URBAN ENERGY TRANSITION, GREEN ENERGY ACCESS AND POLLUTION CONTROL: Empirical Evidence

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ABSTRACT

This study addresses the importance of balancing urban energy transition and green energy access while promoting environmental sustainability. To this end, panel data from 28 African nations between 1990 and 2021 were analysed using the cross-sectional augmented ARDL (CS-ARDL) approach. The findings indicate that the combination of urbanization, welfare, and energy transition reduces pollution in African countries. The study highlights the significance of energy transition in mitigating pollution arising from urban energy transition and green energy access. Additionally, the study suggests essential policy recommendations to foster a cleaner environment in the African region.

Keywords: Urbanisation, Welfare, Energy Transition, Pollution, Africa
JEL classification: O18; P36; Q42; Q53; N57

1. Introduction

Africa stands at a critical juncture in its quest for sustainable development, with urban areas being at the forefront of energy and environmental challenges. As urbanization rapidly transforms African landscapes, the demand for energy continues to surge, leading to increased pollution levels and detrimental impacts on health and surrounding environments (Kennish, 2002; Sahoo & Sethi, 2022). The transition to sustainable and green energy sources in urban areas holds tremendous potential for addressing both energy and environmental concerns (Isola et al., 2017; Steffen et al., 2020). This study examines the intricate dynamics of urban energy transition and green energy access in African countries, unravelling the complex interplay between these factors and exploring the moderating role of the energy transition.

The concept of urban energy transition encapsulates the paradigm shift from conventional, carbon-intensive energy sources towards cleaner and more sustainable alternatives within urban environments (Winkler & Marquand, 2009; Tabash et al., 2022). This transition not only holds promise for mitigating the adverse environmental impacts of energy consumption but also has wide-ranging socio-economic implications, including job creation, improved energy security, and enhanced quality of life for urban dwellers (Rietveld et al., 2016; Mesagan & Vo, 2024). This transition encompasses multiple aspects, including energy generation, distribution, and consumption patterns within urban areas. In Africa, more than 22 countries are already mostly reliant on renewable energy as their primary source of energy. Overall, 40.5% of Africa's energy is sourced from renewable energy (Chandler, 2023; Mesagan et al., 2022). This is higher than the global average of 34.1%. However, access to electricity remains a problem as most of the renewable energy is only available in urban areas. Thus, the problems associated with urban energy transition can only effectively addressed through the adoption of green energy access.

Green energy access refers to the availability and utilization of clean and sustainable energy sources, ensuring reliable and affordable energy for urban communities (Omojolaibi et al., 2015; Ogbuji et al., 2020; Surya et al., 2021). Improving access to green energy is a vital component of sustainable urban development, as it provides an alternative to fossil fuels, reduces greenhouse gas emissions, and promotes a cleaner and healthier living environment. Access to green energy empowers urban residents with cleaner energy options while fostering economic opportunities and enhancing energy security (Majid, 2020; Mesagan et al., 2024). However, green energy access still proves to be a problem in Africa, with up to 600 million people and 950 million people lacking access to clean energy and clean cooking fuels respectively (Acheampong & Menyeh, 2021; Chandler, 2023). This study explores the potential of urban energy transition and improved access to green energy, specifically through the expansion of renewable energy technologies like solar and wind power, in reducing pollution levels throughout Africa.

As the global discourse emphasizes the significance of urban energy transition and green energy access in pollution reduction, the need for this study becomes increasingly apparent. Past research has failed to establish a comprehensive connection between the impact of urban energy transition and green energy access within the pollution model. Furthermore, the novel exploration of energy transition's moderating influence on both urbanization and welfare in Africa's pollution reduction landscape extends the boundaries of knowledge. This holds immense significance for numerous developing countries in Africa striving to strike a delicate balance between economic growth and environmental sustainability, where energy transition emerges as a pivotal factor in reversing the adverse effects of pollution or sustaining environmental progress. However, this challenge is multifaceted, considering that the dynamics of urban energy transition and green energy access are intricately intertwined with income disparities. Thus, the current study holds substantial merit in shedding light on this complex relationship and its implications for Africa's sustainable development trajectory. Thus, we present the specific objectives: (i) to examine the impact of urbanization and welfare on Africa's pollution, (ii) to analyse the moderating influence of energy transition on pollution in Africa, (iii) to determine how urban energy transition affects environmental pollution, and (iv) to examine the impact of green energy access on pollution in Africa.

2. Literature Review

Policymakers and researchers globally are increasingly prioritizing urbanization and welfare in combatting pollution. For example, Turok and Borel-Saladin (2014) explored the problems urbanization causes in Ghana, especially pollution. The study revealed that urbanization is interdependent on other factors to cause environmental degradation, including rapid economic development, and recommended the adoption of urban development concept values. Cobbinah et al. (2017) examined the relationship between South Africa’s living standards and urbanization. The paper found that urbanization and population growth increase pollution and as such are key factors to consider for reducing environmental degradation.

Mesagan and Nwachukwu (2018) examined the factors influencing environmental quality in Nigeria, with specific emphasis on the impact of financial development. The study applied an ARDL bounds testing approach to analyse time series data from 1981 to 2016. The findings showed that although financial development reduces pollution, income and urbanization cause environmental degradation.

Scholars have also focused on the effects of welfare on pollution. Hernández and León (2013) examined how welfare in a tourism-based economy affects environmental degradation. The study shows that the interdependence between welfare and tourism causes pollution to increase over time. Sapkota and Bastola (2017) looked at the effects of income and foreign direct investment (FDI) on pollution in Latin American countries. The study revealed that while FDI improves environmental sustainability, welfare has the opposite effect. However, the interaction of both caused a significant reduction in pollution emissions. A study by Hanh et al. (2020) researched the association of welfare and pollution when considering investment from the foreign sector. The results showed that welfare and pollution had a positive relationship. But with the introduction of investments from the foreign sector, there is great potential for pollution reduction.

Energy transition is a growing term of interest for researchers worldwide. Its relationship to pollution has been investigated more in recent years. Steffen et al. (2020) investigated how to navigate energy transition during the COVID-19 crisis. The study revealed that carbon emissions and air pollution decreased drastically during the first quarter of the COVID-19 crisis. This was due to lockdown measures and shutdown of several businesses and factories. It showed that these led to economic shocks that had an impact on energy transition. The study found that energy transition measures improved air quality and reduced pollution emissions significantly during the crisis. Liu et al. (2022) examined energy transition in Beijing, China and its effect towards air pollution and carbon neutrality by 2050. It sought to find if importing energy would provide better benefits than being self-sufficient. The study shows that energy transition reduces pollution by up to 95% if Beijing remains self-sufficient and 98% if energy is imported till 2050. Thus, energy transition provides notable benefits to pollution reduction.

In summary, understanding the complexities of environmental pollution requires considering various contributing factors. While previous studies have focused on specific indicators such as population, energy transition, trade, energy consumption, and financial development (Chen and He, 2014; Cobbinah et al., 2017; Mesagan & Olunkwa, 2022), they have mainly overlooked urban energy transition and green energy access. This study goes beyond examining the impact of urbanization and welfare, and investigates the moderating effect of energy transition on Africa's decarbonization process. By incorporating interaction terms, we account for the influence of the interaction between urbanization and welfare on the pollution reduction model. This study contributes to the existing knowledge on environmental sustainability models and provides a valuable template for emerging nations.

3. Research Methodology

3.1 Specification of the model

The Energy Ladder Hypothesis, introduced by H. Brooke Eakin in the late 1980s, explains the progression of household energy use patterns during economic development (Hosier and Dowd, 1987). The hypothesis suggests that households transition from traditional fuels to modern and cleaner energy sources as socioeconomic conditions improve. This transition is represented as a ladder, with households ascending to higher levels of energy access and utilization. Initially relying on biomass fuels like firewood and animal dung, households gradually adopt kerosene, coal, natural gas, electricity, and eventually renewable energy technologies, as suggested by Hosier and Dowd (1987) and Bisu et al. (2016).

This study introduces a pioneering integration of the Energy Ladder Hypothesis and the IPAT (Impact = Population × Affluence × Technology) model to deepen our understanding of the intricate relationships between energy transitions, socio-economic factors, and environmental sustainability. By combining the well-established IPAT framework, which considers the impact of population, affluence, and technology on the environment, with the Energy Ladder Hypothesis, which focuses on the shift from traditional to modern energy sources, we can analyse the dynamics of energy consumption patterns and their environmental implications more comprehensively.

The model is expressed in the following algebraic form:

$$I = P \times A \times T \tag{1}$$

where:

P represents population,

A represents affluence or individual wealth,

T represents technology, which also encompasses other potential drivers of carbon emissions, and

I indicates impact.

The IPAT model is an accounting-based framework that has limitations in capturing the complex and dynamic impact of human activities on the environment. To overcome this, Dietz and Rosa (1997) introduced the STIRPAT model, which stands for Stochastic Impacts by Regression on Population, Affluence, and Technology. This framework, as noted by Dietz and Rosa (1997) and York et al. (2003), better accounts for the intricacies of human activities on the environment. The STIRPAT model can be expressed in an algebraic form thus:

$$I_{it} = \lambda_0 P_{it}^{\alpha_1} A_{it}^{\alpha_2} T_{it}^{\alpha_3} \varepsilon_{it} \tag{2}$$

From Equation (2), the intercept λ and the elasticities, α_1, α_2, α_3 correspond to P, A, and T respectively. In addition, the stochastic term ε accounts for uncertainty, while i represents the cross-section and t denotes the time effect. To align with the approach used by York et al. (2003) and Bargaoui et al. (2014), we apply a logarithmic transformation thus:

$$Ln(I_{it}) = \lambda_0 + Ln\alpha_1(P_{it}) + Ln\alpha_2(A_{it}) + Ln\alpha_3(T_{it}) + \varepsilon_{it} \tag{3}$$

The logarithmic term in Equation (3) represents the logarithm, while all other variables and parameters remain unchanged from their previous definitions.

The STIRPAT model, which builds upon the IPAT framework, offers flexibility by incorporating additional factors that drive carbon emissions (Dietz & Rosa, 1997; Dietz, 2007). This adaptability allows researchers to modify the STIRPAT framework to align with specific research objectives. In terms of theoretical contribution, we integrate the population component of

STIRPAT with urbanization (URB). The urban population serves as a more accurate proxy for capturing the amount of urbanization in a country and it can be used to examine how it influences their anthropogenic activities. Similarly, we use energy transition (ET) as a proxy for the technology component in the model. Given that technology plays a crucial role in facilitating the transition to cleaner energy sources, the pace of energy transition is expected to affect carbon emissions. Furthermore, we represent the affluence component of the STIRPAT model with income per person. Thus, to analyse the impact of energy transition on carbon emissions, the resulting estimated model is as follows:

$$CO2_{it} = \lambda_0 + \alpha_1 URB_{it} + \alpha_2 WEL_{it} + \alpha_3 ET_{it} + \alpha_4 FDI_{it} + \alpha_5 TO_{it} + \alpha_6 GFCF_{it} + \varepsilon_{it} \quad (4)$$

where: the term CO2 represents carbon emissions, URB signifies urbanization, ET signifies energy transition, and WEL denotes income per person, which reflects welfare.

In order to address potential model biases, we introduce foreign direct investment (FDI), trade openness (TR), and gross fixed capital formation (GFCF) as covariates that could potentially influence carbon emissions. The parameters in question refer to the regression slopes. However, this study calculates an ET index that measures the proportion of renewable energy to non-renewable energy, capturing the transition pathway as outlined in the research conducted by Taghizadeh-Hesary and Rasoulinezhad (2020):

$$ET = \frac{Renewable}{Nonrenewable} \times 100 \quad (5)$$

In Equations (6) and (7), the model is extended to accommodate the interaction between energy transition and urbanization (URBEN), alongside energy transition and welfare (GREEN). The other variables remain as explained.

$$URBEN = ET \times URB \quad (6)$$

$$GREEN = ET \times WEL \quad (7)$$

In Equation (8), the model is extended to accommodate the interaction between energy transition and urbanization (URBEN), alongside energy transition and welfare (GREEN). The other variables remain as explained.

$$CO2_{it} = \lambda_0 + \alpha_1 ET_{it} + \alpha_2 URBEN_{it} + \alpha_3 GREEN_{it} + \alpha_4 FDI_{it} + \alpha_5 TO_{it} + \alpha_6 GFCF_{it} + \varepsilon_{it} \quad (8)$$

The study employed a panel analysis for 28 African countries for the period 1990 to 2022. Data were sourced from the World Development Indicators (WDI, 2023). Table 1 provides a comprehensive overview of the secondary data, including detailed descriptions and summaries, along with their respective measuring units.

Table 1: Data Identification

Variable	Identification	Description	Source
CO2	Pollution	Represented by CO2 emission per metric tonne	WDI, 2022
URB	Urbanization	Urban population	WDI, 2022
WEL	Welfare	Represented by GDP per capita	WDI, 2022
ET	Energy Transition	Captured by a ratio of renewable and non-renewable energy	Derived
FDI	Financial Development	Represented by credit to the private sector % of GDP	WDI, 2022
TO	Trade Openness	Ratio of exports plus imports over GDP	WDI, 2022
URBEN	Urbanization Energy Transition	Captured by multiplication of energy transition and urbanization	Derived
GREEN	Green Energy Access	Captured by multiplication of energy transition and welfare	Derived

Source: Authors' compilation.

4. Schematic Link and Results

The diagram in Figure 1 illustrates that the correlation between urbanization, welfare, and pollution in African nations can vary. Urbanization contributes to pollution through the expansion of industrial sectors. The growing energy demand in urban areas, driven by rising income levels, often leads to increased reliance on fossil fuel-based energy sources. Consequently, this results in higher emissions of greenhouse gases and pollutants. As countries experience economic growth, they tend to engage in energy-intensive activities and infrastructure development, which typically lead to heightened pollution levels (Hernández and Leon, 2013).

4.1 Conceptual framework

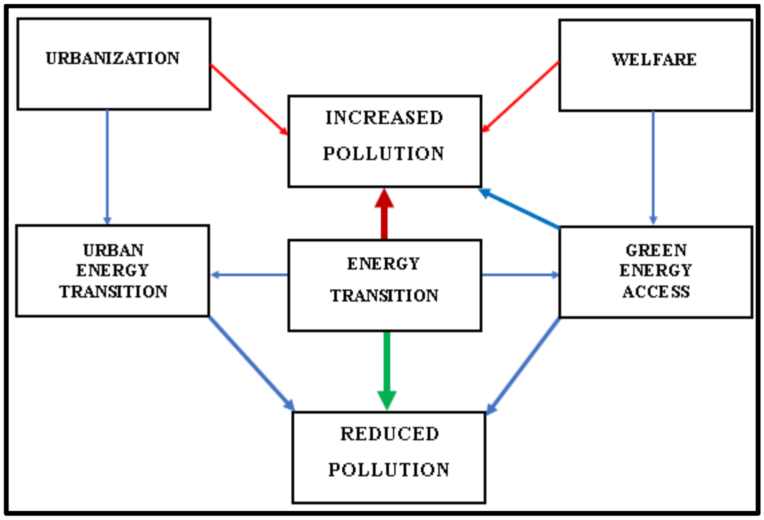

Figure 1: Schematic link for the Study

Source: Researchers' compilation.

However, the combination of energy transition, urban energy transition, and access to green energy presents viable solutions to these challenges. By shifting away from fossil fuel-based energy sources and embracing cleaner and renewable alternatives, we can mitigate pollution risks. It is worth noting that Figure 1 demonstrates both positive and negative effects of the interaction between energy transition and welfare on pollution. It is essential to consider the high poverty rates in Africa, where more than 75% of the population lives below the extreme poverty line of $1.90 per day. This is very high compared to the average of other regions such as Europe (21%), Asia (20%), America (6.2%) and globally (8.5%) (WDI, 2023). The transition to renewable energy in Africa is a costly endeavour, with an estimated price tag of over $30 billion USD, making it accessible only to a privileged few (Mutezo and Mulopo, 2021). For individuals and communities in Africa with limited financial means, this represents a significant financial burden.

Nonetheless, by strategically allocating resources towards research and development, African leaders can drive technological progress and enhance the efficiency and sustainability of green energy solutions. This viewpoint finds support in the works of Pacini and Batidzirai (2013) and Bisello and Vettorato (2018).

4.2 Results

Table 2: Descriptive Statistics

Variable	Mean	Std. dev.	Min	Max
CO2	1.451099	2.061945	0	9.81719
URB	11615582	14642381.18	378614	190138462
WEL	2198.956	2446.494	99.7572	15764.9
ET	469.7159	731.9131	0.060051	5997.32
FDI	927983415	2219251538	749000000	41000000000
TO	63.94159	26.61282	0.756876	152.547
GFCF	10927396533	17330208043	0	150000000000
URBEN	592562564	14930545166	1700000	11000000000
GREEN	356080.1	512691.9	252.058	5000000

Source: Researcher's computation.

Table 2 shows that the average levels for the variables were: 1.45 metric tons per capita for pollution, 11.61 million people for urbanization, 2198.96 United States dollars (US$) for welfare, 469.7 for energy transition, , 927.98 million US$ rate for financial development, 63.94 for trade openness, 10.93 billion US$ for gross fixed capital formation, 592.56 million US$ for urban energy transition, and 356080.1 US$ for green energy. These results show that Africa is behind in urban population and energy access when compared to the rest of the world. With only 44% of Africans living in urban areas, this is below the world average of 57%. In essence, these results highlight the importance for African nations to prioritize enhancing electricity access for their citizens and facilitating urbanization, in order to address the widespread environmental degradation in the continent.

Table 3: Correlation Matrix

	CO2M	*URB*	*WEL*	*ET*	*FDI*	*TO*	*GFCF*	*URBEN*	*GREEN*
CO2	1.000								
URB	0.083	1.000							
WEL	0.696	-0.015	1.000						
ET	-0.358	0.042	-0.378	1.000					
FDI	0.212	-0.071	0.458	0.151	1.000				
TO	0.179	-0.219	-0.347	0.351	-0.065	1.000			
GFCF	0.302	-0.125	0.639	0.234	0.487	-0.253	1.000		
URBEN	-0.234	0.778	0.442	-0.234	0.082	-0.202	0.167	1.000	
GREEN	-0.096	0.328	0.059	0.151	0.020	-0.025	0.007	0.315	1.000

Source: Researcher's computation.

Table 3 reveals the presence of weak correlations between pollution, urbanization, welfare, energy transition, financial development, trade openness, gross fixed capital formation, urbanization energy transition, and green energy access. Therefore, it is justified to combine these indicators into a single equation to enhance the analysis, considering their low collinearity. However, it is worth noting that all other variables demonstrate a reasonably significant relationship.

Table 4: Cross-sectional Dependence Test

Test	*Model I*	*Model II*
	Statistic	*Statistic*
Breusch-Pagan LM	2496.487***	3167.301***
Pesaran CD	11.424***	14.735***
Frees' CD	4.478***	5.913***
Friedman CD	115.930***	135.631***

Note: *** means 1% level of significance.

According to Table 4, Breusch-Pagan, Pesaran, Frees and Friedman's statistics are significant at the 1% critical level, indicating the presence of cross-sectional dependence (CD) among the African countries. This confirms a strong CD among these countries, which means that the first-generation unit root test is inappropriate for determining the panel regressors' stationarity. Therefore, we introduce the second-generation unit root test, which employs Pesaran's CIPS test, and present the results in Table 5.

Table 5: CIPS Unit Root

HO: Non-stationary					
Variables	CIPS at Level (0)	CIPS At First Difference (1)	5%	1%	Status
CO2	-1.364*	-5.853***	-1.53	-1.2	I(1)
URB	0.164	-6.575***	-1.53	-1.2	I(1)
WEL	-0.777	-5.676***	-1.53	-1.2	I(1)
ET	-1.632*	-5.951***	-1.53	-1.2	I(1)
FDI	-2.183***	-7.697***	-1.53	-1.2	I(0)
TO	-1.722*	-5.965***	-1.53	-1.2	I(1)
GFCF	-0.613	-5.655***	-1.53	-1.2	I(1)
URBEN	-1.637	-5.958***	-1.53	-1.2	I(1)
GREEN	-1.698	-5.875***	-1.53	-1.2	I(1)

Notes: 1%, 5%, and 10% level of significance with ***, **, and * respectively.

We utilized the CIPS unit root test developed by Pesaran (2007) to determine the stationarity of various variables, considering the presence of cross-sectional dependence as indicated in Table 4. The results from Table 5 demonstrate that only financial development is stationary at level. On the other hand, pollution, urbanization, welfare, energy transition, trade openness, gross fixed capital formation, urban energy transition and green energy access become stationary after being differenced once. Consequently, we reject the null hypothesis and affirm that all the series under consideration exhibit stationarity.

The study's empirical findings are showcased in Tables 6-7, which display the cross-sectional augmented ARDL (CS-ARDL) estimates for Models I, II, III, and IV. Additionally, to ensure the reliability of our estimates, we utilized the Common Correlated Effects Mean Group estimator (CCEMG) and present the results in Tables 7 and 8.

Table 6: Cross-Sectional Augmented ARDL (CS-ARDL) (I-IV)

Independent Var.	Dependent Var. ΔCO2			
	Model I	*Model II*	*Model III*	*Model IV*
		SHORT RUN		
ΔECM	-0.4730*** (0.0.5422)	-0.5059*** (0.0465)	-0.6204*** (0.0473)	-0.7004*** (0.0616)
ΔURB	-0.0225 (0.0231)	-	-	-0.0037 (0.0212)
ΔWEL	-	0.0105 (0.0095)	-	0.0012*** (0.0001)
ΔET	-	-	-0.0375** (0.0152)	-0.1588*** (0.0400)
ΔFDI	-0.0174 (0.0206)	-0.0486 (0.0539)	-0.0150 (0.0180)	0.0020 (0.0053)
ΔTO	0.0025** (0.0010)	0. 0033** (0.0015)	0.0012* (0.0006)	0.0019 (0.0016)
ΔGFCF	0.0673** (0.0340)	0.1046** (0.0423)	0.0316** (0.0157)	-0.0862 (0.0805)
		LONG RUN		
URB	-0.0191 (0.0164)	-	-	-0.0046 (0.0112)
WEL	-	0.0125 (0.0102)	-	0.0016*** (0.0002)
ET	-	-	-0.0667** (0.0176)	-0.0382** (0.0170)
FDI	-0.0071 (0.0089)	-0. 0226 (0.0256)	-0.0072 (0.0089)	0.0014 (0.0029)
TO	0.0018** (0.0007)	0.0021** (0.0009)	0.0007** (0.0003)	0.0042 (0.0031)
GFCF	0.0513** (0.0260)	0.0527 (0.0415)	0.0176 (0.0126)	0.0431 (0.0387)

Notes: ***, **, and * represent 1%, 5%, and 10% levels of significance.
Source: Authors' compilation.

From the results in Table 6, urbanization has a negative and insignificant impact on pollution in the long and short run. Urbanization reduced pollution by 2.25% in the short run and 1.9% in the long run as shown in Model I. On the other hand, in Model II, welfare had a positive and insignificant impact in both the long and short run, by increasing pollution by 1.05% and 1.25% respectively. Model III shows that energy transition had a negative and significant impact on pollution, with 3.75% in the short run and 6.67% in the long run. The interaction of these variables in Model IV shows that together, urbanization and energy transition have a negative and significant impact on pollution while welfare still increases pollution. This shows the same result in the short and long run.

Table 7: Cross-Sectional Augmented ARDL (CS-ARDL) (V-VI)

Independent Var.	Dependent Var. ΔCO2	
	Model V	*Model VI*
	SHORT RUN	
ΔECM	-0.6211*** (0.0462)	-0.7594*** (0.0937)
ΔURB	-0.3045 (0.3131)	-
ΔET	-0.5778 (0.0007)	-0.0981 (0.0839)
ΔWEL	-	0.0004*** (0.0001)
ΔURBEN	-0.0246* (0.0175)	-
ΔGREEN	-	-0.0012 (0.0008)
ΔFDI	-0.0042 (0.0110)	-0.0057 (0.0140)
ΔTO	-0.0014 (0.0014)	0.0015** (0.0007)
ΔGFCF	-0.0948 (0.0806)	0.0495 (0.0480)
	LONG RUN	
URB	-0.0006 (0.0005)	-
ET	-0.0007 (0.0007)	-0.0320** (0.0150)

Independent Var.	Dependent Var. ΔCO2	
	Model V	*Model VI*
WEL	-	0.0006 (0.0007)
URBEN	-0.0376*** (0.0113)	-
GREEN	-	-0.0007 (0.0005)
FDI	0.0032 (0.0071)	-0. 0018** (0.0007)
TO	-0.0009** (0.0004)	0.0035*** (0.0005)
GFCF	0.0554** (0.0239)	0.0088*** (0.0015)

Note: ***, **, and * represent 1%, 5%, and 10% levels of significance.
Source: Authors' compilation.

Table 7 displays the short- and long-term impact of the variables when interacting with urban energy transition (URBEN) and green energy access (GREEN). Urban energy transition, which is the interaction of urbanization and energy transition, had a negative and significant impact on pollution. In the short run, it reduced pollution by 2.46% at the 10% confidence level, but in the long run, it reduced pollution by 3.76% at 1% confidence level. Green energy, as shown in Model VI, had a positive and insignificant impact on pollution in both the long and short runs. In the short run, green energy access increased pollution by 0.12% and in the long run, by 0.07%. This shows that although urban energy transition may reduce pollution, individuals and households in Africa may not be able to afford it.

Table 8: Robustness Check using the Common Correlated Effects Mean Group estimates (CCEMG) (I-IV)

Independent Var.	Dependent Var. ΔCO2			
	Model I	*Model II*	*Model III*	*Model IV*
		CCEMG		
URB	0. 5501 (0.4935)	-	-	-0. 8788 (0.6055)
WEL	-	0.0009*** (0.0003)	-	0.0007*** (0.0002)
ET	-	-	-0.0253** (0.0179)	-0.4954*** (0.1268)
FDI	0.0092 (0.0081)	-0.0365 (0.0240)	0.0067 (0.0049)	-0.0894 (0.0835)
TO	0.0719 (0.0611)	0.0034*** (0.0018)	0.0008*** (0.0001)	0.0042 (0.0031)
GFCF	0.0677 (0.0485)	0.1197** (0.0722)	0.0547 (0.0440)	0.1821 (0.1707)
Trend	0. 0158 (0.0128)	0.0136 (0.0073)	0.0180 (0.0154)	0.0354 (0.0273)
AV_CO2	0.2460 (0.2160)	0.2792 (0.2176)	0.1376 (0.1338)	0.1954 (0.1577)
AV_URB	0.0577 (0.0690)	-	-	0.1193 (0.0697)
AV_WEL	-	0.0007 (0.0006)	-	0.0021 (0.0011)
AV_ET	-	-	0.0007*** (0.0001)	-0.0009 (0.0006)
AV_FDI	0.0342 (0.0218)	-0.0263 (0.0201)	0.0461 (0.0344)	-0.0677 (0.0485)
AV_TO	-0.0037 (0.0036)	0.0003 (0.0002)	0.0049 (0.0039)	-0.0014 (0.0024)
AV_GFCF	-0.2045 (0.1698)	0.1845 (0.1718)	-0.1778 (0.1879)	-0.1927 (0.1651)
Constant	2.7721 (2.6155)	3.5084 (3.0620)	3.7094 (3.4502)	4.5846 (4.3781)

Notes: ***, **, and * represent 1%, 5%, and 10% levels of significance.
Source: Authors' compilation.

Tables 8 and 9 show the robustness check using CCEMG estimates. The robustness of the estimates for the main regressors is supported by the consistent findings of the CCEMG analysis in Tables 8 and 9, which align with the results of the CS-ARDL analysis in Tables 6 and 7.

Table 9: Robustness Check using the Common Correlated Effects Mean Group estimates (CCEMG) (V-VI)

Independent Var.	Dependent Var. ΔCO2	
	Model IV	*Model V*
	CCEMG	
URB	-0.3045 (0.3131)	-
WEL	-	0.0723 (0.0895)
ET	-0.0008 (0.0007)	0.0256 (0.0215)
URBEN	0.0504*** (0.0195)	-
GREEN	-	-0.0156 (0.0112)
FDI	0.0204 (0.0118)	-0.0104 (0.0085)
TO	0.0007 (0.0009)	0.0015 (0.0010)
GFCF	0.1002 (0.0535)	0.0234 (0.0229)
Trend	0.0385 (0.0273)	-0.0041 (0.0098)
AV_CO2	-0.0906 (0.1564)	0.3044 (0.2866)
AV_URB	0.0215 (0.1249)	-
AV_WEL	-	-0.0004 (0.0003)
AV_ET	-0.0014 (0.0012)	0.0001 (0.0001)
AV_URBEN	0.0004 (0.0002)	-
AV_GREEN	-	-0.2521

Independent Var.	Dependent Var. ΔCO2	
	Model IV	*Model V*
		(0.2319)
AV_FDI	0.0249 (0.0094)	0.0619 (0.0586)
AV_TO	0.0031 (0.0049)	0.0004 (0.0003)
AV_GFCF	-0.4654 (0.4426)	-0.0699 (0.0723)
Constant	8.6639 (7.6952)	0.2033 (0.2475)

Notes: ***, **, and * represent 1%, 5%, and 10% levels of significance.
Source: Authors' compilation.

4.3 Discussion of results

Results in Table 6 show that urbanization has the potential to lower environmental pollution in Africa, given its negative but insignificant impact on pollution in the short and long runs. This can be attributed to the fact that the numbers of urban populations remain largely low in Africa compared to other developed regions of the world. According to the World Bank (2023), evidence in 2021 revealed that about 52% of the population in 53 African countries live in rural areas. While Gabon had the lowest of about 9.6%, Burundi had the highest of about 85.9%. The negative impact of pollution can also be attributed to the low level of industrial pollution in Africa. As affirmed by the United Nations Industrial Development Organisation report, Africa’s low level of industrial development makes the region contribute less significantly to global pollution (see UNIDO, 2006; Ajide & Mesagan, 2022). This result is at variance with Mesagan and Nwachukwu (2018), who found that urbanization contributed significantly to the rising pollution levels in Nigeria. However, the results align with the earlier reviewed studies done by Turok and Borel-Saladin (2014) and Cobbinah et al. (2017), which revealed that urbanization has a negative relationship with pollution.

Welfare, on the other hand, has the potential to increase environmental pollution given its positive but insignificant impact on pollution in both periods. However, when it is mediated with the other regressors like energy transition and urbanization, it has a substantial impact in raising the pollution level. This implies that as countries become wealthier, they tend to rely more on energy-intensive activities and infrastructure development, which usually lead to increased pollution levels (Hernández and Leon, 2013; Sapkota and Bastola, 2017). On the contrary, energy transition significantly reduces environmental pollution in both periods. By shifting from non-renewable energy sources to renewable ones, there would be a reduction in emissions that would result in less pollution both in the long and short runs. About 22 countries in Africa have already made a major transition of their primary energy source from non-renewable to renewable sources, including Angola, Cameroun and Burundi (Chandler, 2023). Also, countries like Kenya and Namibia are leading globally in geothermal and solar power generation, respectively (Pazheri et al., 2014). However, access to electricity is still very low in Africa. Over half of the population in 16 out of the 22 countries do not have access to electricity. These results align with the findings by Xu et al. (2021) that energy transition can greatly reduce pollution.

The results in Table 7 show that urban energy transition has a negative and significant impact on pollution in the short and long runs. The long-run pollution reduction impact of urban energy transition is higher than its short-run pollution reduction impact. This is a good omen indicating that over the long term, urban energy transition will help African nations to lower pollution substantially. As shown by Bisello and Vettorato (2018), urban energy transition has the potential to create significant economic benefits, especially since the renewable energy sector has been a source of job creation and economic growth in many regions. African countries that rely heavily on imported fuels would now have enhanced energy security for their urban areas. This will make them less prone to price fluctuations and supply disruptions (Pacini and Batidzirai, 2013).

Likewise, green energy access has a negative but insignificant impact on pollution in the short and long runs. This means that the average income earned by an African is less than substantial to acquire green energy for the purpose of lowering pollution. While renewable energy costs have been declining in recent years, the initial installation and equipment costs of green energy technologies are still relatively high (Marks-Bielska et al., 2020). Oftentimes, since a significant upfront investment is required, the lack of access to financing for individuals and households in Africa makes it even more difficult for Africans to acquire green energy access. The limited infrastructure in Africa for green energy transition needs over $30 billion USD to deploy green energy adequately (Mutezo and Mulopo, 2021). This is a substantial amount to invest in individuals and communities with limited financial resources.

5. Conclusion

This scholarly paper explored the intricate relationship between urban energy transition, access to green energy, and pollution reduction in the context of Africa. Employing robust CS-ARDL and CCEMG analysis techniques, the study examined a comprehensive dataset spanning 1990 to 2022. Notably, this research distinguishes itself by offering an integrated examination of the synergistic effects of urban energy transition, green energy access, and the moderating role of energy transition on pollution reduction, all within a single analytical framework. The findings indicate that an interplay of urban energy transition, green energy access, and overall energy transition holds immense potential for curtailing pollution levels. In light of these findings, it is strongly recommended that African nations persist in their proactive efforts to combat pollution by fostering the widespread adoption of environmentally-friendly technologies and prioritizing sustainable urban planning as key policies.

5.1 Theoretical and Empirical Contributions

This study shed light on the interplay between energy transition and urbanization, as well as energy transition and welfare, and their impact on pollution levels. The findings reveal that urbanization has a positive effect on reducing pollution in the short term, while welfare does not. However, the presence of energy transition enhances the pollution-reducing potential of urbanization, whereas welfare increases pollution. This underscores the importance of these two factors in mitigating pollution in Africa.

Additionally, the study explored how energy transition moderates the relationship between urban energy transition and green energy access. The CS-ARDL estimates demonstrate that the interaction between urbanization and energy transition leads to pollution reduction both in the short and long terms. Conversely, the analysis indicates that the interaction between welfare and energy transition contributes to environmental pollution. This highlights the crucial role of energy transition in facilitating the impact of urban energy transition and green energy access on environmental sustainability.

5.2 Practical contributions

The findings of this study have significantly enriched our understanding of the intricate dynamics between urban energy transition, access to green energy, and pollution, thereby emphasizing the utmost importance of incorporating energy transition strategies for achieving environmental sustainability. As a consequence, a critical policy recommendation emerges, urging African nations to remain cognizant of the pollution implications stemming from income levels and the substantial investments made in infrastructure development. This is due to the potential exacerbation of pollution levels in the long run, as the concomitant rise in income and infrastructure paves the way for energy-intensive activities. Consequently, African leaders are advised to deliberately prioritize investments in research and development, which would catalyse technological advancements, making green energy solutions more efficient and environmentally friendly. In this regard, the infusion of substantial investment in renewable energy infrastructure, facilitated through the issuance of green bonds to attract private investors, is deemed crucial.

Moreover, recognizing the pivotal role of energy transition in mitigating the adverse consequences of urban energy transition and green energy access on pollution, it becomes imperative for African leaders to proactively allocate funds and foster the development of renewable energy projects, with the overarching goal of curbing potential negative environmental impacts. This necessitates a substantial commitment to bolstering the infrastructure required to support the transition towards renewable energy sources. Furthermore, a pivotal step forward lies in the prioritization of sustainability and the seamless integration of green energy solutions into urban planning. By designing cities that maximize energy efficiency while simultaneously promoting public transportation, African nations can effectively reduce pollution levels and enhance the overall quality of urban life. Additional measures, such as incentivizing energy-efficient technologies, enforcing building codes, and providing attractive incentives for energy-efficient upgrades, are instrumental in curbing energy consumption and mitigating associated pollution levels.

6.3 Limitations of the study and future research directions

While our findings are significant, it is important to acknowledge certain limitations. Firstly, our research focuses on 28 African countries with data on urbanization, welfare, and energy transition. Since each country has its unique experiences, the applicability of our results may not be universal. Future studies could take a comparative approach, using time-series analyses to examine specific nations more closely.

Secondly, recent events like the Ukraine conflict and the COVID-19 pandemic have intensified tensions surrounding fossil fuels such as oil and gas. Sanctions imposed on Russia and the involvement of various countries in the conflict have affected the well-being of citizens and migrants, access to electricity, and pollution levels. Hence, it would be valuable for future studies to incorporate these factors into their decarbonization models. Despite these limitations, our study's findings offer a strong foundation for analysing the connections between urban energy transition, access to green energy, and the reduction of pollution in emerging nations.

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