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Effect of Urbanization and Industrialization on Climate Change

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A B S T R A C T

While urbanization and industrialization have a significant impact on the environment and contribute to climate change, the specific effects of these processes are often inconclusive and context-dependent, warranting further investigation. This research delves into advanced econometric techniques, including regression analyses utilizing time series data, to explore the root causes of the climate crisis. It specifically examines how rapid urbanization and industrialization exacerbate climate change—and vice versa—in Kenya. The findings indicate that urbanization and industrialization have statistically significant positive effects on climate change in the region. Estimates suggest that activities related to urban growth and industrialization are major contributors to rising temperatures and climate-related consequences. To mitigate the impact of the industrial and urban sectors on climate change, recommended strategies include transitioning to renewable energy sources, enhancing energy efficiency, promoting effective urban planning, and investing in green technologies and policies.

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INTRODUCTION

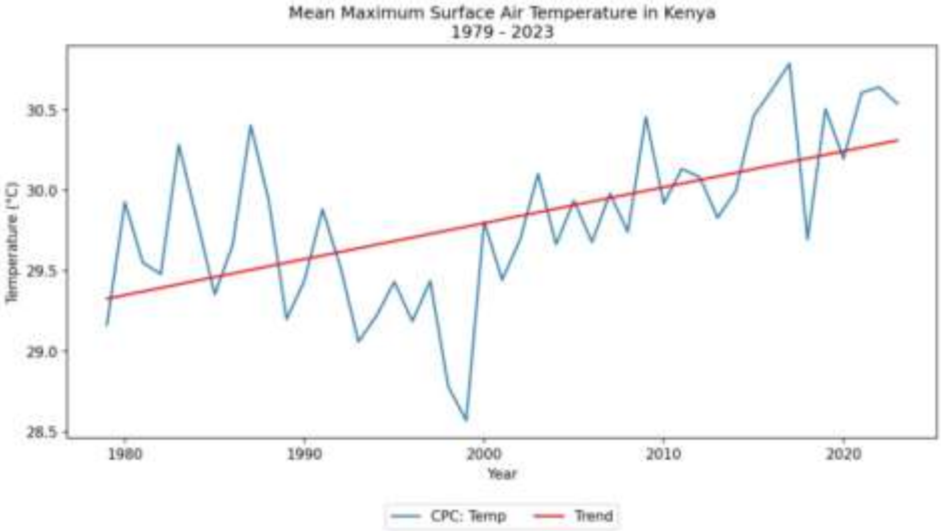
Urbanization and industrialization emerge as pivotal components of global economic development, with more than 56% of the world's population currently inhabiting urban areas—a figure projected to escalate to 68% by 2050 (Zhang, 2016). This substantial urban expansion has profound implications for environmental dynamics, particularly concerning heightened energy consumption, transportation systems, and industrial activities. Such activities have been instrumental in propelling the increase of greenhouse gas (GHG) emissions, altering land use patterns, and exacerbating environmental pollution (Filonchyk et al., 2024). The Intergovernmental Panel on Climate Change has consistently documented that urban and industrial sources account for a significant proportion of anthropogenic GHG emissions, predominantly carbon dioxide (CO_2) and methane (CH_4), which are primary drivers of global warming and its associated climatic alterations (Omotoso et al., 2024; Das et al., 2024). The overarching global challenge resides in the pursuit of inclusive, low-carbon urban and industrial growth while simultaneously adapting to the environmental risks posed by climate change.

Africa's urbanization is occurring at an accelerated rate, with projections indicating that its urban population will double by 2050 (UN-Habitat, 2021). This transition unfolds within a context marked by limited infrastructure, governance challenges, and pervasive poverty. Consequently, urban growth in numerous African cities is predominantly informal, characterized by inadequate housing, inefficient waste management systems, and heightened vulnerability to climate-related hazards (Cobbinah et al., 2023; Uttara et al., 2012). Concurrently, industrialization is prioritized within regional frameworks, such as the African Union's Agenda 2063, alongside national strategies aimed at structural transformation (Moyo, 2020). However, the continent grapples with insufficient technological capabilities and policy frameworks to mitigate the environmental repercussions of such rapid industrial expansion. While Africa contributes a mere 3–4% of global GHG emissions, it disproportionately experiences the adverse effects of climate change, including extreme weather phenomena, desertification, and diminishing agricultural productivity. This paradox underscores the pressing need for climate-smart urbanization and sustainable industrial practices throughout African nations.

In Kenya, urbanization has surged significantly, with urban inhabitants constituting over 30% of the population as of 2022, an increase from 19% in 1990 (Njuguna, 2022). The expansion of urban centres like Nairobi, Mombasa, Nakuru, and Kisumu is largely propelled by internal migration and escalated economic activity. Simultaneously, industrialization is gaining traction, particularly under the "Big Four Agenda" and Vision 2030, which aspire to enhance the manufacturing sector and stimulate employment opportunities (Mwanasiaji, 2019). While these developments yield economic advantages, they concurrently exert considerable pressure on the environment, manifested through increased fossil fuel consumption, rising industrial emissions, deforestation, and the pollution of air and water resources (Odha, 2024; Wadanambi et al., 2020).

According to Kenya's Greenhouse Gas Inventory Report, emissions from the energy, industrial processes, and waste sectors have consistently risen over the past three decades (Kabui, 2020). The 2023 climate report for Kenya accentuates the nation's vulnerability to climate change, highlighting above-average temperatures and escalating sea levels that threaten coastal communities. Extreme events, including prolonged droughts and severe flooding, have adversely affected agriculture, infrastructure, and energy production, exacerbating food insecurity and energy challenges, particularly in regions dependent on agricultural outputs and hydropower (KMD, 2024).

Data from the Climate Prediction Centre indicates a warming trend, with average maximum temperatures rising from about 29.0°C in the late 1970s to around 30.5°C by the early 2020s, a 1.5°C increase linked to global climate change. Figure 1 indicates the average earth temperature for Kenya.



Source: KMD (2024).

Figure 1. Average mean surface temperature in Kenya 1979-2022.

Kenya has implemented initiatives such as the National Climate Change Action Plan and is dedicated to reducing emissions in line with the Paris Agreement. However, there is a paucity of empirical research quantifying the contributions of urban and industrial growth to climate change in the country. This study seeks to fill that gap by analyzing time series data from 1993 to 2023 to evaluate the effects of urbanization and industrialization on climate change in Kenya.

LITERATURE REVIEW

The theory that anthropogenic greenhouse gas emissions are the primary drivers of climate change is increasingly contested by evidence suggesting that other human activities have a more significant impact (Sidiropoulos, 2023). Land-use changes, deforestation, urbanization, and industrial practices significantly alter both land and sea surface temperatures as evidenced by the Human Climate Forcings theorem (Omotoso et al., 2024). Activities such as logging, agriculture, construction, and tourism influence climatic conditions by disrupting ecosystems and altering water dynamics. For instance, deforestation limits CO2 sequestration, while urban development can lead to increased runoff and heightened temperatures. Urban areas, characterized by high concentrations of energy-producing machinery and impermeable surfaces, typically experience temperatures that are significantly higher than those in rural areas, with urban heat islands showing temperature increases of up to 4°C on warm days (Das et al., 2024)

Research indicates that many temperature monitoring stations are influenced by urban heat islands, suggesting that the actual global temperature trend may be lower than reported by datasets like the Hadley Centre and CRU (Sidiropoulos, 2023). Critics argue that proponents of anthropogenic global warming theory mistakenly attribute temperature increases tied to urbanization to rising atmospheric CO2 levels (Alcoforado & Andrade, 2008). Moreover, anthropogenic aerosols and jet contrails may have considerable warming effects that rival those of greenhouse gases. In summary, various human activities exert localized and regional climatic effects equal to or exceeding those of anthropogenic greenhouse gases, necessitating a reassessment of AGW theory and its reliance on a limited set of climate forcings as highlighted by critics such as Roger Pielke.

A study by Sitati et al. (2022) examined greenhouse gas emissions associated with traffic congestion in Nairobi and found that congestion significantly increases CO_2 emissions, particularly during peak hours. The study highlighted the necessity for enhanced urban planning and public transportation systems to reduce these emissions. Similarly, Ogama et al. (2010) explored the effects of urbanization on Nairobi's climate, noting that the city is experiencing rapid growth at approximately 6.9%. They indicated that urban population growth is directly correlated with energy consumption; thus, an increase in fossil fuel use leads to greater emissions of heat from domestic activities and industries, as well as an uptick in greenhouse gases and dust particles in the environment—all contributing to rising air temperatures. Ochola (2018) investigated the environmental stresses associated with urbanization in Nairobi, revealing that unplanned urban growth and industrial activities have strained waste management systems and exacerbated air and water pollution, which in turn heightens urban vulnerability to climate change. Furthermore, Mogaka et al. (2006) addressed the issues of climate variability and water resource degradation in Kenya, linking urban-industrial development to pollution and the overexploitation of water sources, thereby worsening climate-related water scarcity.

METHODOLOGY

The study was conducted in Kenya over a span of three decades, from 1993 to 2023, yielding a total of 31 observations. Data concerning climate change, specifically surface temperature, was sourced from the World Bank Climate Change Knowledge Portal (CCKP), which provides comprehensive global information on climate change and development. Additionally, explanatory variables such as urbanization, along with control variables including carbon emissions, trade, and industrialization, were obtained from the World Development Indicators (WDI) database maintained by the World Bank.

Gupta and Islam developed a single equation growth model that recognizes the differing impacts of climate change based on a country's stage of economic development (Gupta & Islam, 1983; Alcoforado & Andrade, 2008). In this model, average temperature (CLM)—a key indicator of climate change—is assumed to be influenced by two primary factors: urbanization (URB) and industrialization (IND). Within the context of Kenya's developing economy, carbon emissions (CO2), along with the country's exports (EXP) and imports (IMP), are identified as additional determinants of climate change that are not accounted for by the other independent variables. Consequently, they have been incorporated into the econometric growth model, as shown in the general model below (equation 1).

$$CLM = f(URB, C02, IND, EXP, IMP) \quad (1)$$

Further, the basic linear regression model has the following structure (equation 2).

$$CLM_t = \alpha + \delta_1 URB_t + \delta_2 IND_t + \delta_3 C02_t + \delta_4 EXP_t + \delta_5 IMP_t + \varepsilon_t \quad (2)$$

Where δ represents the elasticities of the variables in the regression model. t represents the time dimension, and ε is the error term.

This research conducted regression analyses utilizing time series data to investigate the impact of urbanization on climate change in Kenya. To ensure the accuracy of the estimated results, the study first assessed the stationarity characteristics of each variable using the Augmented Dickey-Fuller (ADF) unit root test. Subsequently, a cointegration test was carried out using the Johansen approach to explore the long-term relationships among the time-related variables. It is important to note that this approach is applicable only when a single cointegrating relationship exists. The analysis employed least squares estimation within a multivariate linear regression model to derive the regression outcomes. Finally, a series of post-diagnostic tests, including the Jarque-Bera normality test, Breusch-Godfrey serial correlation tests, and Breusch-Pagan heteroscedasticity test, were conducted to validate the model's quality and the results obtained.

RESULT AND DISCUSSION

The study applied the Augmented Dickey-Fuller (ADF) test equation to establish the stationarity of the dependent and independent variables. Table 1 show stationarity test results.

Table 1. Unit Root Test Results.

Variables	ADF at Level		Decision	ADF at First difference		Decision
	t-Statistics	P-value		t-Statistics	p-value	
CLM	-5.604	0.000	I(0)	-	-	-
EXP	-0.781	0.809	I(1)	-4.811	0.000	I(0)
IMP	-1.409	0.564	I(1)	-5.184	0.000	I(0)
C02	-0.398	0.897	I(1)	-4.400	0.001	I(0)

IND	-5.292	0.000	I(0)	-	-	-
URB	0.551	0.985	I(1)	-4.169	0.014	I(0)
Notes: Null Hypothesis: variable has a unit root						

The results of the Augmented Dickey-Fuller (ADF) unit root test reveal a presence of mixed integration among the examined variables. Specifically, the analysis indicates that climate change and industrialization are stationary at the level, while urbanization, exports, imports, and carbon emissions demonstrate stationarity at the first difference. These findings highlight a significant differentiation in the integration properties of the variables, underscoring the need for careful consideration in subsequent econometric modelling and analysis.

To apply the Johansen cointegration approach, all-time series variables in the model need to be integrated into order one. However, as shown in Table 1, the dependent variable (climate change) is stationary I(0), whereas the other variables are of order I(1). This discrepancy means that the variables do not share the same integration order, indicating a lack of cointegration or a long-run relationship.

The study then proceeded to estimate a multivariate regression model using the least squares regression approach. The findings of the regression model are presented in Table 2.

Table 2: Regression Results

Variable	Coefficient	Standard error	t- Statistics	p – Value
URB	0.382	0.143	2.670**	0.012
IND	0.360	0.146	2.450**	0.021
C02	0.061	0.022	2.720**	0.011
EXP	0.278	0.096	2.892***	0.007
IMP	0.036	0.102	0.351	0.727
CON	0.624	0.118	5.261***	0.000
Durbin-Watson statistics	1.815		R^2= 0.679	
Breusch-Pagan Godfrey Test	χ^2 (5) = 1.247		Prob> $\chi2$ = 0.317	
Jarque-Bera test	1.136		Prob=0.517	
Note: **, and *** specify significance at the 5 % and 1 % levels				

The results obtained from the estimated econometric model reveal a statistically significant positive coefficient associated with urbanization, quantified at 0.38, with significance established at the 5 per cent level. This finding implies that a 1 per cent increase in urban population growth corresponds to an approximate 0.38 per cent rise in climate change metrics. The substantial influence of urbanization on climate change can be attributed to intensified greenhouse gas emissions and the amplification of localized temperatures, notably through the urban heat island effect. Such dynamics contribute markedly to global warming and the related environmental and public health challenges, as articulated by Uttara et al. (2012). The role of urbanization as a pivotal driver of climate change is further accentuated by its designation as a significant source of greenhouse gas emissions and elevated temperature levels, alongside the broader implications of global warming. These assertions are consistent with the outcomes presented by Uttara et al. (2012) in their investigation of the environmental consequences of urbanization within India and its metropolitan regions.

In the domain of industrialization, the analysis indicates that the estimated coefficient values are statistically significant at the 95 per cent confidence level, with a 1 per cent increase in industrial activities correlating to a 0.36 per cent increase in climate change. This positive coefficient for industrialization underscores its considerable ramifications for climate change, predominantly linked to a substantial rise in greenhouse gas emissions arising from fossil fuel combustion and diverse industrial processes. These activities play a critical role in escalating global temperatures and contributing to various climate-related repercussions, as highlighted in the works of Mogaka et al. (2006) and Wadanambi et al. (2020). Their research in the context of Sri Lanka attributes high levels of greenhouse gas emissions to increased electricity consumption, which is driven by a growing dependence on petroleum-based fuels, particularly coal and liquid petroleum, within the energy sector.

The regression analysis further delineates a positive and statistically significant correlation between carbon emissions and climate change, with a coefficient value of 0.06. This observation indicates that a 1 per cent uptick in carbon emissions is associated with an approximate 0.06 per cent increase in climate change. Carbon emissions, primarily resultant from fossil fuel combustion, serve to trap heat within the atmosphere, leading to global warming and a myriad of climate change effects, including rising temperatures and extreme weather events, along with other consequential environmental and societal challenges.

Additionally, a significant positive relationship is identified between the exports of goods and services and climate change, as evidenced by a coefficient of 0.27. This suggests that a 1 per cent escalation in export activity correlates with a 0.27 per cent increase in climate change. The expansion of export markets typically necessitates augmented production levels to meet global demand, potentially resulting in heightened emissions associated with manufacturing, resource extraction, and transportation. Notably, trade liberalization may incentivize nations to concentrate on sectors subjected to less stringent environmental regulation, which could exacerbate overall pollution levels. Countries with lower environmental standards might further specialize in pollution-intensive exports, thereby intensifying emission levels. In contrast, the coefficient linked to imports is positive but statistically insignificant. Import trade contributes to climate change by increasing energy consumption and greenhouse gas emissions, as well as transportation demands, particularly when reliant on fossil fuel sources, thereby augmenting vulnerabilities to climate change impacts.

The adjusted R-squared value of the model stands at 0.67, indicating that 67 per cent of the variability in the dependent variable can be explained by the independent variables incorporated into the model. Furthermore, the Durbin-Watson statistic, calculated at 1.81, suggests that serial correlation does not present a significant concern within the dataset. Additionally, results from the Breusch-Pagan heteroscedasticity test indicate that heteroscedasticity is also not a salient issue within the analysis.

CONCLUSIONS AND RECOMMENDATIONS

Industrial centres and urban areas play a pivotal role in various socioeconomic activities; however, they are also significant contributors to greenhouse gas emissions and environmental degradation. The implications of global urbanization and industrialization for land surface warming remain inadequately understood. This study employs a least squares estimation technique within a multivariate linear regression framework to analyze time series data from Kenya spanning 1993 to 2023. The findings reveal that urbanization and industrialization in Kenya exacerbate climate change through increased greenhouse gas emissions derived from urban activities, energy consumption, industrial processes, and transportation. This escalation contributes to global warming and its associated impacts.

It is imperative for policymakers to devise and implement strategies aimed at fostering sustainable urbanization and industrialization, emphasizing the importance of green infrastructure, energy efficiency, and investments in clean energy. Effective urban planning, coupled with the integration of green technologies, can mitigate environmental impacts and bolster resilience against climate-related challenges. Striking a balance between urban growth and sustainability is essential for enhancing the quality of life for residents while simultaneously addressing climate change.

Collaboration among governments, businesses, and communities is critical for realizing a sustainable urban future. To combat climate change through sustainable urbanization, cities should prioritize investments in efficient public transportation systems, enforce energy-efficient building codes, and cultivate green spaces to improve air quality. The development of walkable neighbourhoods, the transition to renewable energy, and the enhancement of recycling programs are also fundamental components of this strategy. Furthermore, addressing climate-related risks and engaging residents in urban planning processes will help ensure that local needs are prioritized, thus promoting sustainability and enabling cities to confront urban challenges while mitigating climate impacts.

Mitigating the environmental consequences of industrial activity is essential in the broader effort to combat climate change, given that industries are significant contributors to greenhouse gas emissions through their energy consumption, waste generation, and resource extraction practices. The implementation of stricter regulations along with the promotion of sustainable practices, such as the adoption of cleaner technologies and renewable energy sources, can effectively reduce the carbon footprint of industrial activities. Additionally, fostering corporate accountability and transparency in environmental management further enhances these efforts. By incentivizing sustainable practices, it is possible to work towards a healthier planet and a more resilient economy.

ADVANCED RESEARCH

This study has several limitations; therefore, further research is recommended with a broader scope and a more in-depth approach to gain a more comprehensive understanding of the impact of urbanization and industrialization on climate change.

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