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Article

Green Bonds: A Catalyst for Climate Resilience and Economic Growth in MENA and SSA

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Abstract Green-Inclusive Finance (GIF) emerges as an effective mechanism to address the vulnerabilities faced by low-income populations in the Middle East and North Africa (MENA) and Sub-Saharan Africa (SSA) regions in the context of climate change. By expanding access to diverse financial tools, GIF enables these communities to better mitigate and adapt to the adverse impacts of climate variability. This study analyzes the relationship between green bond issuances and poverty reduction across 73 countries, including 10 representative nations from the MENA and SSA regions, over the period from 2005 to 2021. Applying the System Generalized Method of Moments dynamic panel estimation methodology, the analysis provides strong evidence that a 1% increase in green bond issuances corresponds to a 0.13% reduction in the poverty headcount ratio within the full sample. A non-linear analysis reveals distinct threshold levels for green bond effectiveness—2.03% of total annual issuances for the full sample and 0.95% for the MENA and SSA regions. Notably, countries such as Egypt, Israel, Mauritius, Morocco, Nigeria, Seychelles, South Africa, Turkey, and the UAE surpass the regional threshold, reflecting strong green finance activity. In contrast, Namibia falls below this benchmark, signaling the need for strategic interventions to enhance green bond issuances in the region. These findings highlight the critical importance of exceeding these thresholds to unlock the full poverty-reducing potential of green bonds. As policymakers and stakeholders prioritize this innovative financial tool, it is essential to develop customized approaches that not only meet but surpass these thresholds. Doing so will maximize the impact of green bonds on poverty alleviation and reinforce their role as a transformative instrument in the global effort to achieve equitable and sustainable development.

Keywords green inclusive finance; extreme poverty; MENA; SSA; system GMM

JEL Classification Numbers: C23; G21; O43

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1. Introduction

Countries worldwide, particularly in the Middle East and North Africa (MENA) region, continue to face persistent challenges in combating and eradicating extreme poverty, despite periods of significant growth and development. While economies in the MENA region are projected to grow in the coming years, progress in poverty reduction has remained limited and become virtually non-existent [1]. Empirical evidence indicates an increase in extreme poverty rates in the region from 2015 to 2018, with earlier projections anticipating a further rise in the number of individuals living in poverty [1,2]. Similarly, Sub-Saharan Africa (SSA), home to some of the world's poorest nations, struggles with eradicating extreme poverty due to factors such as debt vulnerabilities, social unrest, and the detrimental effects of climate change [3–5]. In the MENA region, frequent conflicts have resulted in inflation, economic recessions, and widespread physical destruction, disproportionately affecting impoverished populations [6,7]. These longstanding challenges have been further exacerbated by the COVID-19 pandemic, intensifying existing economic and environmental vulnerabilities [8,9]. Addressing these interconnected issues requires sustainable and inclusive policies that tackle both economic and environmental fragilities to enhance resilience in these regions.

The 17 Sustainable Development Goals (SDGs), established in 2015, represent a global commitment to improving lives, promoting peace, safeguarding the planet, and eradicating poverty [10]. Among these goals, eradicating poverty and promoting sustainable practices, including the adoption of renewable resources and energy, hold particular relevance. In the MENA region,

the environmental consequences of the oil and gas industry disproportionately impact impoverished communities, highlighting the importance of mitigating these effects [11]. Developing innovative financial strategies that integrate environmental sustainability with social inclusion is critical to addressing these challenges effectively [12].

This study is motivated by the pressing need to address persistent poverty and environmental vulnerabilities in the MENA and SSA regions, where economic growth has not translated into significant poverty reduction. The stark disparities in green bond investment levels, as illustrated in Figure 1, reflect the untapped potential of green finance as a tool for sustainable development. Despite global advancements in green finance, these regions remain underrepresented in green bond markets due to structural and financial barriers, limiting their ability to adopt this innovative mechanism for poverty alleviation. The objective of this study is to analyze the role of green finance, particularly green bonds issuances, in reducing extreme poverty in MENA and SSA, emphasizing the potential for non-linear effects and threshold dynamics. By identifying critical thresholds and exploring region-specific outcomes, this research aims to inform strategies for integrating green finance into poverty reduction frameworks tailored to the unique challenges of these regions.

Green-Inclusive Finance (GIF) provides tools and mechanisms to mitigate the vulnerabilities of low-income populations to climate change. Among these, green bonds have emerged as a vital source of financing for energy efficiency projects, driving economic growth and recovery [13]. By channeling funds directly into programs that address the root causes of extreme poverty, GIF instruments, including green bonds, hold significant potential for poverty reduction, particularly in countries with underdeveloped financial systems like those in the MENA and SSA regions [14]. While GIF tools demonstrate positive outcomes overall, their implementation and effectiveness face limitations in less developed countries and high-risk sectors. For instance, some studies suggest that green bonds may incur higher pricing but exhibit similar performance to standard bonds, with their poverty reduction impacts varying depending on the nature of the bond offerings and accessibility [15,16].

Although global data on green finance remains limited, existing evidence shows that the MENA and SSA regions lag behind other emerging markets in green bond investments. Bridging this gap and increasing investments in green finance can contribute significantly to reducing poverty in these regions.

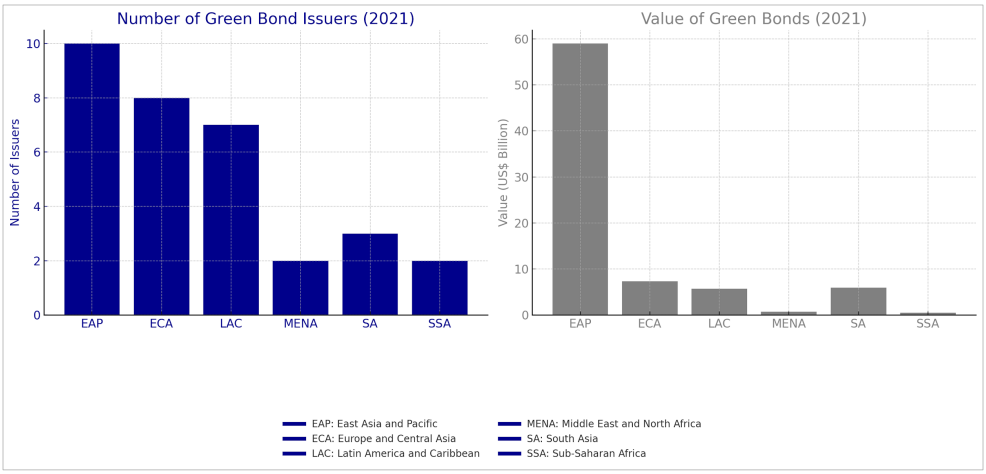

Figure 1. Number of Issuers and Value of Green Bonds in Emerging Markets in 2021 [17].

As shown in Figure 1, the MENA region exhibits the fewest number of green bond issuers and ranks second-lowest in terms of the value of green bonds issued among emerging markets in 2021. This figure highlights the significant gaps in green finance adoption and the opportunities for growth in sustainable financial instruments. MENA reported only two issuers with a total bond value of $0.7 billion, while SSA similarly had two issuers, issuing bonds worth $0.5 billion. SSA emerges as the region with the second-lowest number of issuers and records the lowest overall value of green bonds on a global scale. This stark contrast in investment levels becomes more evident when comparing these regions to East Asia and the Pacific (EAP), which leads in both issuers and bond values and Latin America and the Caribbean (LAC), which also exhibits significantly higher activity. Given these substantial disparities, there exists a compelling opportunity to explore the barriers impeding green bond market development in MENA and SSA. Targeted

policies aimed at strengthening financial infrastructure, addressing regulatory challenges, and mobilizing international investments could serve to enhance participation in green finance within these regions. By bridging the gap, GIF can act as a critical mechanism to drive sustainable economic development and environmental resilience in these underrepresented markets.

Despite the disparities highlighted in Figure 1, which illustrate MENA's lagging green bond investment levels compared to other emerging markets, Figure 2 reveals an encouraging upward trend in green bond investments within the MENA region since 2016. This trend signals growing momentum toward sustainable financing in this underrepresented market. Similarly, SSA has experienced steady growth in green bond issuance. According to the Climate Bonds Initiative, the total green bond issuance in SSA reached $3.8 billion in 2020, marking substantial progress compared to previous years. Prominent issuers in the region include South Africa, Nigeria, Kenya, and Seychelles [18].

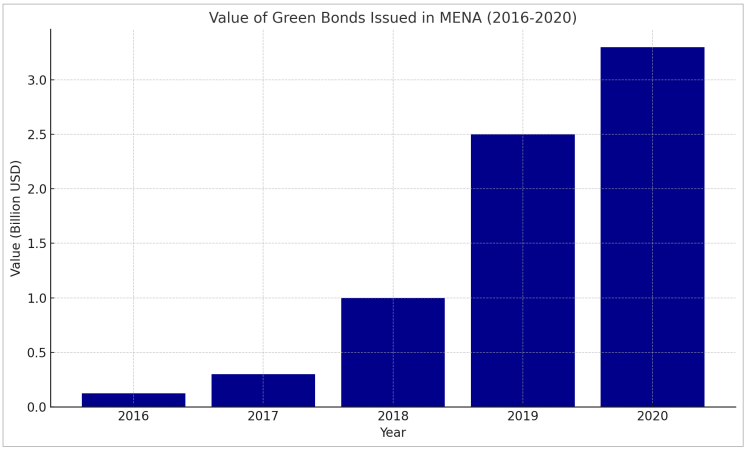

Figure 2. Value of Green Bonds in MENA from 2016–2020 [19].

In particular, South Africa has emerged as a leader in SSA, issuing $466 million in green bonds in 2021—more than double the $200 million issued in 2020. Other countries, such as Kenya and Nigeria, have also expanded their participation, with multiple issuances in recent years [17]. Furthermore, while green loans initially dominated the environmental, social, and governance (ESG) financing landscape, there is now greater diversification of financial products dedicated to ESG instruments [20]. Despite this progress, the region faces increasing challenges from global inflation and varying financial requirements, which have reduced the overall funds available for poverty-eradicating solutions [21]. The European Investment Bank [22] survey of African banks highlights this issue. While the majority of banks acknowledged GIF tools as promising instruments to diversify funding and mitigate climate change, only 17% had integrated GIF products into their offerings, likely due to existing financial and structural barriers.

Given this context, further exploration of the benefits of GIF tools is essential to determine their potential for other countries in these regions to engage more effectively in the green finance market. Both MENA and SSA face significant challenges in eradicating extreme poverty, but they operate under distinct economic, social, and environmental conditions that influence outcomes differently. While existing studies suggest positive associations between GIF and poverty reduction, many fail to establish causality or explore non-linear dynamics. It is crucial to investigate whether threshold effects exist, where specific levels of green finance are required to achieve significant poverty reduction outcomes. Identifying these thresholds can inform more effective interventions and policy strategies.

This study addresses these gaps by analyzing the relationship between green finance and poverty alleviation, focusing on potential non-linear effects. It identifies critical threshold levels of green bond issuances, emphasizing that surpassing these thresholds is essential for achieving meaningful poverty reduction. Key questions guide this research: What is the impact of green bond issuances on extreme poverty alleviation? Is there evidence of non-linearity in the relationship between green bond issuances and poverty alleviation? Do the effects differ between MENA, SSA, and the broader sample? Finally, what policy recommendations can be drawn from these findings?

The insights derived from this research aim to inform tailored policy strategies for MENA and SSA, facilitating the integration of sustainable financial mechanisms into comprehensive poverty alleviation frameworks. The remainder of the study is structured as follows: the next

section reviews the literature, Section 3 introduces the theoretical model, Section 4 describes the data, Section 5 explains the methodology and model selection, Section 6 presents the estimation results, and Section 7 concludes the study.

2. Literature Review

While much research has examined the link between financial development and poverty alleviation, the relationship between green finance and poverty reduction remains relatively understudied. This section explores this connection, focusing on the MENA and SSA regions to provide insights into green finance's potential as a tool for sustainable and inclusive development.

Green finance refers to public policies and financial mechanisms designed to promote environmentally sustainable goods and services while mitigating climate-related risks and damages [12]. In light of the global urgency to address climate change, international organizations have increasingly recognized green finance as a pivotal driver of sustainable growth. Studies have highlighted its dual capacity to drive economic progress and alleviate poverty [23,24]. Moreover, researchers such as Zhou et al. [25] and Yu et al. [13] have demonstrated that the benefits of green finance amplify with higher levels of financial development. These findings align with other study [26] that emphasize green finance's transformative potential in addressing socio-economic inequalities.

However, disparities in green finance's effectiveness are evident in regions like MENA, where energy poverty remains prevalent. El-Katiri [27] observed that energy access in MENA varies significantly based on income and geographic location. Wealthier nations and urban areas typically enjoy better access to electricity, while lower-income countries and rural regions face limited access. This uneven distribution highlights the challenges that nations with underdeveloped financial systems encounter in capitalizing on green finance's potential. Jawadi et al. [28] emphasized that for green finance to be effective in developing countries, it must align with sustainability objectives while addressing socio-economic challenges such as unemployment, inequality, and poverty.

Regional disparities in the effectiveness of green finance are not unique to MENA. For instance, Wang & Wang [29] found that the impact of green finance on economic inclusion in Chinese provinces varied significantly based on the design and implementation of financial mechanisms. Similarly, Doku [30] observed that while climate finance has reduced poverty in SSA, it has also, in some cases, exacerbated social inequality. In the context of Central and Eastern Europe (CEE), Ilić et al. [31] found that while the economic and financial dimensions of green finance positively influenced poverty reduction, the environmental dimension had a statistically significant negative effect. These findings highlight the need for region-specific approaches to green finance.

In the post-pandemic era, green finance has emerged as a crucial instrument for recovery and resilience. Yu et al. [13] emphasized its role in reducing energy poverty and strengthening financial institutions in China following COVID-19. Similarly, Tang [32] highlighted that firms with access to green and social finance were better equipped to withstand economic disruptions caused by the pandemic. These findings suggest that green finance can stabilize economies during crises while supporting environmental goals, although its role in poverty reduction remains complex and context-dependent.

A recurring theme in the literature is the need for supportive policies and targeted interventions to expand green finance. For example, Salman et al. [33] stressed the importance of addressing energy infrastructure gaps to combat energy poverty, while Zhou et al. [25] advocated for fiscal interventions to scale up green finance in underdeveloped regions. Chardeffine & Kahia [34] found that financial development and renewable energy consumption are interlinked in their effects on growth and emissions in MENA, suggesting that policies should consider these interactions. These recommendations underline the importance of institutional frameworks in enabling green finance to achieve its potential in promoting sustainable and inclusive development.

Empirical evidence further highlights green finance's potential in reducing poverty. For example, Xu et al. [35] and Zhao et al. [36] found positive associations between green finance and poverty reduction in China. Wang et al. [37] identified a strong relationship between green finance, financial development, and poverty alleviation in countries under the Belt and Road Initiative. Lee et al. [38] observed threshold effects in China, where green digital finance reduces energy poverty at lower levels of climate risk but becomes less effective or even counterproductive under higher climate risk conditions. Ilić et al. [31] contributed by proposing a methodological framework for assessing the impact of green finance on poverty, outlining key indicators such as

GDP per capita and energy access, and reinforcing the relevance of systematic evaluation tools. These studies together emphasize the crucial role of green finance in addressing both rural and urban poverty while revealing potential threshold effects where its impact is most pronounced under specific conditions.

For the MENA and SSA regions, understanding the potential non-linear dynamics of green finance is critical. While limited literature focuses specifically on GIF tools in these regions, prior research on financial development provides valuable insights into the broader relationship between finance and poverty reduction. For instance, Zahonogo [39] identified a non-linear relationship between financial development and poverty in SSA, suggesting that other factors, such as financial sector development, significantly influence outcomes. Emara & coauthors [40–45] have extensively examined the non-linear impacts of financial development, governance, and technological advancements on economic outcomes, emphasizing the role of threshold effects and asymmetries. Similarly, Emara & Zecheru [46] utilized a non-linear framework to investigate the impact of digitization on inflation, highlighting how structural and technological factors interact to influence economic outcomes. Their findings demonstrate the value of non-linear models in uncovering complex economic relationships, emphasizing how structural factors shape outcomes. This aligns closely with the current study's threshold-based approach to examining the effects of green bonds on poverty reduction. These insights suggest that green bonds and other GIF tools could follow similar non-linear dynamics in the MENA and SSA regions.

Studies by Nsiah et al. [47], Bolarinwa et al. [48], Batuo et al. [49], Asongu [50], Tita & Aziakpono [51], Nandelenga & Odour [52], and Zungu & Grelying [53] have also contributed to the understanding of non-linear dynamics between financial development and poverty reduction in Africa. These works highlight the importance of accounting for region-specific factors when analyzing these relationships. Although these studies do not specifically address GIF tools, they suggest the likelihood of a non-linear relationship between green bonds and poverty alleviation in the SSA region and, potentially, the MENA region. Tang et al. [54] is one of the few studies that has investigated the non-linear effects of green finance on poverty. Their findings indicate that green finance positively impacts poverty reduction, with stronger effects in rural areas compared to urban ones. Over time, however, the impact on rural poverty weakens, while its influence on urban poverty shows a gradual increase.

Existing studies have yet to fully explore the complex, non-linear effects of green finance on poverty reduction, particularly in the MENA and SSA regions. This paper addresses this gap by examining the role of green bonds as a mechanism for reducing poverty in these regions. Using the System Generalized Method of Moments (GMM-SYS) dynamic panel estimation methodology, the analysis investigates not only the effectiveness of green finance in alleviating poverty but also the conditions under which its impact is most pronounced. This approach provides valuable perspectives, contributing both to the academic literature and to practical strategies for policymakers aiming to enhance sustainable development.

3. A Simple Theoretical Model

The Cobb-Douglas production function provides a robust theoretical framework for analyzing the contributions of GIF, specifically green bonds, to poverty alleviation, a central objective of the SDGs. Traditionally used to study the relationship between economic inputs such as capital, labor, and technology and their impact on output, this framework can be extended to incorporate environmental inputs. These inputs represent investments in renewable energy, sustainable infrastructure, and environmentally friendly technologies, which are often financed through green bonds.

By integrating environmental inputs, the modified Cobb-Douglas production function offers a comprehensive approach to understanding the dual role of green bonds in driving economic growth and addressing sustainability challenges. This adaptation highlights the critical role of green bonds as a mechanism for channeling resources toward initiatives that contribute to both poverty reduction and environmental sustainability. The function, incorporating environmental inputs alongside traditional variables, can be expressed as follows:

$$Y = AK^{\alpha}L^{\beta}E^{\gamma}, \tag{1}$$

where Y represents output or income, which directly contributes to poverty alleviation by improving access to basic necessities, enhancing living standards, and reducing vulnerabilities (SDG 1) [55,56], A denotes total factor productivity, K represents physical capital, L represents labor, and E represents environmental and financial inputs through GIF, including green bonds. The exponents α, β, and γ capture the respective contributions of capital, labor, and environmental

inputs to output [57,58]. This formulation enables an analysis of the specific mechanisms through which GIF impacts poverty reduction and sustainable development [59,60].

Green bonds, as a core component of GIF, influence poverty alleviation through several key channels. First, the resource efficiency channel recognizes that green finance investments enhance resource productivity and sustainability. These investments promote the adoption of clean technologies, energy-efficient practices, and environmentally friendly production processes, leading to higher total factor productivity [59,61]. The resulting resource efficiency gains contribute to increased output, economic growth, and poverty reduction.

Second, the job creation and income generation channel acknowledge that green finance initiatives stimulate investments in renewable energy, sustainable projects, and green technologies. These investments generate employment opportunities and increase income levels for individuals and households [62,63]. The creation of green jobs and the associated rise in income contribute to poverty reduction by improving livelihoods and providing economic security.

Additionally, the model accounts for the poverty reduction channel, which recognizes that the income and employment generated through green finance contribute directly to poverty alleviation. By enabling individuals and households to access basic necessities, improve their living conditions, and reduce their vulnerability to poverty, green finance plays a crucial role in poverty reduction efforts [60,62].

By integrating green bonds into the broader framework of GIF, the model highlights their potential as a mechanism for achieving SDG 1. The environmental and financial inputs financed through green bonds align closely with the dual objectives of driving sustainable development and eradicating poverty. Green bonds not only address environmental sustainability but also contribute to reducing economic inequalities and promoting social inclusion. Policymakers and researchers can apply this theoretical framework to assess the effectiveness of GIF mechanisms in achieving poverty alleviation, evaluate the relative importance of different channels, and design targeted interventions to maximize their impact. Although the Cobb-Douglas model provides a strong foundation, empirical validation is essential. Estimating the parameter γ, which captures the contribution of environmental and financial investments to poverty alleviation, requires robust data on green bond allocations, their socioeconomic impacts, and their alignment with SDG indicators. Further research and empirical analysis will enhance the applicability of this framework and support evidence-based policy development.

4. Data

Our study uses a panel dataset comprising 73 developed and developing countries, covering the period from 2005 to 2021. Due to data availability constraints, particularly regarding green bond issuances, we selected 10 representative countries from the MENA and SSA regions. Table A1 in Appendix A provides a comprehensive list of the countries in our dataset. Data on all macroeconomic variables, including the poverty headcount ratio, real GDP per capita growth rate, inflation rate, trade openness as a percentage of GDP, and population growth, has been collected from the World Development Indicators (WDI) database. Data on green bond issuances, however, has been sourced from the IMF Climate Change Indicators Dashboard.

Green bonds, as defined by the IMF, are self-labeled fixed-income instruments where the proceeds are exclusively directed to finance or re-finance, in part or in full, new and/or existing green projects. These bonds are designed specifically to support climate mitigation and adaptation efforts. This definition ensures that green bonds reflect a focused and consistent financial mechanism dedicated to addressing environmental and sustainability challenges. By using green bond issuances as a key explanatory variable, our study effectively captures the financial flow into climate-oriented initiatives and their subsequent impact on poverty reduction. The consistent data provided by the IMF further strengthens the reliability and applicability of this proxy, as it reflects global practices and trends in green finance.

The dependent variable in our model is the poverty headcount ratio, measured as the percentage of the population living on less than $2.15 per day. Our set of explanatory variables includes commonly recognized determinants of poverty, such as the real GDP per capita growth rate, inflation rate, trade openness as a percentage of GDP, population growth, and green bond issuances. For further details on the variables used in our analysis, including their definitions and abbreviations, please refer to Table A2 in Appendix A. Additionally, Tables A3 and A4 present descriptive statistics of the variables used in our study.

5. Estimation Methodology

The GMM-SYS dynamic panel estimation methodology, proposed by Arellano & Bover [64], Blundell & Bond [65], and Blundell et al. [66], is employed to estimate the poverty model. This methodology is particularly suited for addressing potential endogeneity, simultaneity, and unobserved heterogeneity in panel data, which are key concerns in our study. The inclusion of lagged dependent variables as regressors and the use of lagged explanatory variables as instruments allow for unbiased and consistent estimation, even in the presence of two-way causality, such as the potential relationship between green bond issuances and economic development. By accounting for country-specific effects and time-invariant unobserved heterogeneity, GMM ensures the robustness of the results. Our objective is to investigate the effects of macroeconomic variables and green bonds issuances on poverty alleviation. The main model employed is presented as follows:

$$pov_{i,t} = \alpha + \rho pov_{i,t-1} + \beta X_{i,t} + \delta gb_{i,t} + \varepsilon_{i,t}, \quad i = 1,2,\dots N, \quad t = 2005,\dots,2021, \tag{2}$$

where $pov_{i,t}$ denotes the poverty headcount ratio at \$2.15 a day as a percent of the population, $\rho pov_{i,t-1}$ is the lagged poverty variable, $gb_{i,t}$ represents the log of green bonds issuances, $X_{i,t}$ is the vector of explanatory variables which includes the annual GDP growth rate, inflation rate, trade openness as a percentage of GDP, and the annual population growth rate in country i at time t, and $\varepsilon_{i,t}$ is the error term.

Additionally, a dummy variable for the countries in the MENA and SSA regions is added to the model, denoted as $D_{MESA,i}$, to examine the impact of green bond issuances in these two regions. The modified model is as follows:

$$pov_{i,t} = \alpha + \rho pov_{i,t-1} + \beta X_{i,t} + \delta gb_{i,t} + \theta D_{MESA,i} + \vartheta(D_{MESA,i} * gb_{i,t}) + \varepsilon_{i,t}. \tag{3}$$

In line with Brambor et al. [67], the net impact of green bonds issuances on poverty within the MENA and SSA sample is calculated using the methodology commonly employed in recent literature [68–70], which is equal to $\delta + \vartheta\overline{gb}$, where $\overline{gb}$ is the average of the green bonds issuances as presented in the descriptive statistics Tables A3 and A4 of Appendix A and the statistical significance is estimated using the standard errors of the two coefficients, δ and ϑ.

Moreover, to investigate the potential non-linear relationship between green bonds issuances and poverty alleviation, the squared term of the gb variable is introduced into the model, as follows:

$$pov_{i,t} = \alpha + \rho pov_{i,t-1} + \beta X_{i,t} + \delta gb_{i,t} + \gamma gb_{i,t}^2 + \varepsilon_{i,t}. \tag{4}$$

Based on the literature on quadratic regressions and net effects [71,72], the net non-linear effect of green bonds issuances on poverty in the full sample is calculated as $\delta + 2\gamma\overline{gb}$,based on model (4). The negative coefficients for both δ and γ are expected, indicating that a one percent increase in the green bonds issuances reduces poverty by δ, and this effect magnifies at a rate of "2γ". The threshold level or cut-off point of green bonds issuances is determined by $\left|\frac{\delta}{2\gamma}\right|$. When green bonds issuances are under this threshold, any increase contributes to a decrease in poverty. In contrast, levels exceeding the threshold result in a more pronounced reduction in the poverty rate.

To analyze the potential non-linear effect of green bonds issuances on poverty alleviation in MENA and SSA countries, the squared term of the gb variable and its interaction term with the $D_{MESA,i}$ dummy variable is added to the model. The augmented model is formulated as follows:

$$pov_{i,t} = \alpha + \rho pov_{i,t-1} + \beta X_{i,t} + \delta gb_{i,t} + \gamma gb_{i,t}^2 + \theta D_{MESA,i} + \vartheta(D_{MESA,i} * gb_{i,t}) + \varphi(D_{MESA,i} * gb_{i,t}^2 b_{i,t}^2) + \varepsilon_{i,t}. \tag{5}$$

Based on model (5) the impact of green bonds issuances on poverty alleviation is computed as the first derivative pov with respect to gb as follows, $\frac{\partial pov_{i,t}}{\partial gb_{i,t}} = \delta + 2\gamma\ gb_{i,t} + \vartheta D_{MESA,i} + 2\varphi D_{MESA,i} * gb_{i,t}$. This derivative shows that the marginal effect of green bonds issuances on poverty is computed at different values of the gb variable and the variance of this marginal effect is equal to $(\gamma + \varphi)^2 gb_{i,t}$. Like the full sample, the net effect of green bonds issuances on poverty in the MENA and SSA sample is computed as $\delta + \vartheta + (2\gamma + 2\varphi)\overline{gb}$ with a threshold level equal to $\left|\frac{\delta + \vartheta}{2\gamma + 2\varphi}\right|$.

It is worth emphasizing that there are three fundamental points to consider regarding the GMM-SYS dynamic panel estimation methodology: instrumental variable identification, simultaneity, and exclusion restrictions. Firstly, instrumental variable identification involves the careful selection of dependent variables, endogenous variables, and strictly exogenous variables. This

step is crucial for accurately estimating the relationships between these variables. Secondly, simultaneity refers to the issue of endogeneity, which occurs when the explanatory variable is jointly determined with the dependent variable. To address this concern, lagged values of the explanatory variables are used as instruments to address endogeneity and ensure reliable estimation. Lastly, exclusion restrictions are crucial as they ensure that the dependent variable is influenced solely by the strictly exogenous variables through the endogenous variables. In this study, all explanatory variables are considered endogenous, while only time-invariant variables are treated as strictly exogenous, following Boateng et al. [73] and Asongu & Nwachukwu [74]. This approach maintains the integrity of the analysis and allows for a thorough examination of variable relationships.

6. Estimation Results

The results highlight a significant relationship between green bond issuances and poverty reduction, with region-specific insights derived for the MENA and SSA regions. The robustness of the findings is confirmed through statistical tests, including the Arellano and Bond serial correlation test, the Hansen overidentification test, and the Wald validity test. These results provide a comprehensive understanding of how green finance impacts poverty across diverse contexts.

In Table A5, the model is estimated for the full sample, incorporating all relevant macroeconomic explanatory variables alongside the green bonds' issuances variable. The methodological framework examines each variable's contribution and assesses its incremental impact. This leads to the insights in Column 6, where the poverty variable, denoted "*pov*", is regressed on the set of explanatory variables, namely the lagged poverty variable ("*l.pov*"), GDP growth rate ("*gr*"), inflation rate ("*inf*"), openness ("*op*"), population growth rate ("*popgr*"), and the green bonds issuances ("*gb*"). The results indicate that a one percent increase in poverty in the previous year is associated with an increase in poverty in the current year by approximately 0.86% of the population. This finding aligns with studies by Emara & Mohieldin [42], Wu et al. [75], and Xu et al. [35], further confirming consistency within the literature.

The empirical results reveal a clear relationship between economic growth and poverty reduction. Specifically, a one percent increase in economic growth corresponds to a 0.13% decline in the poverty headcount ratio. This result aligns with the robust empirical evidence put forth by Emara & Mohieldin [41,42] as well as Emara [45], substantiating the reliability of our analysis. Furthermore, these results are consistent with similar studies conducted in various regions, reinforcing the generalizability of the findings. Notably, Sehrawat & Giri [76], World Bank Group [77], Fanta & Upadhyay [78], and Cruces et al. [79] have also observed similar patterns between economic growth and poverty alleviation.

Furthermore, the results show that a one percent increase in inflation corresponds to a significant 0.087% decrease in the poverty headcount ratio. This finding aligns closely with the research conducted by Talukdar [80], further supporting the validity of our results. The role of trade openness in poverty alleviation is less pronounced, showing an insignificant impact. This finding is consistent with studies such as Neaime & Gaysset [81], which observed similar patterns in the MENA region. The limited impact may be attributed to structural factors, such as unequal access to opportunities arising from trade or weak institutional frameworks in some developing regions. While trade openness has the potential to spur economic growth, its benefits may not always reach the poorest segments of the population, particularly in contexts marked by inequality or market inefficiencies.

Additionally, our results indicate a significant relationship between the population growth rate and poverty headcount ratio. Specifically, a one percent increase in the population growth rate corresponds to a 0.38% decrease in the poverty headcount ratio. This finding is consistent with Birdsall [82] and Ahlburg [83], who highlighted the complex role of population dynamics in poverty outcomes, potentially reflecting improved labor force participation or demographic dividends.

Extending the analysis, the findings reveal that a one percent increase in green bond issuances is associated with a significant reduction in the poverty headcount ratio by approximately 0.13%, holding all other factors constant. This finding provides robust evidence that green finance contributes meaningfully to poverty reduction. This result aligns with existing literature, including studies by Jones & Brown [84], Otek et al. [85], and Yi et al. [86], which highlight the role of green finance initiatives, such as green bond issuances, in reducing poverty.

For the MENA and SSA regions, the results in Column 7 indicate that the interaction term between green bond issuances and the regional dummy variable ($gb\_D_{MESA,i}$) is statistically insignificant. This finding is consistent with research by Yi et al. [86], which observed no significant

impact of green finance on rural household poverty reduction in China, as well as studies by Tang et al. [54] and Kousar et al. [87] in developing countries and South Asia, respectively. These studies collectively suggest that green finance has a limited impact on poverty alleviation in developing regions.

The results for the linear model imply that allocating funds solely through green bonds may not achieve substantial poverty reduction in the MENA and SSA regions. However, the possibility of a non-linear effect warrants further investigation. There may exist a threshold level beyond which green bonds have a more significant impact on poverty reduction. To explore this, a non-linear model is employed for the full sample, followed by testing for the MENA and SSA regions.

Table A6 presents the results for the full sample, confirming a non-linear effect of green bond issuances on poverty alleviation. The analysis reveals that a 1% increase in green bond issuances reduces the poverty headcount ratio by 0.049%, with an additional reduction of 0.024% for each incremental 1% rise in issuances, resulting in a total effect of 0.048%.[1] This indicates the presence of a threshold level of 2.03% of total annual green bond issuances. Advanced economies with well-established green bond markets have often surpassed this threshold, emphasizing its relevance. These findings are illustrated in Figure 3, which depicts the relationship between net effects, thresholds, and their implications for green finance strategies.

These findings are consistent with Tang et al. [54], who reported a positive impact of green finance on poverty reduction, with a stronger effect on rural poverty compared to urban poverty. Their study highlighted a non-linear dynamic where the impact on rural poverty alleviation gradually weakened while its effect on urban poverty alleviation increased. These insights enhance our understanding of the relationship between green finance and poverty reduction and align with other key studies in the field.[2] The results highlight the importance of surpassing a critical threshold of green investments to achieve significant reductions in poverty. As green bond issuances increase and funds are directed toward environmentally sustainable projects, their cumulative impact on poverty reduction strengthens over time.

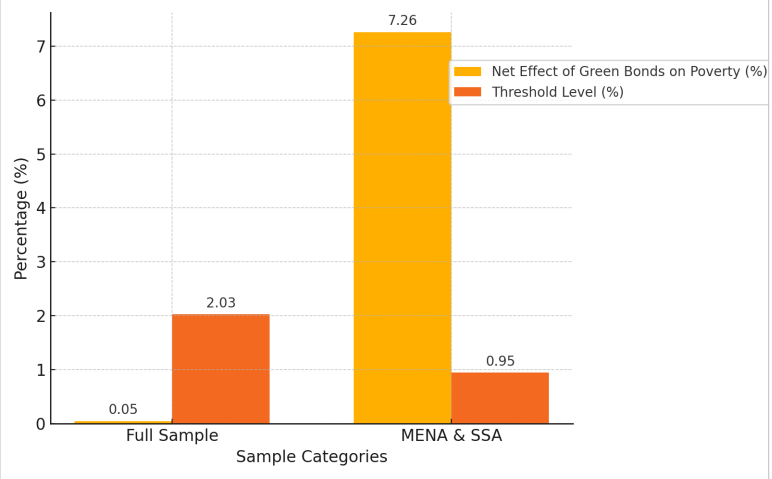

Figure 3. Net Effects and Threshold Levels of Green Bonds Issuances [88].

Column 2 presents the results for the MENA and SSA sample, illustrating the stronger impact of green finance on poverty alleviation in these regions. Specifically, the analysis shows that a 1% increase in green bond issuances reduces poverty by approximately 7.44%. Moreover, the magnitude of the poverty-reducing effect rises by an additional 7.86% of the poverty headcount ratio for each incremental 1% increase in green bonds issuances, resulting in a net effect of 7.26%.[3] The threshold for these regions is identified at 0.95%, notably lower than that of the full sample.

[1] The 0.024% represents two times the coefficient of *gbsq* as reported in Table A6 of Appendix A, reflecting the rate of change in the poverty-reducing effect for each incremental rise in green bond issuances.

[2] The insights provided by the previous works, including Zahonogo [39], Emara [45], Nsiah et al. [47], Bolarinwa et al. [48], Batuo et al. [49], Asongu [50], Tita & Aziakpono [51], Nandelenga & Odour [52], and Zungu & Grelying [53], are acknowledged in understanding the broader non-linear dynamics of financial development and poverty reduction in African nations.

[3] The 7.86% represents the sum of the coefficients of *gb* and $gb\_D_{MESA,i}$, while 7.26% is calculated as 2 multiplied by the sum of the coefficients of *gbsq* and $gbsq\_D_{MESA,i}$, as explained in the methodology section. Detailed coefficient values are provided in Table A6 of Appendix A.

This pronounced effect can be attributed to the "catch-up effect", where marginal returns on investments are higher in regions with underdeveloped green finance infrastructure and larger gaps in poverty reduction efforts [89]. Figure 3 highlights the stark contrast between the impacts observed in the full sample and those in the MENA and SSA regions, emphasizing the need for region-specific strategies to expand green bond activity. By addressing these disparities, policymakers can capitalize on the higher returns of green finance investments to promote sustainable development and poverty alleviation in these regions.

The analysis for these two regions highlights that the regional threshold for average annual green bond issuance is \$0.012422 billion (or \$12.422 million).[4] Based on the latest available data from the IMF on representative countries from the two regions, countries such as Egypt, Israel, Mauritius, Morocco, Nigeria, Seychelles, South Africa, Turkey, and UAE exceed this threshold, indicating robust green finance activity. Namibia is the only country falling below the threshold, signaling a need for increased green bond activity to align with regional goals. Table 1 shows the green bond issuances and their respective statuses against the threshold.

Table 1. Green Bond Issuances: Analysis and Threshold Comparison [88].

Country	Value (billion dollars)	Latest Year	Above Regional Threshold?
UAE	3.654	2022	Yes
South Africa	0.61	2022	Yes
Nigeria	0.05	2022	Yes
Namibia	0.0043	2018	No
Morocco	0.013	2017	Yes
Egypt	1.5	2021	Yes
Turkey	0.013	2022	Yes
Seychelles	0.015	2018	Yes
Israel	1.0	2021	Yes
Mauritius	2.3	2022	Yes

The smaller threshold level observed in the MENA and SSA regions, compared to the full sample, reflects the specific socio-economic and environmental conditions of these regions. Higher poverty rates, the urgent need for sustainable development, and the capacity of green projects to address multiple poverty dimensions simultaneously contribute to this finding. Furthermore, the significant environmental and social challenges faced by these regions emphasize the potential for green finance to deliver impactful poverty-reduction outcomes when the identified threshold is surpassed.

7. Conclusion and Policy Implications

Using GMM-SYS dynamic panel estimation methodology, this study provides valuable insights into the relationship between green bond issuances and poverty reduction across 73 developed and developing countries, including 10 representative nations from the MENA and SSA regions, over the period 2005 to 2021. The findings indicate that a 1% increase in green bond issuances is associated with a 0.13% reduction in the poverty headcount ratio, demonstrating their potential to fund environmentally friendly projects aimed at poverty alleviation. However, results for the MENA and SSA regions did not show significant effects in the linear model, indicating that green bonds alone may not suffice for achieving substantial poverty reduction in these regions.

The non-linear analysis reveals that green bond issuances play a more substantial role in reducing poverty when certain thresholds are exceeded. For the full sample, the net effect is a 0.048% reduction in poverty, with advanced economies often surpassing the global threshold of 2.03% of total annual issuances. In contrast, the impact is more pronounced in the MENA and SSA regions, with a net poverty reduction of 7.26%, provided the lower threshold of 0.95% is surpassed. This indicates the higher potential for green bonds to drive poverty reduction in these

[4] The threshold value was calculated as 0.95% of the average annual green bond issuance for the MENA and SSA region over the period 2014 to 2021. The cumulative total issuance of \$10.460882 billion over this period was divided by eight years to obtain an average annual issuance of \$1.30761 billion. The threshold was then derived as 0.95% of this average, resulting in \$0.012422 billion (or \$12.422 million).

areas and emphasizes the necessity of increasing issuances to unlock the full benefits of green finance.

The analysis of green bond activity in the MENA and SSA regions highlights significant disparities among countries. While nations such as Egypt, Israel, South Africa, and the UAE exceed the regional threshold of $12.422 million, others, such as Namibia, remain below this benchmark. This suggests the need for tailored strategies to enhance green bond activity in underperforming countries and align financing efforts with regional goals.

To maximize the poverty-reducing potential of green bonds, governments, and international organizations should implement targeted policies that stimulate green bond markets. These could include tax incentives, regulatory reforms, and capacity-building initiatives. Development banks and multilateral institutions also have a vital role to play by offering technical assistance, co-financing mechanisms, and risk mitigation tools. For advanced economies or countries surpassing the global threshold, efforts should focus on ensuring resources are allocated efficiently to maximize their impact on poverty alleviation.

While this study provides valuable contributions, further research is necessary to address its limitations and deepen the understanding of green bonds' role in poverty reduction. Future studies should examine long-term effects on broader socio-economic and environmental outcomes, such as income inequality and climate resilience. Incorporating more granular data, such as sector-specific investments and project-level outcomes, could reveal the mechanisms through which green bonds contribute to development. Additionally, comparing the performance of green bonds to brown bonds may offer insights into their relative advantages. Finally, exploring the influence of institutional quality and governance on green bond effectiveness could guide region-specific policy interventions.

This study acknowledges certain limitations. First, data availability in the MENA and SSA regions limited the sample to representative countries, which may not fully capture the diversity of green bond activity. Second, the lack of direct comparisons between green and brown bonds restricts the understanding of their relative benefits. Third, the aggregated nature of the data does not account for variations in green bond returns across maturities or issuance motivations. Addressing these gaps in future research could provide a more comprehensive understanding of green bonds' potential to advance global poverty alleviation efforts.

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Data Availability

Data supporting this study are included within the article.

Author Contributions

Conceptualization: N.E.; Formal analysis: N.E.; Investigation: N.E.; Methodology: N.E., & I-M.C.; Resources: I-M.C., & S.W.; Supervision: N.E.; Writing – original draft: S.W.; Writing – reviewing & editing: N.E. All authors accept responsibility for the entire content of this paper, have reviewed all the results and approved the final version of the paper for publication.

Conflicts of Interest

The authors have no conflict of interest to declare.

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Appendix A

Table A1. Definitions of Economic Variables.

Variable Name	Definition	Abbreviation
Poverty	Poverty headcount ratio at $2.15 a day (2017 PPP) (% of population).	*pov*
Growth	Annual percentage growth rate of GDP at market prices based on constant local currency.	*gr*
Inflation	Change in the log of Consumer price index (2010 = 100) (Authors computation).	*inf*
Openness	The sum of Exports of goods and services and Imports of goods and services as a percent of GDP (constant 2010 US$).	*op*
Population Growth	Change in the log of Population (Total).	*popgr*
Green Bonds Issuances	A self-labelled fixed income instrument where the proceeds directed exclusively in part or in full, new and/or existing green projects.	*gb*

Table A2. List of Countries.

Argentina	Greece	Panama
Australia	Hungary	Peru
Austria	Iceland	Philippines
Bangladesh	India	Poland, Rep. of
Belgium	Indonesia	Portugal
Bermuda	Ireland	Romania
Brazil	Israel	Russian Federation
British Virgin Islands	Italy	Serbia, Rep. of
Canada	Japan	Seychelles
Cayman Islands	Korea, Rep. of	Singapore
Chile	Latvia	Slovak Rep.
China, P.R.: Hong Kong	Liechtenstein	Slovenia, Rep. of
China, P.R.: Macao	Lithuania	South Africa
China, P.R.: Mainland	Luxembourg	Spain
Colombia	Malaysia	Sweden
Costa Rica	Marshall Islands, Rep. of the	Switzerland
Czech Rep.	Mauritius	Thailand
Denmark	Mexico	Turkey
Egypt, Arab Rep. of	Morocco	Ukraine
Estonia, Rep. of	Namibia	United Arab Emirates
Fiji, Rep. of	Netherlands, the	United Kingdom
Finland	New Zealand	United States
France	Nigeria	Vietnam
Georgia	Norway	
Germany	Pakistan	

Table A3. Descriptive Statistic—Full Sample.

Variable	Obs	Mean	Std. Dev.	Min	Max
pov	903	3.96	9.25	0.00	74.30
gr	1904	2.91	4.74	−54.24	26.63
inf	1789	21.81	237.29	−4.48	7481.66
op	1754	0.86	0.66	0.09	4.13
popgr	2043	0.96	1.26	−4.17	18.13
gb	358	4.49	9.69	0.00	72.27

Source: Author.

Table A4. Descriptive Statistic—MENA & SSA Sample.

Variable	Obs	Mean	Std. Dev.	Min	Max
pov	81	6.89	13.17	0.00	52.40
gr	272	3.24	4.23	−14.96	19.05
inf	253	11.11	23.43	−2.40	308.79
op	259	0.70	0.43	0.16	2.06
popgr	280	1.98	1.99	−2.63	18.13
gb	25	0.42	0.55	0.00	1.90

Source: Author.

Table A5. Extreme Poverty and Green Bonds Issuances. Dependent variable: Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population). Estimation Method: Arellano-Bover/Blundell-Bond Dynamic Panel GMM-SYS.

Regressors	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L. pov	0.775***	0.760***	0.755***	0.756***	0.749***	0.861***	0.811***
	(0.039)	(0.041)	(0.045)	(0.045)	(0.040)	(0.048)	(0.049)
gr		0.035*	0.062***	0.004	−0.004	−0.134**	−0.114**
		(0.018)	(0.024)	(0.017)	(0.014)	(0.064)	(0.058)
inf			0.002**	0.002	0.000	0.087*	0.166**
			(0.001)	(0.001)	(0.000)	(0.049)	(0.085)
op				0.511**	−0.161	0.085	0.010
				(0.258)	(0.233)	(0.182)	(0.137)
popgr					0.807***	0.377**	0.323*
					(0.300)	(0.154)	(0.197)
gb						−0.129*	−0.093**
						(0.068)	(0.040)
$gb\_D_{MESA,i}$							1.426
							(1.238)
Net Effect							−0.157
Observations	605	605	587	574	574	134	134
No. countries	48	48	47	47	47	37	37
AB, AR(1) *p*-value	0.0148	0.0111	0.00812	0.0430	0.0428	0.0230	0.0226
AB, AR(2) *p*-value	0.583	0.758	0.999	0.416	0.444	0.305	0.309
Hansen *p*-value	0.0759	0.222	0.0612	0.210	0.430	0.385	0.586
Wald Test *p*-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*Notes: ***, **, and * denotes statistical significance at the 1%, 5%, 10%, levels respectively.Numbers in round parentheses (.) are the robust standard errors.*

Table A6. Extreme Poverty and Green Bonds Issuances—Non-Linear Model. Dependent variable: Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population). Estimation Method: Arellano-Bover/Blundell-Bond Dynamic Panel System GMM-SYS.

Regressors	(1)	(2)
L. pov	0.867***	0.651***
	(0.051)	(0.081)
gr	−0.086	−0.039
	(0.077)	(0.115)
inf	0.121**	0.240*
	(0.061)	(0.125)
op	0.031	−0.147
	(0.152)	(0.403)
popgr	0.214*	0.713**
	(0.123)	(0.289)
gb	−0.049**	−0.095**
	(0.023)	(0.043)

Table A6. (*Continued*)

gbsq	−0.012	−0.049
	(0.018)	(0.034)
$gb\_D_{MESA,i}$		−7.348**
		(2.975)
$gbsq\_D_{MESA,i}$		−3.883**
		(1.617)
Net Effect	−0.048*	−7.262**
Threshold point	2.031	0.946
Observations	134	134
No. of countries	37	37
AB, AR(1) *p*-value	0.00670	0.0193
AB, AR(2) *p*-value	0.227	0.274
Hansen *p*-value	0.315	0.440
Wald Test *p*-value	0.000	0.000

*Notes: ***, **, and * denotes statistical significance at the 1%, 5%, 10%, levels respectively. Numbers in round parentheses (.) are the robust standard errors.*