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Research Article

Climate Change-Urbanization Nexus: Exploring the Contribution of Urbanization on Carbon Emissions in East Africa

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Abstract It is perceived that east Africa, like the rest of the continent, is only a victim than a contributor of climate change, a perception that motivated this study that explores the contribution of urbanization on carbon emissivity in the east African region. We used panel data for selected countries in the region and conducted analysis on the urbanization-carbon emissions models that determines the presence of an Environmental Kuznets Curve hypothesis. Parametric and semi-parametric fixed-effects models analyses were also executed and results compared. Our results strikingly reveal that urbanization and economic growth are responsible for continued environmental deterioration in the region. We recommend future studies to focus on urbanization and how countries in the region can grow without necessarily impairing the environment.

Keywords Economic risks, reversibility and irreversibility, emissivity, temperature

Introduction

The study of climate change and its potential worrying effects did not receive proper attention in Africa until recently when environmental pressures became more prevalent and catastrophic. As these pressures continue to manifest and intensify, attempts to investigate the associated impacts through empirical lens in order to front proper adaptation and mitigation options that have propensity to attenuate its associated risks are increasing. Worldwide, climate impacts are becoming real and persistent due to the increase of heat-trapping gases in the atmosphere such as carbon dioxide (CO_2) that leads to abnormally high temperatures. At least, in every subsequent year since 2000, higher temperatures were recorded and in 2017, Green House Gases (GHGs) emissivity rose to an all-time high (International Energy Agency [IEA], 2018). These phenomena are not without serious regional economic, health and ecosystem implications [1-3]. Studies document evidence that it might be difficult to combat climate change mainly because of the irreversibility of CO_2 concentrations in the atmosphere. Although Awad & Abougamos [4] suggest climate change is reversible, simulation evidences suggest that CO_2 remains irreversible for, at least, 1000 years after emissions stop thereby leading to intense rainfall and floods, permafrost melt and loss of glaciers, hurricanes and heat-waves [5-6].

In the last decade, temperatures of as high as 36° Celsius and 40° Celsius have continued to be reported by a number of countries across the southern stretch of Europe. In Portugal, meteorological data revealed that mercury levels rose to a sizzling high of 45° Celsius in 2018. In over 500 years, the summer of 2003 was Europe's hottest summer with average temperatures maintaining a steady mean of 3.5° Celsius above the normal levels [7]. These developments have overridden the long-standing assumptions that economic risks as a result of global warming are sorely and solely confined to worry some outcomes in agriculture with insignificant spill-overs to other sectors of the economy. Contrary to this perception, it is the entire economy that gets affected [2]. The food security problem is worsening mainly because of the cycle of antecedence of floods and drought that hurt crops and livestock [6]. As a result, farmers and pastoralists are left with narrow livelihood adaptation options.

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It has been observed that El Nino Southern Oscillation and its complementary warm and cold phases are, respectively, responsible for El Nino and La Niña. It is ensconced from past events that adverse weather events are either weak and prolonged or brief and intense [8]. It is also ensconced that weather patterns are no longer predictable and although predictable, dry lands and flash floods are steadily intensifying and spreading leading to enormous loses of property and reduction in yields [3]. There is no doubt that the direct and the indirect, the quick as well as the slow climate change impacts are being felt and affecting everyone and everything, quite frequently and enormously. Meehl & Tebaldi [1] have warned that unless urgent interventions are made, then the future will be characterised by more severe, longer and recurrent climate impacts, a conjecture that is connoted by Colacito *et al.* [2] and Nyangena and Ruigu [3] respectively, who have argued that exceedingly warmer temperatures than normal constrain economic outcomes in a number of ways and that East Africa is poised to experience higher than global mean temperatures by 2100 [2-3].

According to Carter and Parker [9], there is more for Africa to worry than the sheer worries about the warming temperatures. In their analysis, they observe that continued population growth increases natural resource degradation, increases rural-urban migration and catalyses the rate of urban population growth. They glean that this leads to difficulties in meeting the increased energy, food and fresh water demand. Cohen [10] has established that the essence of urbanization for much of the developing world is different from that of the developed world mainly because there is an on-going convergence in urban and rural lifestyles to a level that traditional distinctions between the two set-ups become redundant.

Patz *et al.* [7] considered the growth of urban areas and population as major drivers for climate change, its intensification and a reason for vulnerability of the urban population to the intensified effects. He posits that in China alone, there has been a near 0.05° Celsius increase since 1978, which is largely attributed to land-use change that has led to an upsurge in the urban population.

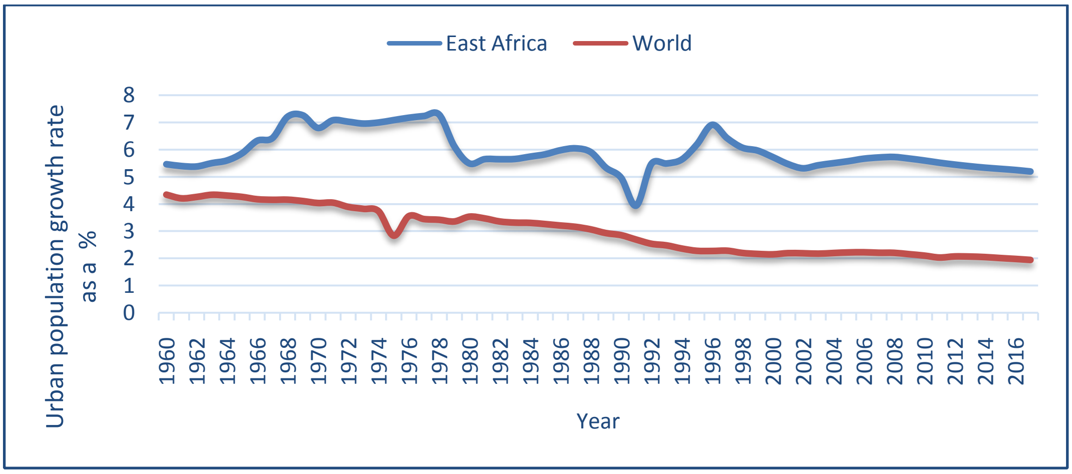

Figure 1: Comparison of Urban Population Growth Rate (annual %) in East Africa and in the World, 1960-2017 [Authors' Calculations].

The East African region, like much of the Sub-Saharan Africa, is experiencing phenomenal population and technological shift that is opening up industries and worsening environmental fragility. The urban population growth, which is way above the world average as shown on Figure 1, leads to increased energy demand. As a consequence, levels of carbon emissions in the region are increasing due to a widening economy [11]. According to the IEA (2018), demand for oil, being the yardstick for economic growth, will continue to increase at the rate of 1.2 millions of barrels per day (mb/d) and will reach about 105 mb/d in 2023, which will be about 7 mb/d increase from 2017. Technology and energy demand will continue to increase and Africa's population that was projected to be 1.22 billion in 2016 will more than double by 2050 to reach 2.5 billion, implying greater environmental stressors if no interventions are made. As aforementioned, emissivity of CO_2 portends adverse outcomes because of its longevity in the atmosphere. Although this discovery does not undermine the role of other GHGs such as methane or nitrous oxide, it is important to note that the other GHGs are not as perpetual as CO_2 in the atmosphere. According to Parry *et al.* [12], projections by the Global Circulation Models (GCMs) and the Special Report on Emissions Scenarios (SRES) model, CO_2 will spur direct physiological effects in the

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near future. As the East African region continues to urbanize, we observe that carbon emission in the region will complicate the climate system, an issue that the study sought to investigate.

Literature Review

Environmental degradation is a global challenge. Burgeoning industrial developments that are attracting rural-urban migration place abundant stress to the environment, mainly in the cities. Against this backdrop, there is an agitation to understand the influence of urbanization that is punctuated by a steadily expanding population. The neo-Malthusian theory argues that increased population reduces the quantity and quality of environmental endowments. The theory advances the idea that preventive and positive checks on population are necessary for sustainability, given the scarcity of natural endowments. Ehrlich & Holdren [13] have echo similar sentiments that if population growth is not abated, then potential gains of improved technology and the stabilized per capita consumption will be at great risk and avoiding damages will be impossible. Already, the East African region is facing a range of climate risk manifestations such as environmental degradations due to prolonged periods of floods, reduced annuals yields in crops and livestock production; increased human and human-wildlife conflicts; animal and plant diseases that have become resistant to particular medicines and pesticides among other life-threatening manifestations [3].

The ecological modernization theory posits that environmental damages rise from low to intermediate stages of development and that these damages can be averted with extra modernization designs that are cognizant of the deteriorating environment. The compact city theory qualifies the arguments and proposes creation of high urban density cities that allow residents to enjoy economies of scale with proper urban public infrastructure, reduced travelling distances; incentivising for the adoption of clean energy alternatives for industrial and domestic use, decreased car use and reduced carbon dioxide emissions [14].

Interventions fronted by the compact city theory have not been appreciated fully due to reasons that are beyond the scope of this paper. Nonetheless, there are ambitious projects that are working to combat the level of emissivity. For instance, in a span of one year (2013-2014), a vehicle scrapping and recycling project in Egypt replaced about 40,000 old taxis and helped avert 130,000 tons of carbon dioxide emissions. In the village town of Ethiopia, a natural regeneration project restored 2,700 hectares of land in less than four years and similar initiatives were made in Chad, Burkina Faso and Niger and the outcome was unrivalled. In Madagascar, Ankeniheny-Zahamena conservancy project netted over four million carbon credits while in Rwanda, the Electrogaz fluorescent lightbulb start-up distributed over 800,000 compact fluorescent lamps that reduces, at least 21,000 tons of CO_2, annually [15-16]. Similar efforts are taking place in many other countries across the continent [16].

The EKC hypothesis is an important tool in estimating environmental impacts. The tool was developed by Kuznet and gained popularity as it explained the relationship between economic growth and market forces, which increase and later decrease economic inequality. This concept has since been applied in explaining a range of aspects in the domain of environmental research and it has been illustrated that there exist a U-shaped relationship between elements under investigation, thus, confirming the EKC hypothesis although some have failed do so.

Zhu & Peng [17] examined the influence of population size, population structure, and consumption level on carbon emissions in China from 1978 to 2008. They expanded the stochastic impacts by regression on population, affluence, and technology and used the ridge regression method, which overcomes the negative impact of multicollinearity among the independent variables. Their results revealed that changes in consumption level and population structure lead to escalations in carbon dioxide emissions. In 2017, Salim, Rafiq & Shafiei [18] investigated the effects of urbanization, renewable and non-renewable energy use, trade liberalization and economic growth on pollutant emissions and energy intensity in selected Asian developing countries from 1980 to 2010. They used both linear and nonlinear panel data econometric techniques alongside the mean group estimation methods, which allows for heterogeneity and cross-sectional dependence. They then applied the autoregressive distributed lag bound testing approach to check robustness of the panel results and used the Environmental Kuznets Curve (EKC) hypothesis to examine the relationship between affluence and carbon dioxide emissions. The estimation results identify population, affluence, and non-renewable energy

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consumption as the main factors in pollutant emissions in Asian countries. The results of the EKC hypothesis showed that when countries achieve a certain level of economic growth, their emissions tend to fall. A similar approach was used by Poumanyvong & Kaneko [19] & Wang [20] who arrived at similar conclusions.

According to Wang [20], inconsistencies in the findings is largely attributed to the scope of a given study, data type and choice of estimates used. Wang [20] has also argued that other than the U-shape of relationship between estimates investigated under the EKC hypothesis, there are additional elements that influence the environment whose control is critical. Such elements, Wang [20] has connoted, include demographic transitions and the structure of industries as argued by Ehrlich & Holdren [13] who also developed the IPAT model.

Shafik [21] adduces that technology plays a favourable role in growth but it is not without damages to the environment due to intensification of energy use. Similar sentiments have been fronted by Awad & Abougamos [4] that energy use and economic growth influence environmental quality. In this study, energy use is assumed to be a proxy of technology with propensity to cause environmental damages. Since few studies have explored the urbanization-carbon emissivity nexus in the region, the study focused on analysing the existence of this nexus using parametric fixed effects panel-data synthesis technique, at a time when countries in the East African region are experiencing steady increases in population upsurge. We compare results of this technique with those of the semi-parametric approach, which does not assume ex-ante restriction on the shape of the (EKC) graphical relationship between the two parameters thereby disambiguating possible functional form misspecifications [4].

Materials and Methods

The Impact, Population, Affluence and Technology (IPAT) model is anchored on Ehrlich and Holdren's [13] academic work(s) who sought to investigate the influence of environmental cost on economic growth. The IPAT model was essentially designed to estimate unsustainability but it was later modified to quantify sustainability. Proponents have argued that the sum total of environmental impacts is a function of an ecological zone's population and its endowments. Chertow [22] has argued that it is Ehrlich (and not Holdren) who fronted the idea that environmental impact is a function of the three factors namely; population, per capital consumption and environmental index that estimates technological application on what is consumed. While Ehrlich and Holdren [13] presented a view that the influence of affluence, population and technology on impact is interdependence, Commoner [23] has gleaned that the relationship is independent. The mathematical representation of the IPAT model is given as:-

$$\mathrm{I} = \mathrm{P} * \mathrm{A} * \mathrm{T} \tag{1}$$

Where;

$\mathrm{I} =$ Impact; $\mathrm{P} =$ Population; $\mathrm{A} =$ Affluence; and, $\mathrm{T} =$ Technology

Despite the contending schools of thought, Ehrlich and Holdren's representations have stood rigorous appraisals but Deitz & Rosa [24] who hold that the IPAT representation is too simplistic and constrains the interactions of population, affluence and technology. In order to address this concern, they re-designed the IPAT model to have a STIRPAT equation. STRIPAT means the assessment of the Stochastic Impacts by Regression on Population, Affluence and Technology. The model is defined as:-

$$\mathrm{I_i} = \mathrm{a}\mathrm{P_i^b}\mathrm{A_i^c}\mathrm{T_i^d}\varepsilon_\mathrm{i} \tag{2}$$

Where;

$a; b; c$ and d are measurable parameters in the equation. ε is the error term while $i = 1$ (which ranges from 1 to 5) represents the panel unit in the model.

The STRIPAT model is to determine the presence of an inverted U-shaped Environmental Kuznets Curve when parameters of interest estimated and fitted on a graph. The extended STIRPAT model is expressed as:-

$$InI_{it} = \beta_0 + \beta_1 InP_{it} + \beta_2 InA_{it} + \beta_3 InEC_{it} + \beta_4 U_{it} + \beta_5 U_{it}^2 + T_t + \varepsilon_{it} \tag{3}$$

Where;

I (impact) is a proxy for the quantity of CO_2 emissions of a country in a given country i; t is the time period for the data under consideration; A is GDP per capita (A^2 is the square of GDP per capita); EC is the amount of energy consumption; U is the degree of urbanization; β_0 is a country-specific environmental impact that is time invariant; T_t is an estimate of time-specific, which is a parameter for technical progress on carbon emissivity

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abatement and ε_{it} is the error term. A typical model for determining the EKC using the semi-parametric fixed effects synthesis approach may be defined as:-

$$InCO_{2_{it}} = \beta_0 + \beta_1 InP_{it} + \beta_2 InA_{it} + \beta_3 InEC_{it} + f(U_{it}) + T_t + \varepsilon_t \quad (4)$$

Whereas the unobserved yet heterogeneous pollution drivers can be eliminated with differencing as shown in the next equation, the functional form $f()$ is unspecified since urbanization is a non-linear inclusion. Variation and within individuals, or equivalently, unobserved heterogeneity can be eliminated through differencing. In this respect, a single fixed-backward iteration is done using the gauss-siedel technique as shown:-

$$InCO_{2_{it}} - InCO_{2_{it-1}} = \beta_1(InP_{it} - InP_{it-1}) + \beta_2(InEC_{it} - InEC_{it-1}) + \beta_3(U_{it} - U_{it-1}) + [f(U_{it}) - f(U_{it-1})] + T_t - T_{t-1} + \varepsilon_t - \varepsilon_{t-1} \quad (5)$$

In line with Awad & Abougamos [4], the series in equation (5), are generated as shown:-

$$P^j(U_{it}, U_{it-1}) = P^j(U_{it} - U_{it-1}) \quad (6)$$

$$P^j(InA_{it}, InA_{it-1}) = P^j(InA_{it} - InA_{it-1}) \quad (7)$$

Where;

$P^j\ (U)$ and $P^j\ (InA)$ are the first j terms in the sequence of functions of $f(U)$ and $f(InA)$ as shown:-

$$P^1(U), P^2(U), P^3(U), \ldots + P^{j+1}(U) \quad (8)$$

The P^j series is the spline interpolation, special type of piecewise polynomial that forms smooth knots. Estimation of the coefficientsβ allows for the computation of the intercepts, which is done using the reduced version of equations (*6*) and (*7*), respectively to form:-

$$\hat{u_{it}} = InEm_{it} - \hat{\beta_1} InP_{it} - \hat{\beta_2} InEC_{it} - \hat{\beta_3} U_{it} - \hat{\beta_0} = f(InA_{it}) + \varepsilon_{it} \quad (9)$$

In order to perform the spline interpolation, u_{it} is regressed on U_{it} as shown in equation (10) and a B-spline regression model of order $j = 4$ is run.

Data and Variables

The panel data used in the study was collated from the World Development Indicator (WDI) from which a balanced panel of the five (5) East African countries was constructed. The data, which spans the period 1960-2014, was used in analysing whether there is a non-monotonic association between urbanization and CO_2 emissions as advanced by the EKC hypothesis or not. It is on this dataset that urbanization-CO_2 emissions(on both the parametric and the semi-parametric panel fixed-effects) models were applied and results compared. Table 1 provides a summary of the data variables, definitions and descriptive statistics.

Table 1: Descriptive Statistics of Variables

Variable	Definition	Mean	Min	Max
CO_2	Carbon dioxide emissions, metric tons per capita	.1146644	.0115981	.3861901
A	GDP per capita (constant 2010 USD)	9.96e+09	5.15e+08	4.95e+10
EC	Energy consumption (kg of equivalent) per 1,000 USD GDP (constant 2011 PPP)	438.6342	356.1152	539.4245
P	Population total	1.57e+07	2786106	5.22e+07
U	Urban population (% of total)	11.809	2.077	31.515

Results and Discussion

Empirical findings for the relationship between urbanization and CO_2 emissions are as shown in Table 2. Column 1 presents variable notation(s) while column 2 presents parametric fixed effects regression results within the urbanization-CO_2 emissions models. It is ensconced from the findings of the parametric results that the elasticity of CO_2 emissions with respect to energy consumption is positive at $p< 0.05$ confidence interval. A unit percentage increase in GDP per capita leads to 29.12% increase in CO_2 emissions, is significant at $p< 0.001$ and has a positive sign as expected. The estimated coefficient for total population although significant at $p < 0.001$, it has a negative sign contrary to our expectation. Similar findings were established for energy consumption. The results suggest that growing urbanization in the east African region significantly contribute to environmental deterioration. The affluence variable has a positive sign and its quadratic terms insignificant. Column 3 presents estimates of the control variables in the semi-parametric fixed effects regression results

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within the urbanization-CO_2 emissions model. The sign for the semi-parametric model output replicates those of the parametric output with coefficients for CO_2 emissions and GDP per capita having a positive sign while energy consumption, total population, affluence and its quadratic form have a negative sign and significant at 10% levels but affluence that is significant at 1%. The quadratic form of affluence is insignificant. The semi-parametric results suggest that economic growth are responsible for continued proliferation of CO_2 in the east African region. Nonetheless, it is important noting that both parametric and semi-parametric models provide robust results and confirm the presence of the urbanization-CO_2 emissions EKC hypothesis.

Table 2: Estimates for Urbanization - CO_2 emissions models

Variable Notation	Parametric Model	Semi-Parametric Model
CO_2	18.75*	2.917***
	(7.378)	(109.9)
InA	29.12***	5.238***
	(6.105)	(0.475)
$InEC$	-21.65***	-3.705***
	(1.715)	(0.766)
InP	-15.37***	-2.676***
	(1.136)	(0.753)
U	1.514***	0.303*
	(0.315)	(0.124)
U^2	-0.00721	-0.000849
	(0.007)	(0.00213)
Constant	-275.2*	-
	(109.9)	
Country dummies	Yes	Yes
Year dummies	Yes	Yes

Cluster-robust standard errors in parentheses $^{*}p< 0.05$, $^{**}p< 0.01$, $^{***}p< 0.001$

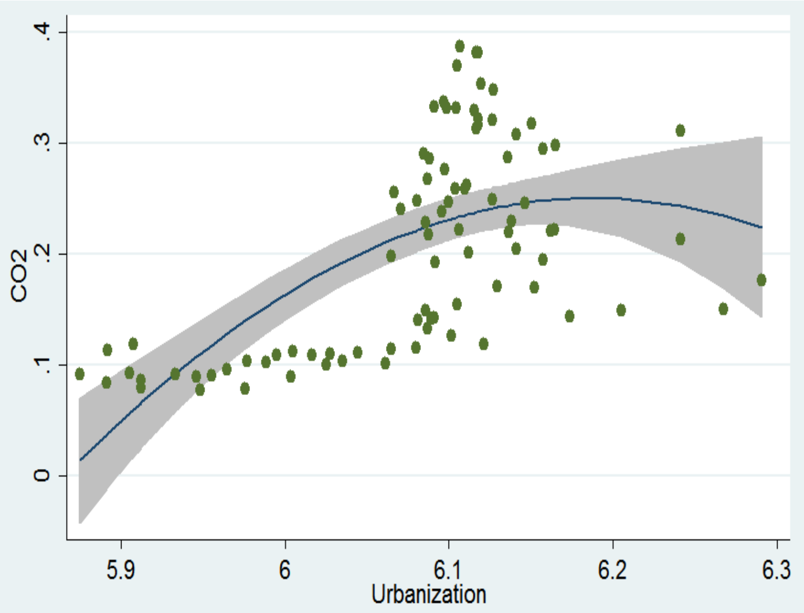

Figure 2: Partial fit of the relationship between Urbanization and CO_2 emissions. Points on the graph are estimated partial residuals for CO_2 emissions. Blue curve represents fitted values of adjusted effects of other explanatory variables in the model. Grey shading shows 95% confidence bands.

The partial fit of the relationship between Urbanization and CO_2 emissions on the semi-parametric fixed effects model is shown on Fig. 2. The figure suggests the existence of an EKC between urbanization and CO_2 emissions in the east African region. It can be deduced from the plot that there will be continued environmental degradation in the region with growing urbanization. When urbanization reaches its optimal point, CO_2 emissions start to decline. Results on Table 2 also suggest presence of an EKC between urbanization and CO_2 in

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the five east African countries. Our results reveal an increased environmental degradation due to continued urbanization in the region. Despite the direct negative effect of population density on environmental restoration, findings from current data as illustrated on Fig. 2 suggest that environmental degradation in the region is reversible and that environmental quality is recoverable.

Conclusion and Policy Implication

The study assesses the climate change-urbanization nexus by exploring the contribution of CO_2 emissions in the east African region by using the urbanization-CO_2 emissions (STRIPAT) models to detect the existence of an EKC. In the east African region, this is possibly the first undertaking that has sought to explore climate change-urbanization nexus on a STRIPAT framework. This framework encapsulates the parametric as well as the semi-parametric fixed-effects techniques. Through our exploration, we note that few studies have placed emphasis on the climate change-urbanization nexus, globally, a development that we suspect is motivated by a perception that Africa's (industrial) emissions are negligible.

In conducting the assessment, panel data (1960-2014) collated from the WDI for the five east African countries of Burundi, Kenya, Rwanda, Tanzania and Uganda was used in conducting the analysis. From the results, striking policy issues can be deduced. It notable that economic growth in the region is worsening environmental degradation, a challenge that is complicated by continued population growth and urbanization. This development has potential to compromise future growth if the increasing environmental risks are not abated through carbon cuts such the encouragement of walking to work or use of mass transport systems. The government should also promote policies that can incentivise retention of rural population in order to contain rural-urban migration. We observe that through concerted regional policy deliberations, environmental degradation in the region is reversible and recommend investment in clean energy to contain CO_2 emissivity, whose environmental effect is not as insignificant as previously thought. People living in urban areas should be encouraged to use public transport and live near their places of work where they can conveniently use bicycles or walk to work. Lastly, we recommend that future studies should focus on how countries in the region can grow without necessarily impairing the environment.

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