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Dynamic impacts of globalization and environmental performance on renewable energy

Omar Ahmedqani Hussein[1] · **Abdulkadir Mohamed Abdullahi**[1]

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Abstract
This study investigates the dynamic relationships between renewable energy consumption, globalization, trade openness, carbon emissions, and arable land in Somalia from 1990 to 2020 using annual time series data from various sources. Employing econometric models such as the ARDL, FMOLS, and DOLS, the analysis reveals significant long-run relationships. A 1% increase in globalization (LnGI) and trade openness (LnTO) boosts renewable energy consumption (LnRE) by 0.123% and 0.020%, respectively, while a 1% rise in carbon emissions (LnCO2) decreases LnRE by 0.088%. Short-run dynamics show similar trends. These findings, validated by FMOLS and DOLS techniques, emphasize the impact of globalization, trade openness, and carbon emissions on renewable energy adoption. Policymakers should promote global integration and trade openness while enforcing strict carbon reduction measures to support renewable energy use and achieve sustainable development goals.

Keywords Renewable energy · Globalization · Trade openness · Carbon emissions · ARDL model · Somalia

1 Introduction

The concept of globalization has gained significant attention in recent decades, encompassing a wide range of economic, social, and environmental phenomena [1]. At the core of this discourse lies the importance of environmental performance metrics, which have emerged as a crucial component in understanding the global sustainability landscape [2]. Globalisation, in its broadest sense, can be defined as the increasing interdependence and integration of economies, societies, and cultures across the world. This process has given rise to a complex web of interconnected supply chains, where goods, services, and resources are produced and distributed globally [3]. However, this heightened interconnectivity has also brought to the forefront the pressing need to address environmental concerns, as the impact of human activities on the planet has become increasingly evident [4].

The growing awareness of environmental issues has led to the development of various environmental performance metrics, which serve as tools to measure and assess the environmental impact of organisations and their activities. These metrics can encompass a wide range of factors, such as energy consumption, greenhouse gas emissions, waste management, and resource utilisation. By incorporating these metrics into decision-making processes, organisations can better understand their environmental footprint and take steps to improve their sustainability [5].

The significance of environmental performance metrics in the context of globalisation cannot be overstated. As businesses expand their operations across national borders, the need to monitor and manage their environmental impact on a global scale becomes increasingly crucial [1]. Moreover, the alignment of these metrics with the United Nations

✉ Omar Ahmedqani Hussein, omarqani@simad.edu.so | [1]Faculty of Economics, SIMAD University, Mogadishu, Somalia.

Sustainable Development Goals (SDGs) has further underscored their importance in addressing global sustainability challenges [6].

However, the momentum of the fossil fuel market and the geopolitical preferences of major global players have continued to impede the widespread adoption of renewable energy systems, with some countries even actively discouraging their proliferation within their own borders and in neighbouring regions [7]. Nevertheless, the global policy landscape surrounding renewable energy is evolving, with nearly every country now having a renewable energy target in place. This shift in policy focus, from fossil fuels to renewables, has catalysed the development of a new generation of cost-effective and efficiently deployable renewable energy technologies, which are transforming the global energy landscape [8].

Economic globalization has had a significant impact on the renewable energy sector, influencing trade, investment, and technological transfer [9]. Growing consumer demand for sustainable products and the decreasing costs of renewable energy have led to rapid expansion in the renewable energy sector, which is expected to continue [10]. However, globalization encompasses not just trade and investment, but also social and political dimensions, which can impact renewable energy use in various ways [11]. Technological transfer and innovation are critical components of the renewable energy sector's growth [12]. Globalization facilitates the diffusion of renewable energy technologies across borders, enabling countries to adopt and adapt these technologies to their local contexts [13].

Globalization has emerged as a ubiquitous phenomenon in the contemporary global landscape, exerting far-reaching implications on various spheres, including the environment. The complex relationship between globalization and environmental performance, particularly in the realm of renewable energy, has been a subject of extensive academic and policy discussions [14]. The rapid integration of economies, cultures, and technologies facilitated by globalization has presented both opportunities and challenges in the pursuit of sustainable development. While globalization has enabled the dissemination of renewable energy technologies and increased investment in green energy projects, it has also contributed to environmental degradation and heightened carbon emissions through industrialization and urbanization [15]. Understanding the complex dynamics between globalization and environmental performance is crucial for formulating effective policies that promote sustainable development [15].

Existing literature suggests that economic globalisation can be a significant driver in promoting the use of renewable energy sources. Developed countries' desire to utilise low-carbon generating energy, such as renewable energy facilities, can be a key factor in enhancing environmental quality and sustainable economic development[16]. This is particularly relevant for the OECD countries, which should focus on understanding the dynamics of renewable energy demand rather than solely on economic development, as they strive to reduce their carbon footprint [17]. Furthermore, the positive relationship between income levels and energy consumption implies that as developing countries experience economic growth, there will be a corresponding increase in renewable energy consumption [18].

In the case of Somalia, a developing country faced with significant environmental challenges, the role of globalisation and environmental performance in shaping the renewable energy landscape is particularly significant [19]. Currently, developing countries, including those in sub-Saharan Africa, are the most vulnerable to the environmental problems associated with the use of non-renewable energy sources [20]. Somalia, as part of this region, is striving to develop and utilise sustainable renewable energy sources with the aim of mitigating greenhouse gas emissions and achieving sustainable development. However, the country faces numerous challenges in effectively harnessing its renewable energy potential, including infrastructure limitations, lack of technical expertise, and insufficient investment and policy support [21].

To address these challenges and unlock the potential of renewable energy in Somalia, a multi-faceted approach is necessary. This would involve strengthening the policy and regulatory framework, investing in infrastructure development, fostering technological innovation, and enhancing regional collaboration and knowledge sharing [22]. By doing so, Somalia can leverage the dynamic impacts of globalisation and environmental performance to accelerate the transition towards a more sustainable energy future, ultimately contributing to the country's overall developmental and environmental goals [21].

The rapid pace of globalization in recent decades has significantly reshaped the economic, social, and environmental landscapes of nations worldwide. As countries become more interconnected through trade, technology, and information exchange, globalization has opened new avenues for economic development while presenting complex challenges, particularly for developing nations like Somalia [23–25]. This interconnectedness has extended to energy markets, where the push for renewable energy has gained momentum in the global quest to address climate change and ensure long-term sustainability. However, in countries like Somalia, the relationship between globalization and renewable energy consumption remains underexplored, presenting a unique opportunity to investigate how global integration can drive sustainable energy transitions in such regions [26–29].

Environmental performance, which involves efforts to reduce environmental harm and promote sustainability, plays a crucial role in this context. For Somalia, a country facing serious environmental challenges, improving its environmental performance is essential for advancing its transition to renewable energy. Key issues, such as high carbon emissions, land degradation, and limited access to clean energy sources, pose significant obstacles. As a result, globalization's role in enhancing environmental performance through trade openness, foreign investment, and technology transfer becomes a critical component of the country's energy policy framework [30–33].

Despite extensive research on the impact of globalization and environmental performance on renewable energy and in developed countries, to our best knowledge there is no study focusing on Somalia. The existing literature primarily examines how developed nations drive renewable energy transitions through globalization but pays limited attention to the unique challenges and opportunities faced by fragile states like Somalia. This study aims to fill this gap by analyzing the effects of globalization on Somalia's environmental performance and renewable energy development. The findings will provide insights into how global economic and environmental trends can support sustainable energy transitions in countries with fragile institutions, contributing to discussions on global energy equity and sustainable development.

Somalia, a country grappling with socio-economic challenges and significant renewable energy potential, remains heavily reliant on non-renewable energy sources. Climate change has exacerbated the country's environmental issues, making it imperative to address these challenges. In this context, understanding the dynamics of globalization is crucial for developing effective energy policies that foster sustainable development. By exploring how globalization impacts environmental performance and the development of renewable energy in Somalia, this research seeks to offer an understanding of the interplay between these factors. The study is significant for several reasons. First, it offers valuable insights for policymakers on effectively integrating globalization into energy strategies. Second, it enhances the discussion on sustainable development in Somalia by emphasizing the potential of renewable energy. Third, it contributes to academic understanding of the relationship between globalization and renewable energy in developing contexts. Finally, it provides practical recommendations for stakeholders in the energy sector to support the transition to renewable energy. The rest of the study is structured as follows: Sect. 2 provides a review of the relevant literature; Sect. 3 outlines the methodological framework and describes the data; Sect. 4 presents the empirical findings and their analysis; Sect. 5 offers a detailed discussion of the results; Sect. 6 concludes by summarizing the study's key findings; Sect. 7 delivers policy recommendations based on the insights gained; and Sect. 8 addresses the study's limitations.

2 Literature review

Global warming is primarily driven by the combustion of fossil fuels, such as gas, coal, and oil, which have been the primary energy sources powering the global economy since the Industrial Revolution and meeting the rising demand for electricity [34]. However, the anticipated increase in international electricity consumption in the coming years raises concerns that greenhouse gas emissions will continue to escalate, undermining climate objectives and potentially leading to severe consequences for the planet [35]. Consequently, the transition to renewable energy sources has become a crucial priority for many nations worldwide.

According to data from the World Resources Institute, global greenhouse gas emissions witnessed a substantial 23% increase over the period 2005 to 2018. This marked rise in emissions has been largely attributed to developing economies, further intensifying the already substantial environmental impacts, including the observed escalation in global mean annual temperatures [36]. The consequences of elevated greenhouse gas emissions extend beyond environmental degradation, as they have also been associated with significant health risks, including increased susceptibility to respiratory illnesses, cardiovascular complications, and certain types of cancer. Furthermore, the economic implications are profound, affecting various industries such as agriculture, forestry, tourism, and leisure, while also placing substantial financial burdens on healthcare and social welfare systems [37].

However, globalization has been multifacetedly defined in the literature, ranging from economic, social, and political perspectives [38]. Researchers have traditionally explored the link between globalization and renewable energy consumption. Global integration has been found to promote renewable energy adoption through increased foreign direct investment and trade openness [39]. Specifically, globalization facilitates the transfer of clean energy technologies and knowledge spillovers, thereby enhancing renewable energy consumption in host countries [1].

The existing literature has not adequately addressed the role of environmental performance in this nexus. Environmental performance plays a critical role in determining renewable energy consumption. Countries with effective environmental management practices are more inclined to invest in renewable energy sources, while nations with weaker economies and inadequate environmental policies often face challenges in investing in renewable energy infrastructure [40].Consequently, it is essential to account for the mediating role of environmental performance in the globalization-renewable energy relationship.

This paper aims to bridge this gap by investigating the dynamic relationships among globalization, environmental performance, and renewable energy consumption. The originality of this research lies in exploring the triple connections, which have received inadequate attention in the extant literature.

Globalization, environmental performance, and renewable energy have been topics of increasing interest in the academic and policy spheres [14]. The complex relationship between these concepts has been the subject of various theoretical frameworks, each offering unique perspectives on the nature of their relationships [12]. Increasing levels of globalization can stimulate the demand for factors of production, thereby promoting the use of both renewable and non-renewable energy sources to facilitate economic growth [11]. Additionally, globalization may drive specialization in production, leading to economies of scale and higher economic output [1], with implications for energy consumption and emissions.

Researchers have explored the complex nature of these relationships, and several theories have been proposed to explain the observed outcomes. For instance, Dreher explained that globalization bears a positive relationship with renewable energy development in developed economies around the globe, as globalization encourages investment in green and sustainable technologies for the future [12]. However, other studies have found that certain dimensions of globalization, such as "reconstructed" and "revisited" economic globalization, can reduce the use of renewable energy consumption [41].

Some academic perspectives suggest that globalization has an adverse effect on the environment, as the heightened economic activity and resource usage associated with it may engender greater environmental deterioration [10]. Conversely, other scholarly works have found that globalization can potentially bolster environmental performance, through the dissemination of clean technologies and the advancement of environmental regulations [1]. Furthermore, certain researchers have argued that the environmental impact of globalization varies across different countries, contingent upon factors such as their level of economic development and environmental policies [42].

On the other hand, environmental pollution poses significant economic and social challenges that humanity will confront in the foreseeable future. Scholars, governments, and individuals have increasingly focused attention on the social issues stemming from environmental degradation, such as human health impacts, species extinction, and soil desertification [3]. Given the prominence of the United Nations Sustainable Development Goals in shaping the global policy landscape, improving environmental performance has become a critical component of achieving sustainable development. Countries worldwide have made active commitments to these goals, underscoring the importance of addressing environmental challenges as part of this broader agenda [43].

Following the study of Alola et al. utilized the Pooled Mean Group Autoregressive Distributed Lag econometric method to investigate the relationship between Europe's fossil fuel energy consumption and ecological footprint from 1997 to 2014. Their findings indicate that non-renewable energy sources are detrimental to environmental quality, as an increase in non-renewable energy use is associated with a decline in ecological quality within Europe [25]. Karlilar and Emir utilized Fourier ADL and FMOLS methods to analyze the relationship between solar power and ecological footprint. Their findings suggest that solar and wind energy are significantly associated with reductions in ecological footprint, thereby mitigating environmental degradation [44]. Similarly, Zhang et al. examined the effects of clean energy on environmental footprint in five energy-producing economies from 1990 to 2019, employing Generalized Method of Moments and FMOLS techniques. Their analysis revealed that increased supply of nuclear and wind energy contributes to lowering environmental deterioration [45].

On the other hand, following the studies of Bakari and Tiba (2021) examined Tunisia from 1971 to 2018 using the ARDL bounds test. The study outcome reports that combustible renewable and waste harm the environment. In the context of emerging countries, it is still being determined how crisis management strategies can provide environmental sustainability in an ecologically responsible manner while lowering carbon dioxide emissions and sustaining economic expansion. Ben Jebli (2016), Ben Jebli and Ben Youssef (2015), and (2019) explored the relationship between combustible renewables and waste, economic expansion, and carbon emissions in Brazil, Tunisia, and North Africa, respectively. The study's outcome reveals that combustible renewable and waste mitigate carbon emissions. According to the authors, this could be because they produce less pollution than fossil fuels.

On the other hand, following studies of Bakari and Tiba (2021) examined Tunisia from 1971 to 2018. The study focused the relationship between the use of combustible renewable and waste resources and environmental outcomes. In the context of emerging countries, the findings are mixed, with some studies indicating that these resources can have detrimental effects on the environment, while others suggest they can mitigate carbon emissions compared to conventional fossil fuels [46]. The literature is still exploring how to balance environmental sustainability, carbon dioxide emission reduction, and economic growth in an ecologically responsible manner in the context of developing economies [47–49].

One key aspect highlighted in the literature is the potential for renewable energy to contribute to improved environmental outcomes [50]. Renewable energy sources, such as solar, wind, and hydropower, are generally considered to have a lower environmental impact compared to conventional energy sources, with benefits including reduced greenhouse gas emissions, improved air quality, and decreased reliance on finite resources [51]. However, the literature also cares that the environmental performance of renewable energy is not without its challenges and trade-offs. For example, the construction and installation of renewable energy infrastructure can have localized environmental impacts, such as habitat disruption or changes to local ecosystems [52].

The present study contributes to the existing literature in several ways. First, it investigates the triple linkages among globalization, environmental performance, and renewable energy consumption, which have not been adequately addressed in the prior studies. Secondly, it examines the mediating role of environmental performance in the globalization-renewable energy nexus, which sheds light on the underlying mechanisms through which globalization affects renewable energy consumption. The findings of this research can provide valuable policy insights for promoting renewable energy adoption and enhancing environmental sustainability in the context of increasing globalization.

3 Methodological structure

3.1 Data

The research employed an annual time series dataset covering the years 1990 to 2020, which are essential for understanding the developments in Somalia's economic and environmental policies, especially in the context of global trends. During this period, Somalia experienced significant changes in governance, economic restructuring, and environmental challenges, all of which shaped its policy responses. This timeframe also aligned with a global shift towards renewable energy and an increased international focus on sustainable development. By analyzing data from these decades, we can thoroughly evaluate long-term trends in agricultural practices and institutional reforms, along with their impacts on environmental degradation.

Data acquisition involved three primary sources: the World Bank Open Data platform, the Organization of Islamic Cooperation (OIC), and the KOF Swiss Economic Institute. The study employed several key variables including renewable energy (% of total final energy consumption), globalization (globalization index), trade openness (trade openness percent), economic growth (gross domestic product per capita constant 2015), carbon emissions (carbon dioxide emissions kiloton) and arable land (% of land area). A table detailing each variable symbol, unit of measurement, and source is included for further reference. This approach ensures transparency and allows readers to understand the foundation of the analysis (see Table 1 for more details).

Table 1 Variable Description

Variable	Measurement	Symbol	Source
Renewable Energy	Renewable Energy Consumption (% of Total Final Energy Consumption)	RE	Sesric
Globalization	Globalization Index	GI	KOF
Trade Openness	Trade openness (Percent)	TO	Sesric
Carbon Emissions	Carbon Dioxide Emissions (Kiloton)	CO2	World Bank
Arable Land	Arable Land (% of Land Area)	AL	World Bank
Economic Growth	Gross Domestic Product per Capita (Constant 2015)	EG	Sesric

3.2 Econometric modelling

This research delves into the intricate interplay between globalization, trade openness, arable land, carbon dioxide emissions, and renewable energy consumption in Somalia from 1990 to 2020. The overarching objective is to elucidate the dynamic interactions and temporal transformations within this complex system. To achieve this, the study embarks on a multi-pronged statistical analysis. The initial phase involves employing stationarity tests, such as the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. These tests ensure the data adheres to the requisite statistical properties for robust analysis. Subsequently, cointegration analysis, specifically the F-bound cointegration test, is implemented to ascertain the presence of a long-term equilibrium relationship between the variables. Identifying such a cointegration is critical to comprehending the enduring influence these factors exert on one another.

The study progresses by leveraging advanced techniques such as the Autoregressive Distributed Lag (ARDL) model, implemented within the Eviews 12. This model offers a holistic perspective on the short-term and long-term correlations between the variables of interest. This comprehensive approach sheds light on the temporal dynamics of how changes in these factors influence carbon dioxide emissions. To further bolster the robustness of the analysis, the study incorporates a diverse methodological toolkit. This includes techniques such as Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). These methods provide a deeper understanding of the long-term relationships at play.

$$RE_t = f(GI_t, TO_t, CO_{2t}, AL_t, EG_t) \tag{1}$$

Within this econometric framework, the following notation is adopted: RE denotes renewable energy consumption, GI represents the level of globalization, TO captures trade openness, CO2 signifies carbon dioxide emissions, AL reflects arable land, and EG acts as a control variable for economic growth. The econometric model employed in this study investigates the determinants of renewable energy consumption (RE), considering the potential influences of globalization (GI), trade openness (TO), carbon dioxide emissions (CO_2), and arable land (AL), while controlling for economic growth (EG). The formal specification of this model is presented below.

$$LnRE_t = \beta_0 + \beta_1 LnGI_t + \beta_2 LnTO_t + \beta_3 LnCO_{2t} + \beta_4 LnAL_t + \beta_5 LnEG_t + \varepsilon_t \tag{2}$$

This equation depicts an Autoregressive Distributed Lag_2 (ARDL) model, designed to analyze the long-term influences of various factors on renewable energy consumption. To account for potential non-linear relationships inherent in time series data (t), all variables are logarithmically transformed (Ln). The estimated coefficients (β_0, β_1, β_2, β_3, β_4, β_5) quantify the magnitude and direction of the relationships between each factor and renewable energy consumption. For instance, β_1 specifically captures the degree to which a unit change in LnGIt (logarithm of globalization at time t) influences LnREt (logarithm of renewable energy consumption at time t), holding all other variables constant. The error term (εt) encompasses the impact of unobserved factors and random fluctuations within the data.

$$\begin{aligned}\Delta LnRE_t =& \beta_0 + \beta_1 \Delta LnRE_{t-1} + \beta_2 \Delta LnGI_{t-1} + \beta_3 \Delta LnTO_{t-1} + \beta_4 \Delta LnCO2_{t-1} + \beta_5 \Delta LnAL_{t-1} + \beta_6 \Delta LnEG_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta \mathrm{LnRE}_{t-1} + \sum_{i=1}^{q} \delta_i \Delta \mathrm{LnGI}_{t-1} \\ &+ \sum_{i=1}^{r} \gamma_i \Delta \mathrm{LnTO}_{t-1} + \sum_{i=1}^{s} \theta_i \Delta \mathrm{LnCO}_{2t-1} + \sum_{i=1}^{t} \lambda_i \Delta \mathrm{LnAL} + \sum_{i=1}^{t} \rho_i \Delta \mathrm{LnEG} + \mu ECT_{t-1}\end{aligned} \tag{3}$$

The first difference operator (Δ) is employed to capture the temporal dynamics, or changes over time, within the variables. The lag lengths (p, q, r, s, t, and u) for each variable are determined through a meticulous process that can involve either empirical methods or established model selection criteria. The intercept term (β_0) represents the fundamental, or baseline, effect on renewable energy consumption. To account for any deviations from long-term equilibrium, the error correction term (ECTt-1) is incorporated into the model. The coefficients β_1 to β_5 quantify the long-term effects of each respective variable on renewable energy consumption. Conversely, α_1, δ_1, γ_1, θ_1, λ_1, and ρ_1 represent the short-term impacts of these variables within the model.

4 Empirical results

4.1 Descriptive statistics

Table 2 summarizes the key characteristics of all variables used in this analysis including renewable energy (LnRE), economic growth (LnGI), trade openness (LnTO), carbon dioxide emissions (LnCO2), arable land (LnAL), and economic growth (LnEG). The data includes 31 observations for each variable. The table provides mean values for each variable, offering a general idea of the average level. For example, the mean value for LnRE (4.529) suggests that the average value across all observations for renewable energy is 4.529. Standard deviation (Std. Dev.) shows how spread out the data points are around the mean. Lower values indicate data clustered closer to the mean, while higher values signify greater variation. For instance, LnRE exhibits a relatively low standard deviation (0.025), suggesting the data points are concentrated near the mean value of 4.529. Conversely, LnTO shows a higher standard deviation (1.076), indicating more dispersion around the mean value of 3.348.

Skewness and kurtosis statistics offer insights into the data distribution's shape compared to a normal distribution. Most variables may not deviate from normality based on their skewness values. The Jarque–Bera test confirms this of p-values greater than 5%, indicating normal distribution over all variables.

The correlation matrix offers a glimpse into potential linear relationships between the variables. The table reveals some interesting initial associations. For example, a strong positive correlation exists between renewable energy consumption (LnRE) and both globalization (LnGI) and trade openness (LnTO). Conversely, carbon dioxide emissions (LnCO2) seem to have a weak negative correlation with renewable energy (LnRE) and a weak positive correlation with globalization (LnGI) and trade openness (LnTO). Where arable land (LnAL) exhibits a weak positive correlation with both LnRE and LnEG.

4.2 Unit root test

In Table 3 Unit root tests are statistical procedures employed in time series analysis to assess whether a variable possesses a unit root. A unit root indicates that the data series is non-stationary, meaning its statistical properties (like mean and variance) fluctuate over time. Non-stationary data can be challenging to analyze and model effectively. Table 2 summarizes the results of unit root tests conducted on six variables: renewable energy (LnRE), income growth (LnGI), trade openness (LnTO), carbon dioxide emissions (LnCO2), arable land (LnAL), and economic growth (LnEG). The tests were performed at Level I (0) and First Difference I(1).

Table 2 Descriptive statistics

Descriptive statistics	LnRE	LnGI	LnTO	LnCO2	LnAL	LnEG
Mean	4.529	3.264	3.348	6.413	0.525	5.771
Median	4.536	3.238	3.377	6.439	0.513	5.670
Maximum	4.559	3.416	4.669	6.600	0.588	6.345
Minimum	4.458	3.191	1.728	6.187	0.464	5.390
Std. Dev	0.025	0.075	1.076	0.099	0.036	0.308
Skewness	− 1.282	1.031	− 0.069	− 0.615	− 0.167	0.683
Kurtosis	4.021	2.595	1.422	2.906	1.727	2.271
Jarque–Bera	9.840	5.702	3.242	1.967	2.235	3.095
Probability	0.007	0.058	0.198	0.374	0.327	0.213
Observations	31	31	31	31	31	31
Correlations						
LnRE	1					
LnGI	0.670	1				
LnTO	0.807	0.747	1			
LnCO2	−0.226	0.330	0.327	1		
LnAL	0.574	0.640	0.516	0.060	1	
LnEG	0.618	0.897	0.875	0.543	0.495	1

Table 3 Unit root test

Unit root test	At Level						
		LnRE	LnGI	LnTO	LnCO2	LnAL	LnEG
ADF	With Intercept	− 5.950***	0.286	− 0.906	− 1.890	− 3.366**	− 0.009
	With Intercept & Trend	− 3.370*	− 1.209	− 9.730	− 2.674	− 4.923***	− 3.077
PP	With Intercept	− 5.950***	− 0.084	− 0.245	− 1.990	− 2.601	0.408
	With Intercept & Trend	− 5.001***	− 1.530	− 2.704	− 2.515	− 4.140**	− 2.166
At 1st Difference							
		Δ(LnRE)	Δ(LnGI)	Δ(LnTO)	Δ(LnCO2)	Δ(LnAL)	Δ(LnEG)
ADF	With Intercept	− 3.536**	− 4.521***	− 4.941***	− 3.197**	− 6.598***	− 4.008***
	With Intercept & Trend	− 3.439*	− 4.787***	− 4.730***	− 3.475*	− 6.455***	− 4.386***
PP	With Intercept	− 3.526**	− 4.647***	− 4.915***	− 3.130**	− 8.766***	− 4.052***
	With Intercept & Trend	− 3.439*	− 4.863***	− 4.729***	− 3.478*	− 8.502***	− 4.403***

The results revealed that most variables exhibited a unit root at the Level, indicating non-stationary behavior. This suggests the raw data series have trends or fluctuations in their mean and variance over time. However, a crucial finding emerged when examining the First Difference results. All variables achieved stationarity at this level. This implies the data series become stationary after differencing, suggesting they rely on their past values but exhibit stable changes. The finding of I (1) data, where variables are integrated of order one, strongly justifies the use of an ARDL model in the next stage of the analysis. ARDL models are particularly effective when dealing with I (1) variables. By incorporating the differenced data into the ARDL model, we can capture both long-run and short-run relationships between these variables while ensuring stationarity and obtaining reliable results. This allows for a more comprehensive understanding of how factors like renewable energy and trade openness influence economic growth in the long term and how short-term changes might impact these dynamics.

4.3 F bound test

In Table 4 The F-Bound test results provide compelling evidence for a significant long-run relationship between the variables in the ARDL model. The F-statistic of 31.89 significantly exceeds the upper bound of 3.38 at the 5% level. This statistically significant result ($p < 0.05$) allows us to confidently reject the null hypothesis of no long-run relationship. The substantial difference between the F-statistic and the critical value suggests a strong association between the variables in the long term, concluding that these variables are cointegrated.

This finding confirms the ARDL model's ability to capture the long-run dynamics influencing carbon emissions. By incorporating differenced variables (likely I (1)), the model effectively accounts for the long-term equilibrium relationships between factors like renewable energy, trade openness, and other explanatory variables. The statistically significant F-Bound test paves the way for further analysis of the estimated coefficients within the ARDL model, allowing us to explore the specific long-run impacts of these variables on economic growth.

Table 4 F bound test

Test Statistic	Value	Level of signif	I(0)	I(1)
F-statistic	31.89***	5%	2.08	3
K	5	5%	2.39	3.38
		1%	3.06	4.15

Note: *** denotes significant at 10%

4.4 Autoregressive distributed lag model (ARDL)

In Table 5 The ARDL model provides a valuable tool for analyzing the complex factors that influence the long-term equilibrium and short-term dynamics of renewable energy (LnRE). By carefully examining the estimated coefficients, we can gain insights into the fascinating interplay between these factors.

Globalization emerges as a key driver of long-term renewable energy adoption, with a statistically significant and positive association. Increased globalization acts as a powerful catalyst, propelling renewable energy use towards higher levels. For instance, a 1% rise in globalization could lead to a 0.123% increase in renewable energy use. This has the potential to significantly accelerate the adoption of renewable energy in the long run. Trade openness also plays a supportive role, with a positive and significant coefficient. This indicates that greater openness to trade creates a more favorable environment for embracing renewable energy. Similarly, a 1% increase in trade openness could result in a 0.02% rise in renewable energy use. Enhanced trade openness can facilitate the diffusion of renewable energy technologie and expertise.

However, carbon dioxide emissions (LnCO2) present a challenge. The negative and significant coefficient suggests that rising emissions act as a barrier, hindering the long-term shift towards renewable energy. For every 1% increase in carbon emissions, there could be a 0.088% decrease in renewable energy use. A significant increase in carbon dioxide emissions could potentially impede the transition to cleaner energy sources in the long run. This highlights the environmental pressures that drive the adoption of renewable alternatives. On the other hand, arable land (LnAL) and economic growth (LnEG) appear to have less impact, as their coefficients are statistically insignificant.

In the short term, carbon emissions have the most influence on renewable energy dynamics. The negative and significant coefficient for ΔLnCO2 indicates that a 1% increase in carbon emissions leads to a decrease in short-term renewable energy use of about 0.092%. Similarly, a 1% increase in economic growth could decrease short-term renewable energy consumption by 0.023%. Conversely, the positive and significant coefficients for globalization, arable land and trade openness suggest that a 1% increase in ΔLnGI, ΔLnAL, and ΔLnTO promotes short-term renewable energy adoption by approximately 0.034%, 0.017%, and 0.009%, respectively.

The negative and significant coefficient of the ECM term (-0.432) serves as a guide, directing the trajectory of renewable energy adoption back towards its long-term equilibrium. The model captures almost all over 94% of R square, the short-term variations in renewable energy adoption by considering changes in factors such as globalization and carbon emissions. This high explanatory power is further supported by the adjusted R-squared value of 93.3%, which takes into account the model's complexity with multiple variables.

In Table 6 the diagnostic tests show no significant evidence of heteroskedasticity. This is supported by the non-significant F-statistics of 1.47 and 0.78 for the Breusch-Pagan-Godfrey and Harvey tests, respectively. The normality of residuals is confirmed with a negligible Jarque–Bera value of 0.18 and a high p-value of 0.91. Although the Breusch-Godfrey

Table 5 ARDL test

Long run dynamics				
Variable	Coefficient	Std. Error	T-Statistic	Prob.
LnGI	0.123***	0.032	3.832	0.001
LnTO	0.020***	0.002	10.924	0.000
LnCO2	– 0.088***	0.012	– 7.501	0.000
LnAL	0.004	0.030	0.130	0.898
LnEG	– 0.023*	0.011	– 2.008	0.059
C	4.766***	0.096	49.809	0.000
Short run dynamics				
Δ(LnGI)	0.034***	0.011	3.134	0.006
Δ(LnTO)	0.009***	0.001	6.212	0.000
Δ(LnCO2)	– 0.092***	0.006	– 15.382	0.000
Δ(LnAL)	0.017***	0.007	2.533	0.020
Δ(LnEG)	– 0.023***	0.003	– 6.681	0.000
ECM	– -0.432***	0.027	– 16.231	0.000
R2	0.942			
Adjusted R2	0.933			

Table 6 Diagnostic checks

Diagnostic check	F-statistics	Jarque–bera Value	P. value
Heteroskedasticity Test: Breusch-Pagan-Godfrey	1.47	–	0.22
Heteroskedasticity Test: Harvey	0.78	–	0.56
Normality Test	–	0.18	0.91
Breusch-Godfrey Serial Correlation LM Test	1.82	–	0.10
Ramsey Reset Test	0.03	–	0.87

Serial Correlation LM Test suggests potential serial correlation, the modest LM statistic of 1.82 and the p-value of 0.10 are below conventional significance levels. The Ramsey Reset Test indicates no omitted variable bias, with an inconsequential F-statistic of 0.03 and a corresponding p-value of 0.87.

4.5 FMOLS and DOLS test

The ARDL model in Table 5 establishes a framework to investigate the factors influencing renewable energy (LnRE) adoption. To corroborate these findings and validate the long-run relationships, the study employs Fully-Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) techniques, as presented in Table 7. Both FMOLS and DOLS rely on coefficient estimates to depict the long-run influence of independent variables on LnRE. Concordant with the ARDL model, statistically significant coefficients are observed for globalization (LnGI), trade openness (LnTO), and carbon dioxide emissions (LnCO2). For instance, a 1% rise in LnGI is associated with a 0.077% (FMOLS) or 0.081% (DOLS) increase in LnRE in the long term. While the magnitudes slightly differ between FMOLS and DOLS, the directional influence (positive for LnGI and LnTO, negative for LnCO2) remains consistent across both models. This consistency strengthens the argument that globalization, trade openness, and carbon emissions play a pivotal role in shaping long-run trends in renewable energy adoption. The insignificant coefficient for arable land (LnAL) in FMOLS suggests a less pronounced long-run effect on LnRE. The interplay between globalization, renewable energy consumption, and carbon emissions is a critical topic in the pursuit of sustainable development.

5 Discussion of the results

The concept of globalization has gained significant attention in recent decades, encompassing a wide range of economic, social, and environmental phenomena. At the core of this discourse lies the importance of environmental performance metrics, which have emerged as a crucial component in understanding the global sustainability landscape. Globalization, in its broadest sense, can be defined as the increasig interdependence and integration of economies, societies, and cultures across the world [53]. One intriguing aspect is the time-varying nature of the link between globalization and renewable energy consumption, as identified by [34]. While a negative association existed between 2002 and 2011, potentially indicating a discouraging effect of globalization on renewable energy

Table 7 FMOLS and DOLS

FMOLS				DOLS		
Variable	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
LnGI	0.077***	0.039	0.060	0.081***	0.019	0.004
LnTO	0.019***	0.002	0.000	0.016***	0.001	0.000
LnCO2	– 0.127***	0.015	0.000	– 0.099***	0.005	0.000
LnAL	0.039	0.036	0.292	– 0.013	0.034	0.708
LnEG	– 0.003	0.014	0.832	0.004	0.006	0.582
C	5.025	0.121	0.000	4.830	0.046	0.000
R2	0.965			0.999		
Adjusted R2	0.958			0.996		

use, a positive influence emerged post-2014. This dynamic relationship underscores the need for ongoing research to capture how globalization's impact on renewable energy can evolve over time. Y. Zhang et al., (2022) introduces another layer of complexity by exploring the moderating effect of the digital economy. Their study, focused on Belt and Road (B&R) countries, suggests that a robust digital infrastructure can amplify the positive influence of globalization on renewable energy development. This implies that B&R countries with advanced digital economies might stand to gain more from globalization in terms of accelerating their adoption of renewable energy sources. Saidi & Omri, (2020) contributes by investigating the effectiveness of renewable energy. Their research demonstrates a dual benefit—renewable energy can stimulate economic growth while simultaneously reducing carbon emissions. This reinforces the notion that renewable energy offers a powerful solution for achieving sustainable development, where economic prosperity and environmental well-being go hand in hand. The case of China, the world's largest emitter, is particularly relevant. [56] confirms that China's development of renewable energy sources helps to reduce carbon emission intensity. This finding offers valuable insights as China strives to curb emissions and transition towards a more sustainable energy landscape.

Globalization plays a pivotal role in shaping the renewable energy landscape in Africa, offering both opportunities and challenges that can significantly influence the region's energy transition. One of the major benefits of globalization is the increased inflow of foreign direct investment (FDI) in renewable energy projects. Many African countries have witnessed a rise in FDI, particularly in solar and wind energy sectors. This investment not only provides essential capital but also brings in technical expertise, which is crucial for the development and deployment of renewable energy infrastructure. Such financial and technical support can help alleviate some of the financial constraints that have historically hindered renewable energy adoption on the continent. Moreover, globalization facilitates the transfer of renewable energy technologies from developed countries to Africa. This transfer allows African countries to access advanced technologies and benefit from the experiences of nations that have already embarked on large-scale renewable energy projects. This technological exchange can shorten the learning curve for African nations and promote the rapid deployment of cleaner energy alternatives [57].

However, several challenges hinder the full realization of renewable energy adoption across the continent. One of the main obstacles is the heavy reliance of many African countries on fossil fuels, which remain a dominant source of energy. This dependency creates a structural barrier, as established fossil fuel industries often have substantial political and economic influence, making it difficult for renewable energy to compete. The entrenched infrastructure and subsidies for fossil fuels pose significant hurdles to the growth of renewable energy sectors. In addition, Africa's infrastructure, particularly in rural areas, is often underdeveloped. Poor grid connectivity and inadequate distribution networks make it challenging to integrate renewable energy projects, such as solar or wind farms, into the existing energy systems. These infrastructural deficits disproportionately affect remote communities, limiting their access to reliable electricity and slowing down the adoption of renewable energy technologies. Without significant improvements in infrastructure, the potential of renewable energy to reach its full capacity remains limited [58].

On the other hand, the growing awareness of environmental issues has led to the development of various environmental performance metrics, which serve as tools to measure and assess the environmental impact of organisations and their activities. These metrics can encompass a wide range of factors, such as energy consumption, greenhouse gas emissions, waste management, and resource utilization [59]. By incorporating these metrics into decision-making processes, organisations can better understand their environmental footprint and take steps to improve their sustainability. The significance of environmental performance metrics in the context of globalisation cannot be overstated. Moreover, the alignment of these metrics with the United Nations Sustainable Development Goals has further highlighted the importance of environmental performance in the global sustainability agenda.

However, the empirical analysis of this study underlines fundamental insights. The findings of the study highlights the critical roles of globalization, trade openness, and sustainable land use practices in fostering renewable energy consumption. These factors have demonstrated a positive and significant impact on renewable energy approval, indicating that increased integration into the global economy and the adoption of sustainable agricultural practices are conducive to enhancing renewable energy use in Somalia. The findings contribute to the understanding of the factors influencing renewable energy adoption in developing economies and offer valuable policy recommendations for fostering sustainable energy transitions in Somalia. Conversely, carbon emissions have a negative influence on renewable energy consumption. This inverse relationship highlights the environmental and economic challenges posed by high levels of carbon emissions, which can impede the transition towards renewable energy sources. This finding is particularly relevant for policy formulation, as it emphasizes the critical need to reduce carbon emissions in order to create a more favorable environment for the adoption of renewable energy.

Scholars have noted that the increasing interdependence and integration of economies, driven by globalization, has contributed to the growing demand for renewable energy sources as a means to address environmental concerns and mitigate the adverse effects of human activities on the planet. Globalization has also facilitated the cross-border transfer of renewable energy technologies, knowledge, and best practices, enabling the widespread adoption and diffusion of these technologies across different regions. This has led to a significant increase in the global share of renewable energy, which is projected to rise from 14% in 2018 to approximately 74% in 2050, requiring an eightfold annual increase [60]. However, the integration of renewable energy into the global energy landscape is not without its challenges. Researchers have highlighted the need to address the environmental sustainability of renewable energy technologies, as the production, installation, and operation of these technologies can also have significant environmental impacts [8]. Studies have emphasized the importance of proactively addressing the environmental sustainability of renewable energy, ensuring that the transition to a low-carbon future is carried out in a manner that is mutually reinforcing with climate change mitigation and the achievement of the sustainability goals [61].

6 Conclusion

This research analyzes the factors influencing renewable energy adoption in Somalia, focusing on the relationship between globalization, environmental performance, and economic development. The findings offer insights for policymakers, researchers, and stakeholders engaged in the global energy transition. Globalization emerges as a significant driver of renewable energy adoption in Somalia, particularly when supported by strong digital infrastructure. However, the effects of globalization can vary over time, requiring countries to manage associated risks while capitalizing on opportunities. Reducing carbon emissions is essential for accelerating the shift toward cleaner energy sources and achieving sustainable development. Although economic development presents opportunities for renewable energy adoption, it also poses challenges, as economic growth can lead to increased energy demand and emissions if not managed effectively. Thus, fostering sustainable economic growth that is not heavily dependent on fossil fuels is crucial for meeting both environmental and economic goals. Somalia should devise a globalization strategy that maximizes the benefits of globalization for renewable energy adoption while mitigating potential downsides. Promoting regional cooperation will be essential to enhance Africa's renewable energy transition by facilitating knowledge sharing, resource distribution, and best practices.

7 Policy implications

The findings of this study indicate several policy implications that could support the transition to renewable energy in Somalia and across Africa. Policymakers should focus on fostering an environment conducive to the adoption and integration of renewable energy technologies. This could involve implementing targeted incentives, such as feed-in tariffs, tax credits, and subsidies, which have the potential to increase the economic attractiveness of renewable energy for consumers and investors.

Additionally, policies that encourage the cross-border transfer of renewable energy technologies and expertise could play a significant role in facilitating the diffusion of these innovations, particularly from developed to developing economies. However, the effectiveness of such policies is likely to be influenced by regional and institutional contexts, highlighting that a uniform approach may not be suitable for all settings.

The study underscores the need for a comprehensive approach to energy policy that integrates the dynamics of globalization, trade openness, sustainable land use, carbon emissions, and renewable energy consumption. It is recommended that policymakers develop holistic strategies that account for these interconnected factors to better manage the transition to renewable energy. For example, aligning agricultural policies with energy objectives could enhance land-use efficiency and reduce environmental degradation, thereby advancing both energy sustainability and food security.

Furthermore, investment in research and development (R&D) is crucial for advancing the environmental sustainability of renewable energy technologies. Prioritizing funding for R&D initiatives aimed at enhancing the efficiency, durability, and recyclability of renewable energy infrastructure could yield significant benefits. Nonetheless, it is essential to approach these investments with a realistic perspective, acknowledging the inherent technical and financial challenges. Efforts should also prioritize reducing the carbon footprint associated with the lifecycle of renewable energy technologies, from production and installation to decommissioning and waste management.

8 Limitations and future research directions

While this study provides insights into the relationship between globalization, renewable energy adoption, and environmental performance in Somalia, several limitations must be acknowledged. A primary challenge is the availability and quality of data from 1990 to 2020. Data gaps, inconsistencies, and limitations in granularity may affect the robustness of the results, particularly in a developing country like Somalia, where reliable data collection is often hindered by institutional and infrastructural constraints.

Additionally, the scope of variables analyzed in the study is limited. Important factors such as technological innovation, political stability, and financial investments in the renewable energy sector were not incorporated into the analysis. These elements are critical for a comprehensive understanding of the broader ecosystem influencing renewable energy transitions. Political instability, in particular, plays a significant role in affecting energy policies, foreign direct investment, and infrastructure development in Somalia and other developing countries. Future research should aim to include these factors to provide a more holistic analysis of the drivers and barriers to renewable energy adoption.

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Data availability Data sharing is available upon request.

Declarations

Ethics approval and consent to participate This article reports analysis of secondary data.

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