.5092 *	−3.2131 **	−3.5286 **	−3.6467 **	−1.6275 **	−1.8186 *
lnGF	−0.0679 ***	−0.0636 ***	−0.0596 ***	−0.0762 ***	−0.0806 ***	−0.0729 ***	−0.0713 **
lnREcons	1.0766 **	0.9298 *	0.8904 *	1.2347 *	1.2787 **	0.6059 **	0.6512 *
lnREpro	−0.3986 *	−0.4850 *	−0.4602 *	−0.4714 *	−0.5007 **	−0.2438 *	−0.2955 *
GDPgr	−0.1259 ***	−0.1387 ***	−0.1423 ***	−0.1514 ***	−0.1462 ***	−0.1031 ***	−0.1103 ***
lnREMIT		−0.6737 *	−0.5990 *	−0.6732 *	−0.6922 **		−0.4549 *
INFLAT			0.0213	0.0390 **	0.0422 **		0.024
lnURBAN				1.8999 *	2.0559 **		1.003
lnTRADE					−0.3447		−0.3719
_cons	5.0708 **	7.0170 *	6.2676 *	5.2164 *	6.9254 *	2.9152 **	4.4556
Observation	1340	1323	1323	1273	1272	1340	1272
AR1	0.085	0.026	0.025	0.024	0.024	0.022	0.003
AR2	0.211	0.144	0.144	0.146	0.145	0.121	0.104
Hansen	0.534	0.508	0.464	0.512	0.634	0.805	0.768
Instruments	28	29	30	31	32	28	32
Countries	74	74	74	73	73	74	73

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The validity of the GMM estimations is supported by several diagnostic tests. The Hansen test does not reject the null hypothesis, indicating that the instruments are valid. The Arellano–Bond AR(2) test confirms the absence of second-order serial correlation. In addition, the number of instruments remains below the number of cross-sectional units, avoiding the problem of instrument proliferation.

The System GMM results confirm and strengthen the findings from the static models. REpro continues to exhibit a negative and statistically significant impact on poverty, while REcons shows a positive effect. Ecological footprint also remains negatively associated with poverty, with the largest magnitude among the green variables, indicating a strong short-term linkage between resource-based economic activity and income generation.

Green finance is found to significantly reduce poverty at the 1% level, confirming its important role as a mechanism for promoting inclusive development. Economic growth (GDPgr), which was insignificant in some static specifications, becomes negative and highly significant in the dynamic model, indicating that once persistence and endogeneity are accounted for, economic growth contributes to poverty alleviation.

Overall, the dynamic results provide more reliable evidence and confirm the robustness of the estimated relationships across different model specifications and poverty line (which is in 2.15 USD per day and 3.65 USD per day).

4.3.1. REcons and REpro Mismatch and Renewable Energy Paradox

A central finding of this analysis is the marked divergence between the poverty impacts of REcons and REpro, substantiating the existence of a “renewable energy paradox”. REcons is positively associated with poverty; whereas, REpro exhibits the inverse relationship. The coefficient for REcons exhibits a higher magnitude than that of production, indicating that consumption side dynamics disproportionately influence poverty outcomes. This implies that promoting renewable energy adoption without implementing adequate compensatory mechanisms may impose asymmetric financial burdens on vulnerable demographic groups.

REpro contributes to poverty reduction by stimulating investment, creating employment opportunities, and expanding energy supply. The development of renewable energy infrastructure supports economic activity and enhances long-term energy security, thereby improving living standards. As explained by Adom, Amuakwa-Mensah [1], Xu and Xu [11], the expansion of REpro acts as a profound catalyst for sustainable poverty reduction when decentralized RE production systems at the micro level provide remote and marginal communities with reliable electricity access. This directly eradicates energy poverty and prevents the exorbitant costs and geographical constraints of national grid extensions. In addition, The establishment of stable, localized power generation extends productive working hours and fosters the emergence of small-scale rural industries, thereby directly generating employment and enhancing household income. Concurrently, at the macro-level, green finance channeled into RE production drives structural industrial upgrading, cultivating “green jobs” that absorb the labor force and foster inclusive economic growth [8,11].

Conversely, the mandatory transition toward RE consumption often entails a severe “Poverty-CO2 Reductions Paradox”, disproportionately penalizing low-income demographics. The initial phase of green technology adoption necessitates massive infrastructure investments. To offset these expenditures, governments and utility providers frequently transfer the transition costs to end-users via elevated electricity tariffs, carbon taxes, or the removal of fossil-fuel subsidies [4]. Moreover, energy constitutes a fundamental necessity, rendering its demand highly price-inelastic among the poor. When clean energy prices surge, low-income households, who lack the financial capacity to substitute or upgrade their technologies, are disproportionately burdened. This cost shock essentially acts as a regressive tax, forcing the impoverished to drastically curtail other essential expenditures, such as education, healthcare, and foods, merely to sustain basic energy needs [1]. Consequently, this budget squeeze exacerbates their vulnerability and deepens the poverty trap in the short term. In addition, regulatory adjustments and structural changes in production systems require new skills and technological adaptation, which may limit the ability of vulnerable groups to benefit from the transition in the short term.

These findings are consistent with previous studies [21,23,24], which highlight the uneven distributional effects of the energy transition. The results emphasize that policies should differentiate between the supply and demand dimensions of renewable energy and incorporate targeted support measures to protect vulnerable groups.

Overall, the transition to renewable energy is intrinsically a double-edged sword characterized by divergent distributional impacts. While macro-level RE production generates positive externalities that promote sustainable livelihoods and economic autonomy, the micro-level cost burdens associated with mandatory RE consumption impose severe financial shocks on vulnerable populations. The renewable energy paradox represents a key constraint in the green transition process and underscores the need for carefully designed policies that balance environmental objectives with social inclusion.

4.3.2. Green Finance (GF) as a Mechanism for Poverty Mitigation

The empirical results consistently indicate that green finance (lnGF) exerts a negative and statistically significant effect on poverty (POV) at the 1% level across all specifications. This finding suggests that the expansion of green finance plays a meaningful role in alleviating poverty.

This result aligns with recent empirical studies emphasizing the dual role of green finance in promoting environmental sustainability and social welfare—Houssam, Ibrahim [59], Tang, Wang [9], Zia, Zhong [60], and Xu, Wang [8]. Investment in environmentally friendly activities not only improves environmental quality but also contributes to poverty reduction through multiple channels. In particular, public investment in renewable energy, used here as a proxy for green finance, supports the development of energy infrastructure, which is a fundamental prerequisite for long-term economic growth.

However, green investments are often characterized by high initial costs, long payback periods, and uncertain returns, making them less attractive to private investors. In this context, public investment plays a catalytic role by signaling government commitment to sustainable development, thereby encouraging private sector participation. This signaling effect helps mobilize capital flows into green sectors, expanding economic opportunities and improving overall welfare.

Moreover, access to energy is a critical dimension of multidimensional poverty. As shown by Zhong, Zhou [61], Lee, Li [62], Deka and Efe-Onakpojeruo [27] and Adom, Amuakwa-Mensah [1], by facilitating investments in renewable energy infrastructure, green finance contributes to reducing energy poverty, improving access to electricity, and enabling productive economic activities. Consequently, green finance emerges not only as an environmental policy tool but also as an effective mechanism for poverty alleviation.

4.3.3. Ecological Footprint (EF) and the Growth–Poverty Trade-Off

The ecological footprint (EF) captures the intensity of natural resource use and environmental pressure generated by economic activities. The empirical findings show that among green factors, EF has the largest effect on poverty.

EF exhibits a negative and significant effect, suggesting that increased economic activity, reflected in higher resource consumption, can contribute to poverty reduction. This result reflects the traditional development pattern observed in many countries, where economic expansion driven by resource utilization generates employment, income, and improved living standards, reinforcing the idea that economic expansion, despite increasing environmental pressure, can reduce poverty in the short to medium term. This is also found by Jin, Fu [21], Qamruzzaman, Karim [23] and Liu and Ge [15].

Developing nations frequently adopt a “grow first, clean up later” paradigm, intentionally maintaining lax environmental regulations and weak institutional frameworks [42,63]. This regulatory leniency acts as a catalyst for expanding energy-intensive and highly polluting sectors, which are deemed necessary to propel macroeconomic growth and generate immediate livelihood opportunities for the poor. Interestingly, industries characterized by high carbon emissions and environmental degradation are typically heavily reliant on low-skilled labor, creating labor-intensive industrialization which boosts employment rates [2]. Consequently, these dirty industries provide stable income streams and act as a crucial livelihood safeguard for the poor, who would otherwise be excluded from skill-intensive green industries. The haven pollution effect and global capital reallocation also contribute on the nexus of environmental degradation and poverty reduction in developing countries in attracting dirty Foreign Direct Investment (FDI) substantially amplifies the ecological footprint of the host nation [17,64,65]. It simultaneously injects massive capital and generates extensive employment opportunities, ultimately mitigating domestic poverty.

This dual effect highlights a fundamental trade-off. On one hand, resource-intensive growth can improve welfare and reduce poverty. On the other hand, excessive reliance on natural resources leads to environmental degradation, which may undermine long-term sustainability and potentially reverse poverty reduction gains through climate change and ecological damage.

Additionally, the transition toward greener production systems requires technological upgrading and workforce reskilling. A portion of the labor force, particularly low-skilled workers, may struggle to adapt to these changes, becoming temporarily vulnerable. At the same time, regulatory pressures and the high costs of green investment may constrain business activity and limit job creation. Therefore, while economic expansion contributes to poverty reduction, the findings underscore the importance of managing environmental sustainability through well-designed policies that mitigate the adverse effects of ecological degradation on vulnerable populations.

In general, the positive correlation between environmental degradation and poverty reduction is not a statistical anomaly, but rather a profound manifestation of the global division of labor and the Pollution Haven Effect. Therefore, the short-term sacrifice of environmental quality serves as an inevitable stepping stone for rapid poverty alleviation. To dismantle this environment-poverty trade-off, future policy frameworks must prioritize inclusive green growth and Just Transition strategies, ensuring that the shift toward sustainable production does not marginalize the vulnerable low-skilled workforce.

4.3.4. Role of Macroeconomic Factors

The dynamic GMM estimations reveal that macroeconomic variables play a significant and nuanced role in shaping poverty outcomes.

Economic growth (GDPgr) and remittances (REMIT) consistently contribute to poverty reduction, while inflation (INFLAT) and urbanization (URBAN) tend to exacerbate poverty. The dynamics of economic growth present a particularly compelling narrative. While static models suggest a spurious positive relationship between growth and poverty, likely capturing the short-term adjustment costs of structural transformation, the dynamic GMM estimations robustly demonstrate a negative and significant effect. In developing economies, economic growth is frequently coupled with rising income inequality and escalating carbon emissions. While economic expansion intrinsically alleviates poverty, the concomitant inequality and environmental degradation can inadvertently exacerbate it. Static models fail to disentangle these opposing forces, erroneously aggregating the detrimental impacts of pollution and inequality into the GDP variable, which masks the true impact of growth. In contrast, the System GMM estimator effectively isolates these mechanisms by controlling for structural inertia, confirming the robust poverty-reducing effect of economic growth. This indicates that, once persistence and endogeneity are accounted for, economic growth contributes to poverty alleviation. This finding supports the broader literature emphasizing the long-term benefits of growth [40,52,66–68]. However, it also highlights that the transition process, especially in developing economies undergoing rapid industrialization, can temporarily displace workers lacking the necessary skills to adapt to new economic structures. Although System GMM proves that economic growth reduces poverty, the opposite results of static estimations also act as a warning sign for the quality of growth. If the economy grows based on environmental destruction and resource exploitation, and without effective wealth redistribution policies, the benefits of growth will flow to the rich instead of the poor.

In line with the literature [52,66], remittances emerge as a strong poverty-reducing factor. They enhance household income, improve consumption capacity, and support

investment in education and small businesses. At the macro level, remittance inflows can stimulate economic activity and job creation, further contributing to poverty reduction.

In contrast, inflation negatively affects welfare by eroding purchasing power, disproportionately impacting low-income households. When inflation outpaces income growth, vulnerable populations face increased risk of falling into poverty. This finding is also in line with the literature [57,67–69].

Urbanization also shows a positive association with poverty, which aligns with Meka’a, Djamen [70], Mwakalila and Muba [71], and Wang and Xu [72]. Although urban areas offer better infrastructure and employment opportunities, rapid and unplanned urbanization can lead to labor market mismatches, informal employment, and increased inequality. Rural populations transitioning to urban areas may lack the skills required for modern economic sectors, increasing their vulnerability [73,74]. In addition, the migration from rural to urban area creates pressure on infrastructure, increasing living costs and escalating inequality, worsening the situation of the poor [55,75,76]. Moreover, unplanned urbanization makes polarization effect on production factors which is attracted to urban regions, especially skilled labor. This erodes resources for rural development increasing incident of poverty [56].

4.3.5. Heterogeneity by Income Groups

To explore distributional differences, the analysis incorporates dummy variables based on World Bank income classifications. The results, presented in Table 5, confirm that the core relationships between green factors and poverty remain robust across income groups. However, the magnitude of coefficients varies, indicating differences in sensitivity.

Table 5. Heterogeneous test for different income groups.

Variables	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365
L. pov365	0.8651 ***	0.8613 ***	0.8392 ***	0.8541 ***	0.8253 ***	0.8097 ***	0.8392 ***
lnGF	−0.0639 **	−0.0633 ***	−0.0752 ***	−0.0660 ***	−0.0740 ***	−0.0851 ***	−0.0752 ***
lnREcons	0.7604 **	0.7959 **	0.9377 **	0.8243 **	1.1663 **	1.2528 *	0.9377 **
lnREcap	−0.2946 **	−0.3169 **	−0.3010 **	−0.3034 **	−0.4775 **	−0.4581 *	−0.3010 **
GDPgr	−0.1552 ***	−0.1524 ***	−0.1678 ***	−0.1697 ***	−0.1494 ***	−0.1487 ***	−0.1678 ***
lnEF	−1.8515 **	−1.9495 **	−1.8338 **	−2.1220 **	−3.5823 **	−3.2039 *	−1.8338 **
lnREMIT	−0.5883 **	−0.5872 **	−0.6117 **	−0.5032 **	−0.6369 **	−0.6917 *	−0.6117 **
Infl		0.0168	0.0300 *	0.0316 *	0.0405 **	0.0413 **	0.0300 *
lnUrban			0.9211 *	1.2030 **	1.9582 **	1.9694 **	0.9211 *
lnTRADE			−0.1998	−0.2093	−0.2608	−0.4594	−0.1998
lowInc	6.6506 **	6.6587 **	6.5469 **	3.3703 **			6.5469 **
lowMidInc	3.1616 *	3.1857 *	2.8813 *		−0.7374		2.8813 *
UppMidInc	2.1652 *	2.1909 *	1.6426			−1.2406	1.6426
_cons	1.9669 *	2.0216	2.456	4.6030 **	6.7352 *	7.6396 *	2.456
Observation	1323	1323	1272	1272	1272	1272	1272
AR1	0.025	0.025	0.025	0.024	0.024	0.024	0.025
AR2	0.137	0.137	0.133	0.137	0.145	0.141	0.133
Hansen	0.563	0.577	0.652	0.624	0.614	0.661	0.652
Instruments	32	33	35	33	33	33	35
Countries	74	74	73	73	73	73	73

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Middle-income countries tend to exhibit slightly larger coefficients compared to low-income countries, suggesting stronger responsiveness of poverty to both green and macroeconomic factors. Nevertheless, when examined separately, only the low-income group

consistently shows strong statistical significance, while middle-income groups display weaker significance levels.

When income groups are included jointly, all categories become significant, with the largest coefficients observed for low-income countries. This indicates that poverty in poorer economies is more sensitive to changes in explanatory variables, reflecting structural vulnerabilities and limited adaptive capacity.

Overall, these findings suggest that policy interventions may have heterogeneous effects depending on the level of economic development, with stronger impacts observed in lower-income contexts.

4.3.6. Heterogeneity by Regions

Regional heterogeneity is analyzed using dummy variables for major world regions. The results reveal notable differences between poverty (POV) estimations, as well as between aggregated and disaggregated models (Table 6).

Table 6. Heterogeneous of regions to drivers of poverty.

Variables	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365	GMM pov365
L. pov365	0.8602 ***	0.8608 ***	0.8449 ***	0.8550 ***	0.8871 ***	0.9010 ***	0.8986 ***
GF	−0.0644 ***	−0.0636 ***	−0.0666 ***	−0.0613 ***	−0.0541 ***	−0.0568 ***	−0.0530 ***
lnREcons	0.9378 *	0.9303 *	1.1509 **	0.8357 *	0.7417 *	0.3369 *	0.3345 *
lnREpro	−0.4881 *	−0.4875 *	−0.5091 *	−0.5231 *	−0.3331	−0.1274	−0.1277
GDPgr	−0.1379 ***	−0.1388 ***	−0.1407 ***	−0.1371 ***	−0.1477 ***	−0.1614 ***	−0.1597 ***
lnEF	−3.5123 *	−3.5232 *	−3.4953 **	−3.7769 **	−3.2600 *	−2.1355 **	−2.4395 **
lnREMIT	−0.6822 **	−0.6764 **	−0.6963 **	−0.6899 **	−0.5285 *	−0.2966 *	−0.2875 **
EastAsia	−0.1432						4.2106 *
EuroCenAsi		0.0016					3.8263 *
LatinAmer			−1.2927 *				3.7389 *
MENA				−0.7735			3.6538 **
SouthAsia					−2.1700 **		2.8145
SSA						2.5161 **	6.2986 **
_cons	7.0644 *	7.0437 *	7.3100 **	7.9768 *	5.7211 *	3.5291 *	
Observation	1323	1323	1323	1323	1323	1323	1323
AR1	0.025	0.025	0.025	0.025	0.025	0.024	0.024
AR2	0.143	0.144	0.141	0.144	0.146	0.144	0.145
Hansen	0.508	0.520	0.555	0.520	0.483	0.530	0.528
Instruments	30	30	30	30	30	30	34
Countries	74	74	74	74	74	74	74

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In the aggregated poverty model, most green and control variables retain their expected signs and significance, although some variables, such as GDP growth and inflation, lose significance. Among regions, Sub-Saharan Africa (SSA) shows the highest sensitivity of poverty to explanatory factors, followed by East Asia, Europe and Central Asia, the Middle East and North Africa, and Latin America.

When models are estimated separately by region, the magnitude of coefficients changes substantially, particularly for renewable energy variables (REcons and REpro). Although the direction of effects remains consistent, the variability suggests that regional structural differences, such as energy systems, institutional quality, and labor market conditions, play an important role.

In some regions, particularly South Asia and SSA, REpro becomes statistically insignificant, indicating structural constraints in translating energy investments into poverty reduction.

Overall, the findings suggest that while the general impact of green factors is robust, their effectiveness varies across regions. In some cases, aggregated models provide more reliable estimates, while in others, region-specific models better capture local dynamics.

Across all specifications, the results highlight three key insights. First, green factors matter, but their effects are not uniform. REpro and green finance contribute to poverty reduction, while REcons may have short-term adverse effects. Second, economic growth remains essential, but its impact depends on the analytical framework. Dynamic models reveal its poverty-reducing role once structural adjustments are accounted for. Third, context matters significantly. Both income level and regional characteristics influence the magnitude and significance of effects, emphasizing the need for tailored policy approaches.

5. Conclusions and Policy Implications

5.1. Conclusions

The transition toward a green economy has increasingly been recognized as a necessary strategy for safeguarding the natural environment while ensuring long-term sustainable development. Against this backdrop, the present study investigates the impact of ecological footprint, green finance, and renewable energy, disaggregated into consumption and production, on poverty dynamics toward achieving the first Sustainable Development Goal. While the global policy agenda generally portrays the green transition as a pathway capable of achieving climate mitigation, economic prosperity, and social inclusion simultaneously, the empirical evidence presented in this study suggests that such an assumption may be overly simplistic. Rather than generating uniformly positive social outcomes, the green transition produces heterogeneous poverty effects depending on the specific dimensions through which the transition takes place.

Using a two-step System GMM estimator, the analysis addresses key econometric challenges associated with dynamic panel data, including endogeneity, heteroskedasticity, and autocorrelation. The empirical investigation is based on a panel of 74 developing countries over the period 2000–2022. The results provide robust evidence that different dimensions of the green transition influence poverty through distinct transmission mechanisms. Green finance, renewable energy production, and ecological improvement, measured by ecological footprint, are found to contribute significantly to poverty reduction. In contrast, REcons exhibits a positive association with poverty, indicating that the demand-side adoption of renewable energy may impose short-term adjustment costs on vulnerable households before the long-term benefits of the transition are fully realized. Macroeconomic variables also exert significant influence. Economic growth (GDPgr) and remittances (REMIT) contribute to poverty alleviation; whereas, inflation (INFLAT) and urbanization (URBAN) tend to exacerbate poverty. These findings underscore the complex interaction between structural transformation, macroeconomic stability, and social outcomes. These findings remain robust across alternative model specifications and heterogeneous country groups.

From a broader perspective, the results reveal a fundamental trade-off in developing economies. On the one hand, economic expansion, reflected in increasing ecological footprint and GDP growth, can contribute to poverty reduction by generating income and employment opportunities. On the other hand, the environmental degradation associated with such growth poses risks to long-term sustainability and may undermine future welfare gains. This highlights the need for a transition toward environmentally sustainable growth pathways.

The divergent impacts of REpro and REcons reveal what this study terms the “green transition paradox”. While the expansion of renewable energy is universally championed as a pillar of sustainable development, its socio-economic implications are not unequivocally positive. The supply side expansion of renewable energy bolsters productive capacity,

generates employment, stimulates investment, and fortifies energy security, thereby directly contributing to poverty alleviation. Conversely, the rapid acceleration of REcons may inflate household energy expenditures and impose stringent technological adaptation costs, particularly in economies lacking robust infrastructural and social protection networks. This asymmetry highlights the critical necessity of distinguishing between the supply and demand dimensions of the energy transition. Furthermore, it asserts that the efficacy of a green transition must not be evaluated exclusively through environmental metrics, but rather through its capacity to equitably distribute transitional costs and benefits across all society.

Green finance, proxied by public investment in renewable energy, is shown to play a crucial role in mitigating poverty. By facilitating the development of green infrastructure and signaling government commitment, it helps attract private investment and expand economic opportunities. At the same time, remittances represent an important complementary financial resource that enhances household resilience and supports poverty reduction. In contrast, inflation and unplanned urbanization disproportionately affect vulnerable populations by eroding purchasing power and increasing living costs. These results demonstrate that green transition cannot be separated from macroeconomic stability and structural development. Environmental policies are likely to be most effective when implemented alongside sound macroeconomic management and inclusive social policies.

The heterogeneity analysis further reveals that the effects of green and macroeconomic factors vary across income levels and regions. Lower-income countries exhibit higher sensitivity to these factors, reflecting structural vulnerabilities and limited adaptive capacity. Regional differences also indicate that the effectiveness of green transition policies depends on local economic structures, institutional quality, and energy systems. These findings imply that there is no universal green transition strategy applicable to all developing countries. Instead, transition policies should be tailored to national development conditions, institutional capacity, and socioeconomic priorities.

More importantly, the findings challenge the conventional practice of treating green transition as a homogeneous policy or a single environmental indicator. Instead, this study argues that the green transition should be understood as a multidimensional structural transformation operating through interconnected financial, energy, environmental, and social channels. From this perspective, green finance represents the financial engine that mobilizes investment toward sustainable activities; REpro reflects the transformation of the energy supply system; REcons captures changes in energy demand and adoption behavior; while ecological footprint represents the environmental outcome of the transition process. Together, these dimensions form an integrated transition process whose combined effects ultimately determine whether green transition becomes socially inclusive.

5.2. Policy Implications

Based on these findings, several policy implications can be derived:

1. Promoting an inclusive green transition

Governments should rigorously integrate environmental objectives with social policies frameworks by investing in education, retraining, and skill development programs. This integration empowers vulnerable populations to navigate the structural shifts inherent in a green transformation. Policymakers must explicitly distinguish between the supply and demand dimensions of the renewable energy transition. While expanding production capacity yields employment and productive benefits, policies incentivizing REcons must be phased gradually. Such policies should be inextricably linked with targeted subsidies, affordable financing mechanisms, and robust social safety nets to mitigate excessive adjustment costs for low-income households. A genuinely inclusive transition dictates that

marginalized communities emerge as beneficiaries, rather than casualties, of structural economic transformation.

2. Expanding and diversifying green finance mechanisms

Strengthening green finance should remain the foundation of an inclusive green transition. Public investment should be complemented by innovative financial instruments, such as blended finance, green bonds, and concessional lending, to mobilize private capital toward renewable energy and sustainable activities. More importantly, green financial resources should prioritize projects capable of generating employment opportunities and improving livelihoods among vulnerable populations rather than focusing exclusively on emission reduction.

3. Balancing growth and environmental sustainability

Policymakers should pursue economic growth strategies that reduce ecological pressure while maintaining their poverty-reducing effects. This requires incentivizing cleaner production technologies and supporting energy-efficient investments. Environmental policies should avoid imposing disproportionate costs on disadvantaged populations. Cleaner production technologies, energy efficiency improvements, and environmentally friendly industrial upgrading should therefore be integrated with poverty reduction strategies to ensure that environmental gains do not come at the expense of social equity.

4. Leveraging remittances for productive investment

Institutional mechanisms should be strengthened to channel remittance inflows into productive sectors, enhancing their contribution to employment creation and long-term development.

5. Ensuring macroeconomic stability and inclusive urbanization

Maintaining macroeconomic stability remains indispensable for achieving an inclusive green transition. Controlling inflation is essential to protect purchasing power, particularly for low-income households. At the same time, urbanization policies should focus on inclusive planning, job creation, and support for rural-to-urban migrants to prevent increased vulnerability. Green transition policies are therefore most likely to succeed when supported by complementary macroeconomic and social policies that strengthen adaptive capacity.

5.3. Limitations and Future Research

Despite its contributions, this study faces several limitations. First, data constraints, particularly regarding multidimensional poverty indicators, limit the scope of analysis across a large number of countries. Second, the proxy used for green finance (public investment in renewable energy) does not fully capture the diversity of green financial instruments, such as green bonds, private climate finance, or sustainable credit.

Third, the analysis does not explicitly account for potential non-linearities or interaction effects among variables. Although the System GMM approach addresses major econometric concerns, it may still face challenges related to instrument validity and may not fully capture feedback effects between poverty and explanatory variables. In addition, the robustness analysis focuses on alternative poverty indicators in adapt with different combination of control variables, estimating by various static analytical methods, and investigates heterogeneity analysis for different income and regional groups. It does not exploit other dynamic panel estimations, test with alternative lagged structure, exclusion, with exclusion of small groups or periods, or do additional sensitive analysis.

Finally, other relevant factors, such as green innovation, education level, income inequality, financial development, institutional quality, and governance, etc., are not included in the model and could further improve explanatory power.

Future research should address these limitations by incorporating broader measures of green finance, exploring non-linear relationships, and examining feedback mechanisms between poverty and environmental factors to provide a more comprehensive understanding of the green transition–poverty nexus. More importantly, future studies may further develop the multidimensional architecture of green transition by examining how financial transformation, renewable energy development, environmental sustainability, and social inclusion interact dynamically throughout different stages of economic development. Such efforts would contribute to a more comprehensive understanding of how developing countries can design transition pathways that simultaneously achieve climate objectives, poverty reduction, and sustainable development.

Ultimately, the findings of this study suggest that the success of the green transition should not be judged solely by the amount of renewable energy generated, the volume of green investment mobilized, or the reduction in ecological pressure. Its true success lies in whether the transition is capable of improving environmental sustainability while ensuring that no vulnerable population is left behind. In this sense, a transition cannot be considered genuinely green unless it is also inclusive.

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Conflicts of Interest: The authors declare no conflicts of interest in this research.

Appendix A. VIF and IPS Check for Stationary of Variables

Variable	VIF	Stationary	Z-t-Tilde-Bar	Sig.	Z-t-Tilde-Bar	Sig.
POV		I(1)	0.6915	0.7554	−16.292	0.0000
EF	2.07	I(0)	−2.737	0.0031		
GF	1.19	I(0)	−11.9869	0.0000		
GDPgr	1.10	I(0)	−16.5342	0.0000		
INFLAT	1.03	I(0)	−15.43	0.0000		
REC	1.40	I(1)	2.5032	0.9938	−18.784	0.0000
REMIT	1.44	I(1)	−1.6174	0.0529	−17.6901	0.0000
REP	1.42	I(1)	6.3557	1.0000	−15.3666	0.0000
TRADE	1.55	I(1)	−1.5055	0.0661	−18.0811	0.0000
Urban	1.59	I(1)	0.7753	0.7809	−17.0725	0.0000

Appendix B. White Test for Heteroskedasticity of OLS Estimation

```
.imtest, white
chi2(54) = 463.53
Prob > chi2 = 0.0000
```

Cameron & Trivedi's decomposition of IM-test

Source	chi ²	df	p
Heteroskedasticity	463.53	54	0
Skewness	109.03	9	0
Kurtosis	5.55	1	0.0185
Total	578.1	64	0

Appendix C. Wooldridge Test for Autocorrelation in Panel Data

H₀: no first-order autocorrelation

F (1, 71) = 57.441

Prob > F = 0.0000

Appendix D. Hausman Test for FEM or REM

	(b)	(B)	(b – B)	sqrt(diag(V_b – V_B))
	fe	Re	Difference	Std. Err.
lnGF	−0.392471	−0.421395	0.028924	
lnEF	−14.84074	−16.48551	1.644761	0.6359085
lnREcons	14.8891	11.99395	2.895141	0.5532706
lnREcap	−5.82385	−5.291372	−0.532478	0.0913239
GDPgr	0.12636	0.1528502	−0.0264902	
lnREMIT	−1.04266	−1.410582	0.3679211	0.0501684
Infl	0.0343696	0.0502961	−0.0159265	
lnUrban	4.061242	4.519648	−0.4584052	0.1318105
lnTRADE	−1.115901	−1.538743	0.4228426	0.0567454

b = Consistent under H₀ and H_a; obtained from xtreg.

B = inconsistent under H_a, efficient under H₀; obtained from xtreg.

Test of H₀: difference in coefficients not systematic

chi²(9) = (b – B)'[(V_b – V_B)^{−1}](b – B) = 88.93

Prob > chi² = 0.0000

(V_b – V_B is not positive definite)

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