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The dynamics of urban growth rate on carbon footprints in the SADC

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ABSTRACT

This paper examines the influence of urban growth rates on per capita carbon emissions across 13 member countries of the Southern African Development Community (SADC), by examining urban growth dynamics with data from 2002 to 2022. Urban growth rate is captured through three separate indicators: urban growth, the urban-to-rural population growth ratio, and the urban-to-total population growth ratio. Data analysis was conducted employing the Panel Estimated Generalised Least Squares (EGLS) method, specifically the cross-sectionally seemingly unrelated regression (SUR) method. The results from the empirical analysis showed that all three urban growth rate proxies exert negligible influence on carbon emissions per capita, suggesting that urban expansion within the SADC region has not substantially contributed to increased carbon emissions over the years examined. Therefore, given the continuing rise in urban populations across Southern Africa and the accompanying escalation in carbon footprints, institutional and managerial policies promoting environmentally sustainable production to lower carbon emissions per head may not need to account for specific urban growth dynamics such as those examined in this study. However, accounting for specific urbanisation characteristics should be based on preference and what might be fundamental and material to an organisation or institution, provided cost does not outweigh the benefit.

Contribution/Originality: The study contributes to the literature by examining the influence of three urban growth rate dynamics on carbon emissions in the SADC, a region with limited literature in subject matters relating to the urbanisation-carbon emission nexus, using three urbanisation dynamics. The study also examined the dependent variable (Carbon emissions) using per capita carbon emissions rather than whole emissions that are popularly used in literature.

1. INTRODUCTION

1.1. Background

The increase in atmospheric greenhouse gas emissions has been widely recognised as a primary driver of climate change (Kayani, Sadiq, Aysan, Haider, & Nasim, 2023; Nuţă et al., 2021). Moreover, greenhouse gas emissions have been widely associated with the energy demand, generation, and consumption, all of which increase with urban growth. This interconnection explains the growing interest in the impact of urban growth on carbon emissions in the literature (Abdallh & Abugamos, 2017; Huo et al., 2020; Liu, Tian, Li, Song, & Ma, 2018; Liu & Bae, 2018; Liu, Gao, & Lu, 2017; Sufyanullah, Ahmad, & Ali, 2022). Carbon dioxide has been identified as one of the key contributors to global warming, which results in the worldwide rise in sea levels, atmospheric temperature, threats to our ecosystem, human health hazards, and extreme weather events (Intergovernmental Panel on Climate Change, 2022; Raihan, 2023). These environmental challenges are, however, manageable if their underlying determinants are adequately identified and mitigated, including rapid urban growth and the accompanying rise in energy use. Empirical evidence indicates that urban areas account for a substantial share of global energy use, contributing approximately 70% of global carbon emissions (Luqman, Rayner, & Gurney, 2023; Seto et al., 2014). This proportion is expected to rise, particularly in regions experiencing accelerated urban growth such as sub-Saharan Africa. Sub-Saharan African countries exhibit one of the fastest rates of urban growth globally. Moreover, the expansion of the urban population naturally drives higher energy demand and supply, with more pressure to meet this rising energy demand sustainably.

Projections show that by 2030, Africa will comprise one-fifth of the global population (World Economic Forum, 2017). Yet, Africa accounts for 3% of energy-based carbon emissions and 5% of global energy consumption, based on the International Energy Agency (2023). Notwithstanding the comparatively small emission contribution of Africa, the rate of urbanisation reveals a potential rise in the share of global energy consumption and emissions of Africa, possibly reaching as high as 11% by 2050 (Le Roux & Cilliers, 2024). Moreover, based on the United Nations' (UN's) projections, 90% of the urban populations in the world would be from Asian and African cities, with 2.5 billion additional urban residents to be anticipated by 2050 (Amponsah et al., 2022; Li, Stringer, & Dallimer, 2022; United Nations Department of Economic and Social Affairs Population Division, 2018). Furthermore, the (Organisation for Economic Co-operation and Development, 2022) earlier indicated this potential with the track record of urban growth, reporting 4,500 new cities and an additional residential population of 500 million across Africa between 1990 and 2020. Hence, the continent has the potential to be a major global carbon emissions contributor in the near future.

2. LITERATURE REVIEW

This literature review section gives an overview of energy consumption and urban growth patterns in Africa (especially in Southern Africa). Furthermore, it synthesises previous empirical findings on the relationship between urban growth and carbon emissions.

2.1. Energy Consumption, Urban Growth, and Carbon Emissions in Africa: Stylised Facts

Energy consumption in Africa remains comparatively low relative to other regions of the Globe, despite the continent accounting for approximately 18.8% of the world's population (Center for International Relations and Sustainable Development, 2025; United Nations Department of Economic and Social Affairs Population Division, 2024; World Bank, 2024a). This disparity is attributed mainly to Africa's relatively low level of urban growth (around 60% of its population still resides in rural areas (Angelopulo, 2021), which corresponds with the energy demand and consumption (International Energy Agency, 2023). As of 2022, Africa ranked fifth globally in energy consumption (Table 1a), (as a *continent*, trailing behind *countries* like China (25.6%), the United States (14.6%), India (6.8%), and Russia (5.4%).

Table 1a. Energy consumption in Africa compared to high-consuming nations in Terajoules (TJ).

Rank	Country/Region	TJ
1	China	159 079 227
2	United States	90 978 682
3	India	42 506 363
4	Russia	33 824 455
5	Africa	33 337 003
6	Japan	16 427 931
7	Brazil	12 582 435
8	Canada	12 441 945
9	Iran	12 242 084
10	Korea	11 711 459

Source: International Energy Agency (2023).

Consequently, Africa's comparatively low energy consumption explains its position as the world's lowest carbon-emitting continent (International Energy Agency, 2023). However, the continent's rapid demographic and urban expansion may soon alter this ranking if current energy and urbanisation trends persist.

A deeper look at the energy landscape of Africa reveals that ten countries with the highest energy consumption (mainly in sub-Saharan Africa) represent a large share of the total energy use of the continent (Table 1b). Household consumption and industrial operations primarily drive this concentration. However, it is important to investigate the content of the energy used across various sectors in order to get a deeper understanding of the dynamics of energy consumption on the continent. Identifying the dominant sources and patterns of consumption provides critical insights into the structural causes of energy demand and, by extension, the continent's energy source profile (Figures 1, 2, and 3).

Table 1b. Top ten energy consumption in African countries in Terajoules (TJ).

Rank	Country (in Africa)	TJ
1	South Africa	5 162 229
2	Egypt	4 245 351
3	Nigeria	3 111 747
4	Algeria	2 856 730
5	Ethiopia	1 963 934
6	Democratic Republic of Congo	1 675 849
7	Kenya	1 226 231
8	Tanzania	1 097 685
9	Uganda	956 416
10	Morocco	942 416

Source: International Energy Agency (2023).

According to the International Energy Agency (2023), the Industrial, transport, and residential sectors are the main sources of energy consumption in Africa, and the demand in these sectors rises with the rate of urbanisation (see Figure 1). Altogether, these industries (commercial and public services included) cover a huge (92.4%) share of the overall final energy demand of the continent, underscoring their central role in shaping Africa's energy landscape. Among these, the transport and residential sectors are the main consumers of energy (which is a combined 69.6%). Contrastingly, the Forestry, Agriculture and Fishing sectors represent the smallest share of energy demand, highlighting the unequal distribution of energy consumption across economic activities.

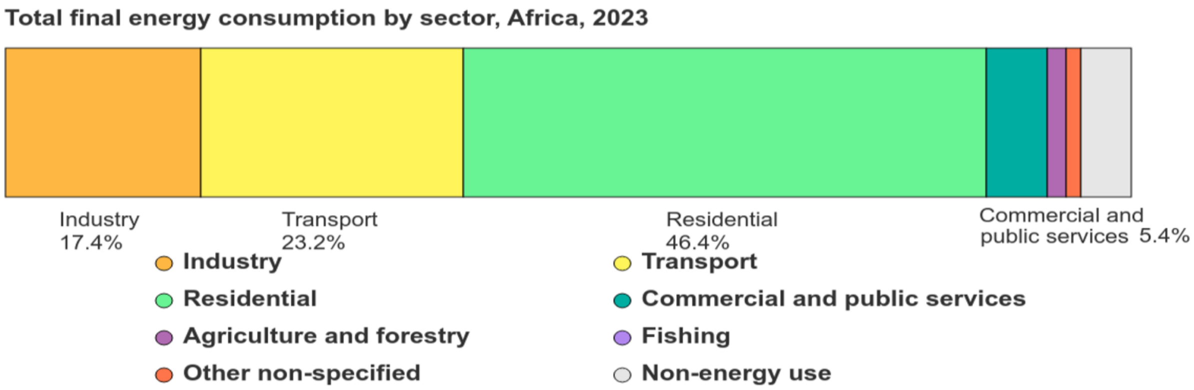

Figure 1. Total final energy consumption by sector in Africa, 2023.

Note: Agriculture & forestry (1.62%); Fishing (0.03%); Other non-specified (1.39%); Non-energy use (4.46%).
Source: International Energy Agency (2023). Licence: CC BY 4.0.

Aside from the prevalent energy-consuming sectors, the energy generation sources also play crucial roles in CO_2 emissions reduction. According to empirical sources, the energy used across Africa's transport, residential and industrial sectors is mainly sourced from fossil-based natural resources, such as natural gas, coal and crude oil (see

Figure 2). The continual dependence of Africa on these energy sources underscores a significant structural challenge in transitioning toward cleaner and more sustainable energy systems.

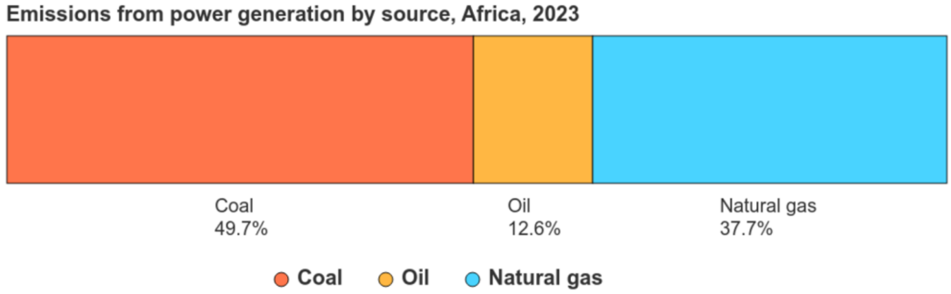

Figure 2. Emissions from power generation sources.

Source: International Energy Agency (2023). Licence: CC BY 4.0.

These fossil-based energy resources are among the main combustion-associated sources of CO_2 emissions, and their consumption has notably risen in recent periods, especially in the transport and industrial sectors that influenced by the energy demands of urbanisation (see Figure 3).

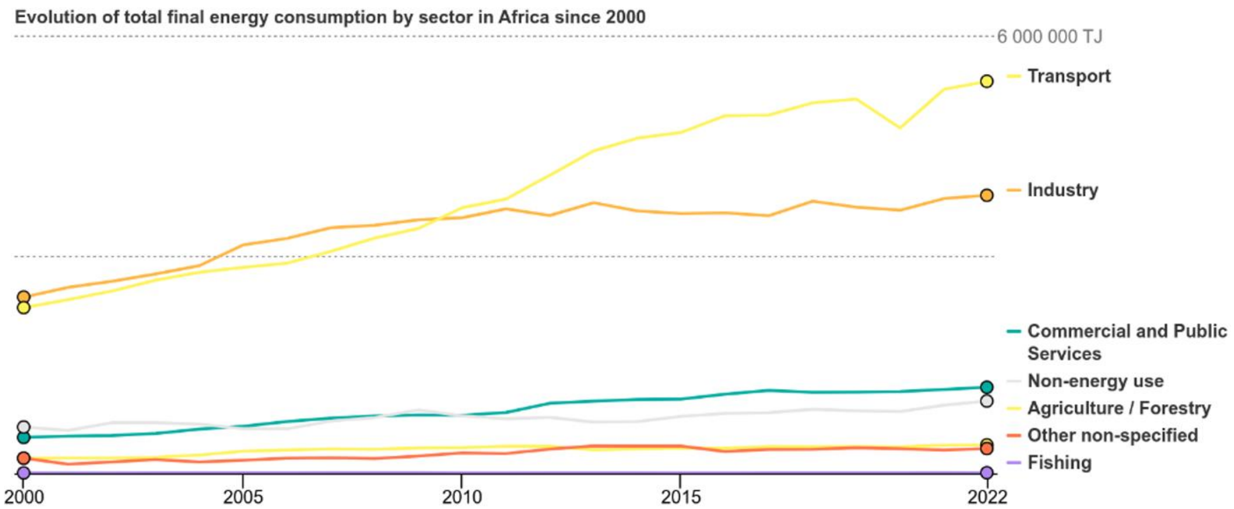

Figure 3. Evolution of total final energy consumption by sector in Africa.

Source: International Energy Agency (2023). Licence: CC BY 4.0.

This consistent rise in energy-related CO_2 emissions over the years can be explained by the high urban growth rate. The United Nations Department of Economic and Social Affairs Population Division (2018), United Nations Department of Economic and Social Affairs Population Division (2024), and Intergovernmental Panel on Climate Change (2023) predicted that, by 2050, continued urban growth may cause an inevitable escalation in industrial and transport-sector emissions at unprecedented levels. This estimation is affected by land-use changes (usually associated with urban growth), which disrupt the natural possibility of carbon sequestration through deforestation and a decline in afforestation initiatives.

2.2. Urban growth in Southern Africa

Ali (2021) and Macharia, Pinchoff, Taylor, and Beňová (2023) Report that sub-Saharan Africa is experiencing an exceptionally high rate of urbanisation, positioning it (alongside Asia) as one of the regions undergoing the most rapid urban transitions globally. Figures 4a and 4b illustrate urban growth across 13 member states of the Southern African Development Community (SADC), highlighting the trends in urban population growth.

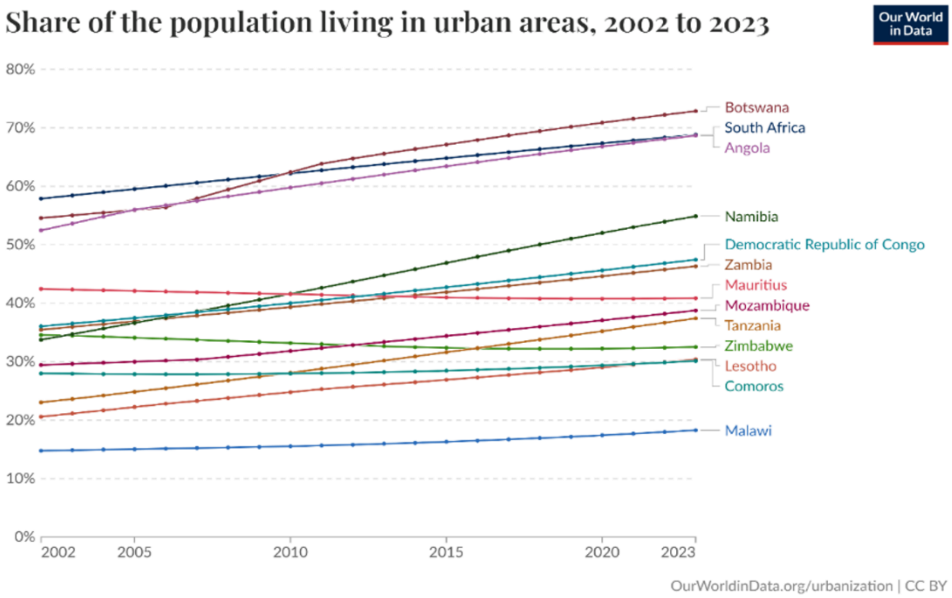

Figure 4a. The population living in urban areas in Southern Africa.

Note: Estimates of city and metropolitan area populations are based on national definitions of what constitutes a city or metropolitan area. Cross-country comparisons should therefore be made with caution.

Source: World Bank (2025), Our World in Data (2024).

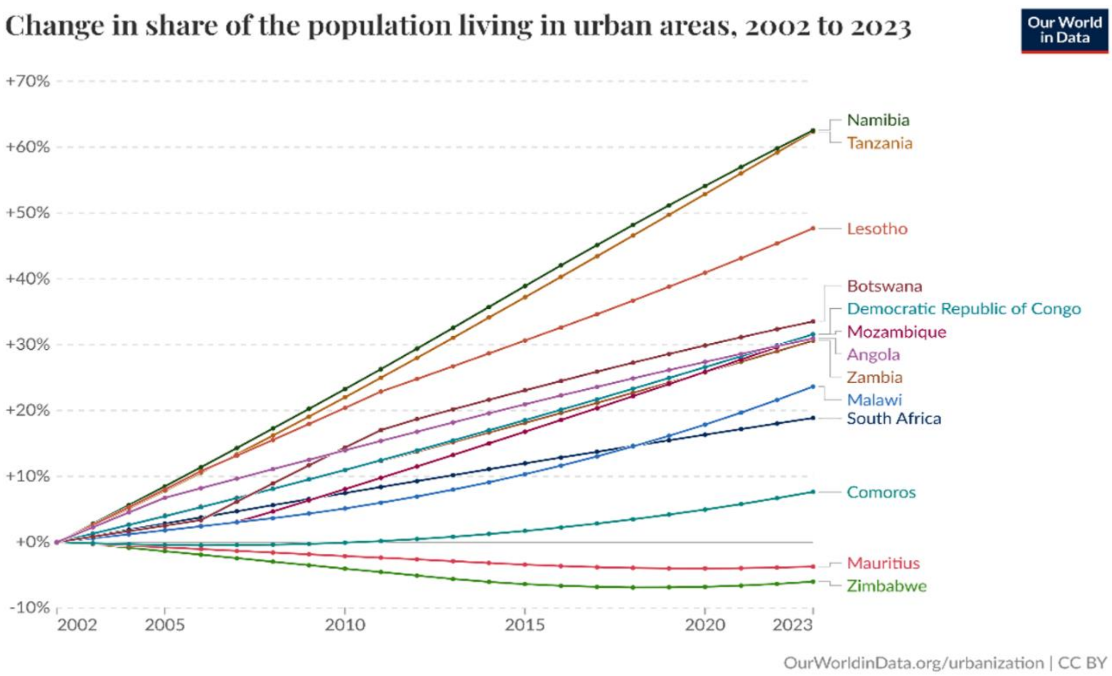

Figure 4b. Change in the share of Southern Africa.

Note: Because estimates for city and metropolitan areas are based on national definitions of what constitutes a city or metropolitan area, cross-country comparisons should be made with caution.

Source: Our World in Data (2024), World Bank (2025).

Figure 4a shows a steady increase in the urban population of almost all countries, except Mauritius, Comoros, and Zimbabwe. According to Figure 4b, there were tangible changes in the share of people living in urban areas between 2002 and 2023. The countries with the highest percentage of urban population change above 60% were Namibia and Lesotho, while Tanzania had above 40% change in urban population. Comoros seems to have a slight increase, although still below 10%.

2.3. Carbon Emissions in Southern Africa

Figure 5 presents the trends in per capita CO_2 emissions across Southern Africa from 2002 onward. South Africa consistently recorded the highest per capita CO_2 emissions, yet it also demonstrated the most significant reduction in emissions over the observed period. In contrast, while most countries maintained relatively stable emission levels, Botswana, Mauritius, and, over recent years, Lesotho exhibited inconsistent but, overall, still-increasing patterns in CO_2 emissions per capita.

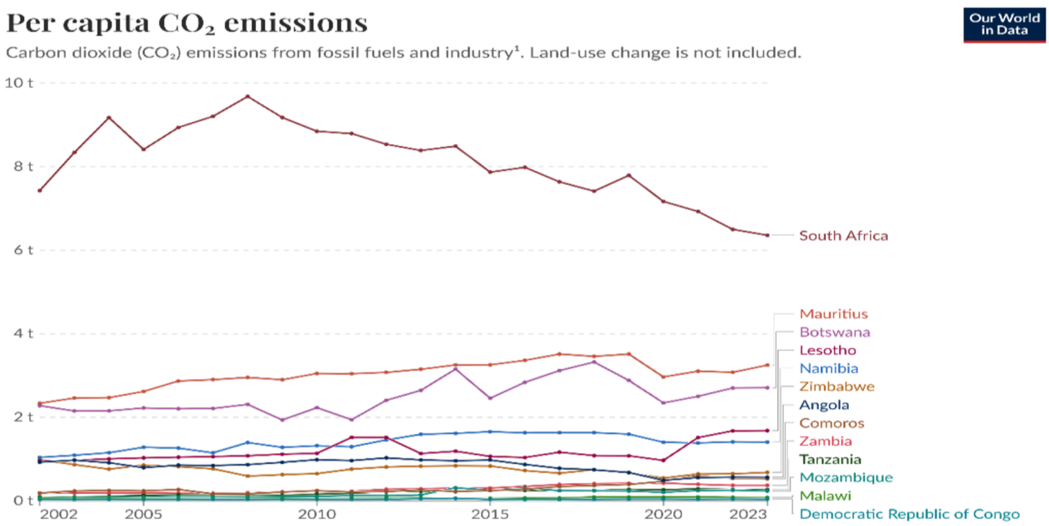

Figure 5. Southern Africa carbon emissions per capita.

Note: 1. Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO_2) emitted from the burning of fossil fuels and directly from industrial processes such as cement and steel production.
Fossil CO_2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes.
Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Source: Global Carbon Budget (2024). Population based on various sources (2024).
OurWorldInData.org/co2-and-greenhouse-gas-emissions | CC BY

Figure 6 depicts the trends in per capita CO_2 emissions across Southern African countries from 2002 to 2023. The data indicate that South Africa, Zimbabwe, and Angola achieved reductions in per capita emissions over this period. In contrast, while Malawi and the Democratic Republic of Congo maintained relatively stable emission levels, the remaining countries experienced increases in per capita CO_2 emissions.

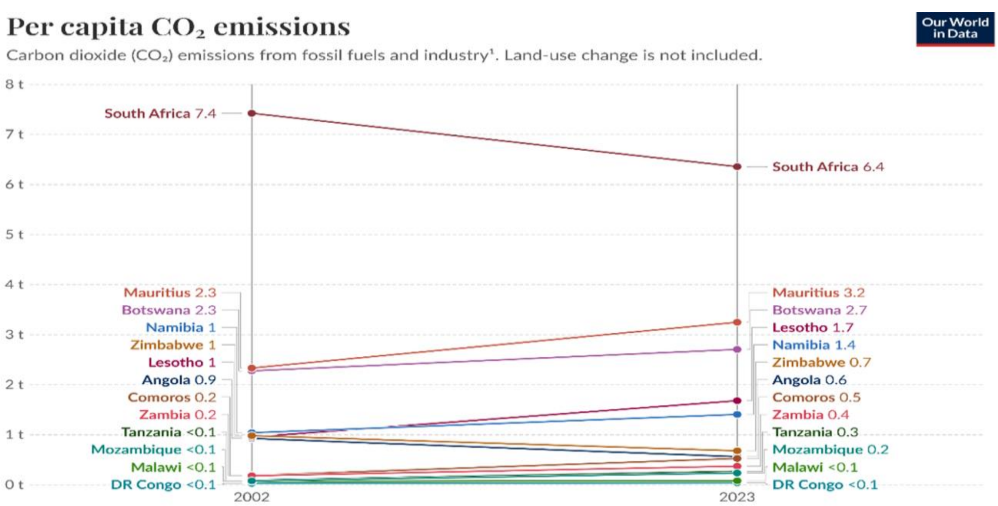

Figure 6. Slope of carbon emissions per capita changes.

Note: Values are approximated.
Fossil emissions: Fossil emissions measure the quantity of carbon dioxide (CO2)
emitted from the burning of fossil fuels, and directly from industrial processes such as cement and steel production.
Fossil CO2 includes emissions from coal, oil, gas, flaring, cement, steel, and other industrial processes.
Fossil emissions do not include land use change, deforestation, soils, or vegetation.

Source: Global Carbon Budget (2024). Population based on various sources (2024).
OurWorldinData.org/co2-and-greenhouse-gas-emissions | CC BY

With accelerating urban growth and rising energy consumption in sub-Saharan Africa, numerous studies have examined the impact of urban growth on carbon dioxide (CO_2) emissions in the region. Many of them indicate that urban growth contributes to increased CO_2 emissions, primarily by intensifying human activity and energy demand (Afriyie, Wang, Hu, Ampofo, & Asante, 2023; Ali, 2021; Kwakwa & Alhassan, 2018; Li et al., 2022; Nondo & Kahsai, 2020). However, there remains a paucity of research specifically focused on the Southern African Development Community (SADC). Accordingly, this study examines the impact of urban growth on CO_2 emissions in thirteen SADC nations (Angola, South Africa, Mozambique, Namibia, Zambia, Zimbabwe, Lesotho, Botswana, Comoros, Tanzania, the Democratic Republic of Congo, Mauritius, and Malawi) from 2002 to 2022.

2.4. Empirical Review

In this section, the paper presents a synthesis of the discussed studies in relation to urbanisation and CO_2 emissions at the global, continental, and regional scales, with reference to methodological techniques, time periods, and the results thereof.

2.4.1. Global Evidence on Urban Growth and CO_2 Emissions

Empirical research on the urbanisation nexus emissions worldwide has shown a mixed number of studies and in many cases, without unanimous findings. Indicatively, Ali, Bakhsh, and Yasin (2019); Dogan and Inglesi-Lotz (2020); Kim, Lim, and Jo (2020); Zhang and Tan (2016); and Zoundi (2017) discovered positive relationships between urban population measures and CO_2 emissions. However, the measurements are in disparity, considering variables such as life expectancy, age, labour force, density, labour force participation, and unemployment. Longitudinal-based empirical studies that cover long periods (21–43 years) consistently report a positive relationship between urbanisation and CO_2 emissions. These include the findings of Li and Lin (2015); Zi, Jie, and Hong-Bo (2016); Zhang and Tan (2016); Bekhet and Othman (2017); Liu and Bae (2018); Ali et al. (2019); Wang and Su (2019); and Sufyanullah et al. (2022). These works suggest that (in more cases) urban population growth leads to higher emissions via increased human activity and mobility. Other studies, on the other hand, show that urban growth may decrease CO_2 emissions. For instance, studies like Abdallh and Abugamos (2017) in the MENA region, Liu et al. (2018) and Huo et al. (2020) on Chinese provinces, and Luqman et al. (2023) on cities across China, India and the USA, report that urbanisation can lead to emissions reduction. Similarly, Kayani et al. (2023) found that integrating urbanisation with renewable energy consumption was linked with lower CO_2 emissions, highlighting the potential for urban areas to align with cleaner energy practices. The findings of some studies worldwide are mixed or situational. As an illustration, Svirejeva-Hopkins, Schellnhuber, and Pomaz (2004) have found that urban growth positively affected the carbon dioxide emissions in the Arab States, China, the Asia-Pacific region, whereas it had a negative effect in sub-Saharan Africa, Latin America, the Caribbean, and economies still in transition. Similarly, 137 countries (with data from 2002 to 2012) were evaluated by Wang and Wang (2021). They, however, found positive impact of urbanisation on emissions in the high-income nations, negative impacts in the upper-middle-income nations, and an inverted U-shaped association in the low-income nations, and this highlighted how the economic structure and level of development mediated the relationship between urbanisation and the environment. Nuţă et al. (2021) also claim that urban growth as a process determines the results of $CO2$ emission more than the features of urban communities that are already urbanised, because industrialisation and the implementation of green technologies are diverse in different urban areas. Other studies illustrate temporal nuances in the urbanisation–emissions relationship. The works of Anser, Alharthi, Aziz, and Wasim (2020) and He, Xu, Shen, Long, and Chen (2017) report the U-shaped relationships with short-term decreases in emissions and long-term growth. Al-Mulali, Fereidouni, Lee, and Sab (2013) noted a bidirectional effect with slower urban growth rates associated with lower emissions. Liu et al. (2017) emphasise regional differences, highlighting that urbanisation increased emissions in less-developed areas of China but reduced them in more developed regions.

2.4.2. Empirical Evidence from Africa and the Middle East

The research in Sub-Saharan Africa and MENA also presents mixed results, and is dependent on the time and methodology, this is:

Using 12 MENA countries (1996 - 2014), Kavanagh (2021) observed that urban growth only had positive short-run but negative long-run impacts on CO2 emission. Abdallh and Abugamos (2017) found similar results in applying the STIRPAT framework to 20 MENA countries (1980 – 2014). Afriyie et al. (2023) analysed 37 Sub-Saharan African countries based on the Pooled Mean Group Autoregressive Distributed Lag model, where urban growth did not meaningfully affect CO 2 emissions in the short run and the long run, but the use of energy did influence emissions. Ali (2021) reported comparable findings across 49 countries, noting that urban growth had a positive effect on overall energy consumption but a negative one on electricity consumption. In contrast, Nondo and Kahsai (2020) and Kwakwa and Alhassan (2018), focusing on South Africa and Ghana, observed a positive relationship between urban growth and emissions over 43–47 years of data. Collectively, these studies, summarised in Table 2, underscore the variability of urbanisation's impact on CO_2 emissions, reflecting differences in geography, temporal coverage, methodological approach, and socio-economic context.

Consequently, examining the SADC region provides valuable new insights into this relationship, particularly given its unique urban growth patterns and developmental characteristics. Besides this, unlike this paper, the reviewed studies only captured the total, but not the per capita, measurement of carbon emissions, which provides another perspective on the effects of urban growth.

Table 2. Empirical studies on the impact of urban growth on carbon emissions.

Authors	Location	Coverages	Estimators	Result
Liu et al. (2018)	China	2008-2015	Panel regression	Positive
Liu et al. (2017)	China	1995-2012	STIRPAT	Negative sig.
Liu and Bae (2018)	China	1970-2015	ARDL, VECM	Positive sig.
Huo et al. (2020)	China	2000-2015	STIRPAT	Negative sig.
Ali et al. (2019)	Pakistan	1972-2014	ARDL, VECM	Positive sig.
Wang, Yao, Xu, Sun, and Li (2021)	OECD nations	1960-2014	ARDL	Negative sig.
Bekhet and Othman (2017)	Malaysia	1971-2015	VECM	Positive sig.
Li and Lin (2015)	China	1971-2010	STIRPAT	Negative sig.
He et al. (2017)	China	1995-2013	STIRPAT	U-Shaped
Sufyanullah et al. (2022)	Pakistan	1990-2015	ARDL, VECM	Positive sig.
Zhang and Tan (2016)	China	1997-2012	GMM	Positive Sig.
Wang and Su (2019)	China	1990-2015	D-K	Positive sig.
Anser et al. (2020)	SAARC	1994-2013	STIRPAT	U-Shaped
Zi et al. (2016)	China	1979-2013	Panel regression	Positive Rel.
Al-Mulali et al. (2013)	MENA	1980-2009	DOLS	Positive Sig.
Kavanagh (2021)	MENA	1996-2014	STIRPAT	Inverted U-Shaped
Abdallh and Abugamos (2017)	MENA	1980-2014	STIRPAT	Inverted U-Shaped
Kwakwa and Alhassan (2018)	Ghana	1971-2013	Modified OLS	Positive sig.
Nondo and Kahsai (2020)	South Africa	1970-2016	VECM	Positive sig.
Afriyie et al. (2023)	37 SS Nations	1995-2017	ARDL	Insignificant
Ali (2021)	49 SS Nations	1980-2014	Panel regression	Insignificant
Nuţă et al. (2021)	Europe	1990-2015	Fixed Effect	Positively Sig.
Amin, Altinoz, and Dogan (2020)	Europe	1980-2014	OLS, D-K & DOLS	Positive & Negative
Luqman et al. (2023)	39 nations	2000-2018	Cluster analysis	Negative impact
Wang and Wang (2021)	137 countries	2002-2012	Panel threshold	U-Shaped
Kayani et al. (2023)	Global study	2000-2019	Fixed effect OLS	Negative Sig.
Svirejeva-Hopkins et al. (2004)	1001 Cities	1990-2000	Panel regression	Positive & Negative

Note: (Key): OLS (Ordinary Least Squares); POLS (Pooled Ordinary Least Squares); ARDL (Augmented Auto Regressive Distributed Lag); STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology); VECM (Vector Error Correction Model); D-K (Driscoll-Kraay standard errors); GMM (Generalised Method of Moments); DOLS (Dynamic OLS); SS (Sub-Saharan); MENA (Middle East and North Africa).

3. RESEARCH METHODOLOGY

3.1. Research Philosophy and Design

Due to the quantitative nature of the data obtained from secondary sources and subjected to statistical analysis, this study adopts a positivist research philosophy. Furthermore, a causal research design was deemed appropriate as it facilitates the examination of cause-and-effect relationships between the independent variable (urban growth) and the dependent variable (per capita CO_2 emissions).

3.2. Data Source and Variable Measurement

The analysis focuses on the impact of urban growth on per capita CO_2 emissions. Data for both the primary variables and the control variables were sourced from publicly available global databases, including the World Bank (2024b) and Our World in Data (Ritchie et al., 2023; Roser et al., 2023), spanning 21 years from 2002 to 2022.

3.3. Population and Sample Selection

The study population comprises the Southern African Development Community (SADC) region. This region was selected over other sub-Saharan African blocs due to its relatively high average GDP per capita, estimated at USD 4,020.73 in 2024 (World Bank, 2024b). From the 16 SADC member states, a criterion-based sampling method was employed to select a final sample of 13 countries for the period from 2002 to 2022. The selection criteria were as follows:

1. Consistency and availability of data (Data for Eswatini were incomplete).
2. Seychelles and Madagascar possess unique geographic and socio-economic profiles, including geographic isolation.
3. Madagascar is a low-income, agriculture-based economy with limited industrial activity, making CH_4 and N_2O emissions more relevant than CO_2 (World Bank, 2024c).
4. Seychelles is classified as a high-income, tourism- and service-dependent economy, also with limited industrial activity (World Bank, 2024c).

3.4. Measurement of Variables

The variables employed in this study, along with their measurements, are summarised in Table 3.

Table 3. Variables, their measurements, and data representation for this study.

Abbreviation	Variable (Type)	Measurement	Data Representation
URB	Urban growth (IV)	Urban population growth (annual %), urban-to-population growth, urban-to-rural growth	Annual urban growth (URBGR); Urban growth/Population growth (URBPOPGR); Urban growth/Rural growth (URBRURALGR)
CO2PC	CO_2 emissions per capita (DV)	Year-on-year change in per capita CO_2 emissions	CO_2 emissions pc current year – CO_2 emissions pc previous year
POPGR	Population growth (CV)	Annual % change in total population	Year-on-year % change
GDPGR	GDP growth (CV)	Annual % change in GDP	Year-on-year % change
GHGPC	Greenhouse gas per capita (CV)	Year-on-year change in GHG emissions per capita	GHG pc current year – GHG pc previous year

Note: Per capita (pc); Independent variable (IV); Dependent variable (DV); Control variable (CV).

We included GHGPC as a control variable, as CO_2 constitutes a major component of total greenhouse gas emissions resulting from anthropogenic activities. A non-significant or inverse relationship between CO2PC and GHGPC would indicate potential model misspecification (Asumadu-Sarkodie & Owusu, 2017; Mansoor & Sultana, 2018).

3.5. Model Specification

The model specification follows a linear panel framework adapted from Le, Le, and Taghizadeh-Hesary (2020) with separation of independent and control variables.

$$CO2PC_{i,t} = \alpha_0 + \beta_1 URB_{i,t} + \gamma_1 GDPGR_{i,t} + \gamma_2 POPGR_{i,t} + \gamma_3 GHGPC_{i,t} + \epsilon_{i,t} \quad (1)$$

Where:

- α_0 is the intercept.
- β_n represents coefficients of the independent variable.
- γ_n represents coefficients of control variables.
- $\epsilon_{i,t}$ is the error term.
- i and t denote cross-sectional units and time, respectively.

With urbanisation (urban growth) being disaggregated into three components, urban growth (URBGR), urban-to-rural growth (URBRURALGR), and urban-to-population growth (URBPOPGR), the model becomes.

$$CO2PC_{i,t} = \alpha_0 + \beta_1 URBGR_{i,t} + \beta_2 URBRURALGR_{i,t} + \beta_3 URBPOPGR_{i,t} + \gamma_1 GDPGR_{i,t} + \gamma_2 POPGR_{i,t} + \gamma_3 GHGPC_{i,t} + \varepsilon_{i,t} \quad (2)$$

3.6. Estimation Technique

Panel regression analysis was employed to estimate the effect of urban growth on per capita CO_2 emissions. Before estimation, several diagnostic tests were conducted, two pre-estimation and two post-estimation tests:

- The panel unit root test and the Hausman test are the two pre-estimation tests used to assess the stationarity level of variables and to determine the suitability of fixed versus random effects models, respectively. The results of these tests are seen in Tables 4 and 5.
- While the cross-section dependence and multicollinearity tests were the post-estimation tests used to assess the presence of cross-section correlation and the presence of multicollinearity based on the variance Inflation Factor (VIF) among variables. The results of these tests are embedded in Table 6.

4. RESULTS AND FINDINGS

This section of the paper dwells on pre-examinations and results.

4.1. Pre-Examination Diagnostics

Table 4 for the stationary test presents the outcome of the unit root test at the level and first difference:

Table 4. Panel unit root test.

Test	Results: Level				Results: First difference			
Methods	**LLC**	**IPS**	**ADF**	**PP**	**LLC**	**IPS**	**ADF**	**PP**
URB_POPGR	0.270	0.026	0.002	0.000	N/A	N/A	N/A	N/A
URB_RURALGR	1.000	0.000	0.000	0.000	N/A	N/A	N/A	N/A
URBGR	0.012	0.274	0.231	0.062	0.000	0.000	0.000	0.000
POPGR	0.023	0.032	0.035	0.922	N/A	N/A	N/A	N/A
GDPGR	0.000	0.000	0.000	0.000	N/A	N/A	N/A	N/A
GHGPC	0.652	0.963	0.838	0.091	0.000	0.000	0.000	0.000
CO2PC	0.833	0.957	0.783	0.783	0.000	0.000	0.000	0.000

Note: Im, Pesaran & Shin W-stat (IPS), Levin, Lin & Chu t* (LLC), Augmented Dickey-Fuller Chi-square (ADF), Phillips-Perron-Chi-square (PP).

- At this level, GDPGR is stationary in all the employed unit root test measures, such as LLC, IPS, ADF, and PP. Other variables, such as URB_POPGR, URB_RURALGR, and POPGR, are stationary, based on the results of at least three of the four methods at the same level. Unfortunately, the remaining variables are not stationary, as indicated by the results of every method employed, necessitating a further examination of first differences.

- · The first difference examination shows that *all* the remaining variables are stationary at this level under every method. Since only URBGR, CO2PC, and GHGPC need to be tested at first difference, these first difference representations were used for analysis.

4.2. Regression Results

The paper employed the Panel Estimated Generalised Least Squares (EGLS) method using cross-section Seemingly Unrelated Regression [SUR] with the fixed-effect model for the analysis:

- The Hausman test (Table 5) shows a chi-squared p-value of 0.019, implying that the fixed-effect model is more appropriate than the random-effect one.

Table 5. Hausman test.

Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	16.750473	7	0.0191

According to the study's Panel EGLS analysis results in Table 6, none of the urbanisation proxies is statistically significant at the 0.05 threshold. This means that neither the urban growth-to-population growth ratio, nor the urban growth rate when compared to the rural population growth, nor the growth of the urban population impacts CO_2 emissions per capita.

Table 6. Panel Least Squares regression and post-estimation diagnostics.

CO2PC	Panel EGLS (Cross-section SUR)				MC.
Independent	Coeff.	Prob.	Impact	Decision	Cent. VIF
URBPOPGR	0.0010	0.39	Negligible	Cannot be rej.	1.0278
URBRURALGR	-0.00014	0.23	Negligible	Cannot be rej.	1.0313
URBGR	-0.0062	0.33	Negligible	Cannot be rej.	1.2510
POPGR	-0.0308	0.00	Negative	Reject	2.5330
GHGPC	0.0089	0.00	Positive	Reject	1.4234
GDPGR	0.0219	0.00	Positive	Reject	1.4669
Adj. R-Squared	0.99				
Durbin Watson	2.07				
Cross-Section Dependence: Breusch-Pagan LM				Pesaran CD	
	Stat.		Prob.	Stat.	Prob.
	17.594		1.00	-0.156	0.87

Note: Rej. (Rejected), MC (Multicollinearity), Cent VIF (Centred variance inflation factor).

In addition, all the control variables, POPGR, GDPGR, and GHGPC, are statistically significant. Therefore, an increase in population (POPGR) leads to lower CO_2 emissions per capita (pc), which is not expected, as one would assume that increased human activity would lead to more CO_2 emissions. However, GDPGR has the expected positive impact on CO_2 emissions pc. Growth in domestic productivity signals higher productivity and activity; thus, GDP growth is a more appropriate measure of human activity growth than just population growth. Based on the coefficient result for POPGR (-0.0308) and GDPGR (0.0219), the impacts of a 1% increase in population growth and GDP growth on CO_2 emissions will be mild because of the small magnitude changes (-0.0308kt and 0.0219kt, respectively). This means that a mere population growth or increased growth rate in countries in the SADC does not lead to higher emissions; instead, higher emissions are associated with productive activities in the SADC that increase GDP.

With an R-squared of 0.99 and an ideal Durbin-Watson value of 2.07 (between 1.5 and 2.5), the null hypothesis "Urbanisation does not impact the CO_2 emissions pc in Southern Africa" cannot be rejected.

4.2.1. Diagnostics

The results from the post-estimation diagnostic tests in Table 6 show useful results, and their interpretation is as follows:

- The results of the cross-section dependence displayed in Table 6 (both the Breusch-Pagan LM and Pesaran CD's p-values) show that there is no cross-sectional dependence (correlation). This validates the quality of the regression results obtained from the analysis. Hence, the error term of the individual variables in the panel is independent of each other and does not have a cross effect on each other.
- Additionally, according to Table 6, there is no multicollinearity among the variables in the model, as all the centred VIFs are below 5. This also validates the results obtained, especially because the VIFs are all below 5.

4.3. Discussions

The results obtained from Table 6 show unexpected outcomes with population growth and the urbanisation proxies. These results are similar to those observed by Satterthwaite (2009): He illustrates that a growing population in an area does not necessarily induce GHG emissions, but rather the specific types of human activities. This view is similar to a 2024 United Nations research study (Muttarak, 2024) which examined low-income countries and found that a 40% population increase corresponded to just a 5% increase in emissions. However, despite similarities, their results differ because this paper captures emissions per capita.

Drawing from these examples, the findings of this paper can be logically explained by three possibilities: the nature of human activities in the SADC, the per capita emission measurement, and the lack of increased per capita CO_2 emissions in the SADC (as seen in Figures 5 & 6). This result is further explained as follows:

- Firstly, the nature of activities in Africa, as shown in Figure 1, indicates that domestic activities are the most energy-consuming (46.4%), followed by transport (23.2%) and industrial activities (17.4%). This result implies that industrial activities (known for extreme carbon emissions) constitute the least of these three major energy-consuming human activities in Africa. Hence, since only South Africa is known for its heavy industrialisation and high carbon emissions in the SADC, one can state with respect to the SADC that population increases in urban areas may not lead to higher carbon emissions per person as expected, as long as industrial activities are not on a rapid rise.
- Secondly, the measurement of carbon emissions in this paper was captured as emissions per head. Hence, without higher industrialisation, which alters the structure of emissions, the impact of urbanisation will not be substantial in the SADC; the influence becomes negligible.
- Lastly, per capita carbon emissions did not increase in most of the countries of the SADC (Figures 5 & 6). This means that per capita emissions may not increase if the population growth rate in a location outweighs the rate at which carbon is emitted (in kilotonnes).

5. CONCLUSIONS

This paper examined the impact of urbanisation on the CO_2 emissions per capita in the examined SADC nations from 2002 to 2022. The examination was on data from 13 of the 16 SADC nations using the Panel EGLS method of analysis. The findings from the study indicated that urbanisation had no impact on CO_2 emissions pc during this period, seeming to disagree with all the following prior reviewed studies: Abdallh and Abugamos (2017); Al-Mulali et al. (2013); Ali et al. (2019); Anser et al. (2020); Bekhet and Othman (2017); He et al. (2017); Huo et al. (2020); Li and Lin (2015); Liu et al. (2017); Liu et al. (2018); Liu and Bae (2018); Sufyanullah et al. (2022); Wang et al. (2021); Wang and Wang (2021); Wang and Su (2019); Zhang and Tan (2016) and Zi et al. (2016) with all of them showing the impact of urbanisation on CO_2 emissions. However, this paper differs from them in that it captures per capita carbon emissions, focuses on sub-Saharan Africa, and examines different expressions of urbanisation.

In addition, an explanation of the results from this paper could also be drawn from the contradicting trends in Figure 4b and 6, which show that:

- Some nations display a negative relationship between urbanisation and CO_2 emissions pc: More urbanisation led to a reduction in CO_2 emissions pc in South Africa and Angola, while Mauritius is getting less urbanised, but displays higher emissions pc. In contrast, other nations with growing or shrinking urbanisation also showed a concurring relative increase or decrease in CO_2 emissions, respectively (Tanzania, Lesotho, DRC, and Malawi).

5.1. Policy and Managerial Implications

The findings of this study reveal conflicting outcomes based on different locations, and when analysed collectively, may indicate a negligible impact. They imply that urbanisation in the SADC does *not* have an effect on CO_2 emissions pc. Therefore, institutional and managerial policies encouraging environmentally friendly productivity activities to reduce CO_2 emissions do not necessarily need to take specific urbanisation characteristics into account.

However, accounting for specific urbanisation characteristics should be based on preference and what might be fundamental to an organisation or institution, provided cost does not outweigh the benefit. For instance, policies aimed at managing sustainable cities would most likely need to address urbanisation, as it is fundamental to strategies in that line. However, policies concerning sustainable banking may not need to account for urbanisation per capita, because (in this case) urbanisation has no effect on carbon emissions per capita and may not be material to sustainable banking, especially because the financial services sector may not be as associated with emissions as the construction and urban planning sector.

In addition, per capita carbon emissions do not accurately reflect the total volume of carbon emitted within the SADC region. Therefore, policies that need to account for urbanisation characteristics should consider gross carbon emissions within that area, rather than per capita, because urbanisation has a negligible impact on per capita carbon emissions.

Furthermore, an increase in urban population may be associated with changes in the structure of emissions because more industrial-based activities (as seen in developed nations) may have a different impact on carbon emissions than in urban areas with only increased domestic activities. In such cases, institutional and managerial policies may indeed need to account for urbanisation.

5.2. Limitations and Future Research

This paper was limited to the impact of urbanisation on carbon emissions per capita within the SADC region of Africa. Therefore, the method employed did not capture the context of long- and short-run effects. Hence, future studies may investigate the impact of urbanisation in the SADC by assessing these short and long-run consequences. Furthermore, studies could examine the impact of urbanisation on total CO_2 emitted in the SADC by testing the effect of urbanisation at each level of emissions using *quantile regression analysis*. This will also provide deeper insights into the pattern of influence from urbanisation.

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