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Sustainability of Urbanization, Non-Agricultural Output and Air Pollution in the World's Top 20 Polluting Countries

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Abstract: Rapid urbanization is being increasingly recognized as a significant factor of environmental pollution across the world. However, the significance of sustainable urbanization in controlling both pollution and population remains either limited in scope, in the case of developed countries, or less researched, in the case of developing nations. To fill this gap, the present study employed both theoretical and empirical tools to investigate the significant link between sustainable urbanization, pollution and non-agricultural output. In order to empirically examine the supposed link among the key variables mentioned above, the present study considered a panel of the world's top 20 polluting countries for the 1991–2018 period, which significantly includes both developed and developing nations. Panel vector error correction model and panel co-integration techniques were employed to derive the possible correlation between the variables through sustainable urbanization. Empirical findings show an absence of equilibrium relations among the three variables in the panel of developed countries. However, the study clearly finds that all the three indicators maintain long-run associations for the panel of developing countries. Furthermore, in the short run, the results determine unambiguously that there are significant causal interplays between any two sets of variables and the remaining one variable for both the panel data of developed and developing countries. On the other hand, short-run interplays among the variables we considered exist for both developed and developing economies. From the perspective of policy formulation, the present study shows that policy makers from both the developed and developing nations should be cautious before encouraging urbanization, at least in the short term. However, the combined effects in the short and long term suggest policy makers should be more careful before encouraging urbanization in developing economies.

Keywords: urbanization; pollution; sustainability; panel co-integration; VECM

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1. Introduction

Human needs are well achieved with resource scarcity. Economic development combined with rapid economic growth exploits natural resources and generates environmental pollution [1,2]. However, economic growth is realized in terms of urbanization around the world, and the academic community has recognized the urban character of countries as a significant cause of environmental pressure [3,4] (In the present study we have used the term country, nation and economy interchangeably as there are no such differences among them in economics). In other words, Rapid Urbanization is increasingly shown to be an important determinant of environment degradation mainly in the form of air pollution, as well as in terms of physical pollution [3] both in developed and developing countries. Rapid urbanization increases not only air pollution [2] but also physical pollution [3]—namely noise pollution, light pollution, etc. However, here we shall limit our analysis to air pollution on the grounds that, in the context of growth and urbanization, air pollution can represent overall pollution [1,2,5]. Urbanization in developed countries and its impact on the environment is well recognized [5], but its influence on air pollution in the developing economies is less discussed in the existing literature [6], and this aspect is critically considered in the present study.

With sustainable development as our goal, sustainable urbanization in terms of optimal uses of resources and labor has a higher economic significance [5]. In this context, the interplay between the elements inherent to urbanization may have a significant role [7,8]. Considering the issue of urbanization from the point of view of growth, one could argue that the environmental effect of urbanization via growth is also important. Rapid urbanization within a highly dense area with limited space degrades the environmental quality in terms of increased air pollution [9]. Indeed, higher spatial density leads to traffic congestion and causes greater air pollution [10–12]. In sum, urbanization leads to large-scale production which, combined with increasing physical urban size and with traffic congestion, leads to higher pollution [13]. Moreover, it appears that the link between urbanization and spatial concentration produces both positive and adverse effects on the environment and that negative effects dominate over the positive ones [14,15].

Apart from growth, urbanization and environment, issues like resource and population growth are also acknowledged in the early studies. Growth and pollution in terms of environmental Kuznets curve are first considered in 1991 by Grossman and Krueger [16]. They have shown an inverted U-shaped relationship between environmental pollution and economic growth [17]. In 2004 the association between pollution and growth has been demonstrated for developed countries [18]. On the other hand, in 2010 Andrew and Jorgenson claimed that environmental pollution has been positively impacted by the growth of population [19,20].

Urbanization is a multidimensional process, which involves the population, the economy, space and society. The environmental consequences of urbanization vary among countries and regions depending on their degree of sustainable development [21]. A few studies have used indicators, such as population, per capita gross domestic product, the level of urbanization and industrial structures, to examine the effect of urbanization on energy use and carbon emissions in different countries. It has been observed that urbanization has led to reduction of energy use in the countries of the low-income group but to increasing energy use in countries of the middle-income and high-income groups. Moreover, urbanization had a positive impact on carbon emissions when all-countries studies are considered [22]. Finally, an inverted U-shaped relationship between degrees of urbanization and carbon emissions in developing countries has been shown [23,24]. However, it also appears that in the Wuhan metropolitan area the association between environmental quality and urbanization quality is diversified [25].

The global phenomena mentioned above have consequences on the local and urban levels of government [26]. Due to this global urbanization wave, cities have to face many challenges, involving the growth of poverty, shortage of natural resources, spatial dynamics, urban pollution and social stress, along with their influence on climate change [27,28]. Sustainability is the watchword for countering this negative trend. This is the reason why the concept of “Smart Sustainable Cities” (SSCs) carries its relevance in the studies on smart cities in recent years. The term SSC marks a programmatic direction toward future urban development and the achievement of higher levels of well-being [29].

This short introduction not only justifies the link between urbanization, environment, and non-agricultural productivity (in terms of overall output growth) but also raises the following and so far untested or relatively less discussed issues related to the topic we are interested in. First and most important, the issue of sustainable urbanization under the lens of pollution, population and growth has not been discussed yet for panels. Owing to the first point, we can address the second gap in terms of the following question: Can sustainability be achieved even under the active interactions between urbanization, pollution and growth due to the population parameter? Third, the above-mentioned link between urbanization, pollution and growth is not new; however, such analysis in the presence of the population factor for developing nations is relatively less discussed.

Fourth, similar analyses to track both the short-run and long-run linkages in the presence of the population factor for the panels of developed and developing countries are also less frequent in the extant literature. In this context, we started by setting up a proper theoretical background so as to justify the link between the variables. Then, in order to verify it empirically, we considered panels of both developed and developing economies.

The paper is organized in the following way. Section 2 reviews the existing literature on the said issues. Section 3 reveals the possible theoretical explanations, whereas Section 4 illustrates the same in empirical terms. Section 5 presents the results and offers a possible analysis. Conclusions are made in Section 7.

2. Literature Review

Issues related to pollution, urbanization and productivity have been studied intensively in the literature. To offer a better understanding of the existing literature, we have divided this section in three different sub-sections—namely, "urbanization and pollution", "urbanization, pollution and population", and finally "sustainable urbanization and pollution". We discuss them one by one below.

2.1. Urbanization and Pollution

Studies recognized the impact on pollution of rapid urbanization combined with economic growth and have tested such impact both in theoretical and empirical terms [3,30–38]. There are a few studies where pollutants such as sulphur dioxide and carbon monoxide have been considered while examining the impact of urbanization on pollution, and significantly, a positive effect has been identified [3]. Broadly speaking, compact rapid urban formation is negatively associated with dependence on cars and positively associated with the use of public transport and walking, which help mitigate atmospheric pollution [30]. At the same time, a few articles have found that these pollutants are less problematic following urbanization or that the pollutants are insignificant when tracing the said association [31,32].

From a closer point of view, there are few studies where cities and metropolitan areas are accorded relevance compared to the whole country. Using a data set of ozone levels for 45 large U.S. metropolitan zones, a study by Stone examined the association between urbanization and pollution in terms of ozone emission and also advocated for decentralized urban formation to control pollution [33]. Similarly, Schweitzer and Zhou have used a data set of neighborhood-level concentrations of O_3 in 80 U.S. metropolitan areas and put forward similar arguments [34]. Again, using data on ozone levels in New York City, Civerolo et al. found an adverse effect of rapid urban formation on ozone concentration [35]. Apart from these, there are few studies that consider PM 2.5 concentrations as the representative polluting element, and they also found the same negative effect of urbanization on pollution [36,37]. Moreover, considering a data set of nitrogen dioxide for 83 cities globally, Bechle et al. drew no significant association between urbanization and nitrogen dioxide [38].

2.2. Urbanization, Pollution and Population

On the contrary, there are a huge number of studies on urbanization, population and pollution in connection with energy consumption. Jones used a cross-sectional data set on the listed 59 developing countries with respect to the year 1980 to investigate the correlation between energy use and urbanization. The study claims that a 4.5% increase in energy consumption may be caused by a 10% increase in urban population [39]. In another study Parikh and Sukhla used panel data of developing countries for the period 1965 to 1987 and obtained results similar to Jones' [40]. Imai, instead, using data from 1980 to 1993 for India, China, Iran, Thailand, Japan, Turkey, U.S. and Germany, identified a positive correlation between urbanization and pollution via energy consumption [41]. In a more recent study, Salim and Shafiei used data from 1980 to 2011 for OECD countries and found a positive correlation between total population, urbanization and pollution via energy consumption [42].

2.3. Sustainable Urbanization and Pollution

In order to achieve sustainable urbanization by means of optimal pollution–labor allocation, more attention is needed to state management in terms of good governance. Good governance is helpful to environment quality [7,8], whereas poor governance may generate large harmful effects on the environment [43–45]. A lack of good governance can generate adverse environmental effects mostly due to poor environmental regulations and policies, which in turn may produce large-scale environmental pollution and also degrade environmental quality [7]. Furthermore, it has been shown that poor governance in terms of corruption can also affect economic growth negatively via decreasing environmental quality [8]. In fact, as poor governance in the government system often overlooks the optimum level of social welfare, an inverted U-shape environmental Kuznets curve may be experienced for any level of income per capita [43]. Again, the same negative consequences of governance on the environment are identified even under the presence of a strict trade policy, the effects of which are significantly reduced [46]. Interestingly, poor governance further accelerates its adverse effect on the environment in the presence of the pollution haven hypothesis for developing countries [9,47–49].

From this brief review, we identify two major gaps. First, the issue of sustainable urbanization under the lens of pollution, population and growth has not been discussed yet for panels. Second, studies on urbanization and pollution along with the short-run dynamics and long-run associations in the presence of non-agricultural output growth and population are less discussed for the panels of developed and developing countries.

3. Economic Arguments behind the Link between Urbanization, Pollution and Urban Production

Broadly speaking, there are two sides to rapid urbanization. The first one involves expansion of urban production or non-agricultural output (Y), (here, we consider non-agricultural output as the total production because non-agricultural output represents the output produced in the urban area), and the other one exploits the environment in the form of pollution (P). More specifically, we divided the overall urbanization (U) in two different parts. One is referred to as traditional urbanization (U_T), where the concept of sustainability is given little consideration, whereas the second one adopts all measures to achieve sustainability, and we refer to it as green urbanization (U_G). In both cases, urbanization refers to the total urban population. More specifically, U may be presented in the linear form as follows [28]:

$$U = U_T + U_G \tag{1}$$

Following the above-stated arguments we can specify U_T as

$$U_T = \gamma_1 (L_U Y) \tag{2}$$

where L_U is urban labor, and γ_1 represents urbanization (in traditional terms) per unit of urban labor-augmented urban output. Equation (2) shows that traditional urbanization is a function of urban labor or urban population-augmented output [39]. It should be noted that here we assume that urban labor and urban population are growing at the same rate [8], and hence the change of γ_1 over time can be represented as

$$\gamma_1 = \gamma_0 e^{\theta t} \tag{3}$$

where γ_0 is the initial value, θ explains its growth rate, and t represents the time variable. Then,

$$\dot{\gamma}_1 / \gamma_1 = \theta \tag{4}$$

where (•) represents time derivation. Therefore, the change of traditional urbanization over time can be written as

$$\dot{U}_T/U_T = \theta + (\dot{L}_U/L_U) + (\dot{Y}/Y) \tag{5}$$

Similarly, for green urbanization, we can derive its growth in the following manner. Following the arguments about sustainability we can identify U_G as

$$U_G = \gamma_2(L_U Y) \tag{6}$$

where γ_2 represents urbanization (in green terms) per unit of urban labor-augmented urban output. Equation (6) shows that the green urbanization, which is inclusive of sustainability, is a function of urban labor- or urban population-augmented output [44]. Hence, the change of γ_2 over time can be represented as

$$\gamma_2 = \gamma_0 e^{(\theta-\psi)t} \tag{7}$$

where ψ is the growth rate of pollution, which has an adverse effect on green urbanization. Therefore, $(\theta - \psi)$ describes the growth of green urbanization per unit of urban labor-augmented urban output. Then,

$$\dot{\gamma}_2/\gamma_2 = (\theta - \psi) \tag{8}$$

Therefore, the change of green urbanization over time can be represented as

$$\dot{U}_G/U_G = (\theta - \psi) + (\dot{L}_U/L_U) + (\dot{Y}/Y) \tag{9}$$

Now, plugging Equations (5) and (9) into a modified form of Equation (1), we get

$$\dot{U}/U = (2\theta - \psi) + 2(\dot{L}_U/L_U) + 2(\dot{Y}/Y) \tag{10}$$

Expression (10) reveals the association between population growth, urbanization and output. Equation (10) suggests pollution, population and growth are positively associated with urbanization in the long term.

4. Data and Empirical Methodology

In order to empirically verify the proposed link among the three key variables—urbanization, non-agricultural output and pollution—the present study used data from the World Bank for the period 1991–2018 across the panel of the world's top 20 polluting countries. It is also to be noted that the data for most of the variables of our concern during 2019 and 2020 were not available for developing countries (though they were partially available for developed countries), and hence, in order to keep a balance in our empirical verification (or to avoid any statistical bias), we limited our data to the period 1991–2018. Urbanization was measured as the total urban population, non-agricultural output as the combination of the industrial and service-related activities measured in current USD, and pollution data—limited to air pollution—are given by the quantity of CO_2 emissions measured in kilotons. Although urbanization may take different forms in different countries, the present study did not take these differences into account and identified it with the total urban population. A total of 20 countries were divided into two panels according to the state of development. The panel of developed economies included 11 countries: U.S., Canada, Germany, U.K., France, Italy, Japan, South Korea, Saudi Arabia, Poland and Australia. The panel of developing economies included nine countries: China, Russia, India, Brazil, Mexico, South Africa, Indonesia, Turkey and Iran. Figure 1 shows a map representing the geographical locations of the two groups of countries.

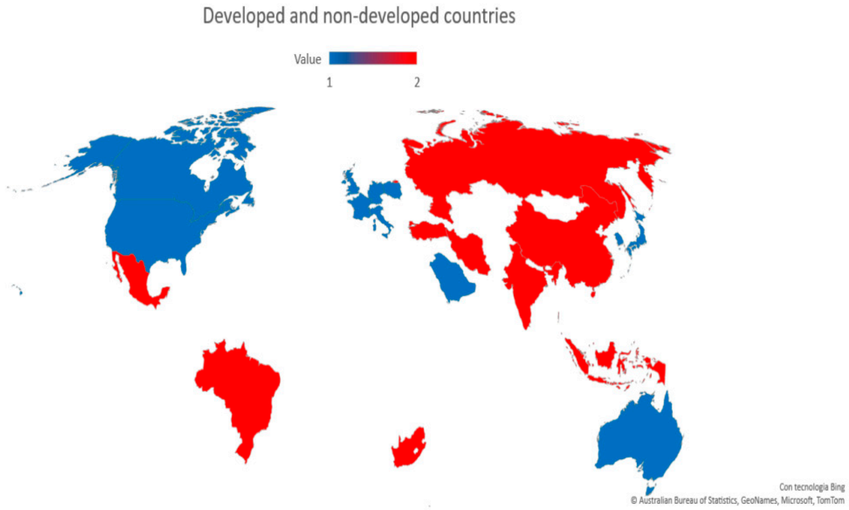

Figure 1. Map showing geographical locations of the countries. Notes: The panel of developed economies (in blue color) included 11 countries: U.S., Canada, Germany, U.K., France, Italy, Japan, South Korea, Saudi Arabia, Poland and Australia. The panel of developing economies (in red color) included 9 countries: China, Russia, India, Brazil, Mexico, South Africa, Indonesia, Turkey and Iran.

To have a better idea of the interrelationships among the three variables, the study preferred a dynamic panel model over the individual country model. Furthermore, the division of the 20 countries into developed and developing panels was important as these two categories represent best the nature of independence between their members. The empirical methodology thus followed the panel unit root and panel cointegration test, VECM and the test for panel causal interplays (refer to the Flow Chart, Table 1).

Table 1. Flow Chart of the Methodological Steps.

Steps	Methodologies	Section Numberings
1	Panel unit roots	Section 4.1
2	Test for panel cointegration	Section 4.2
3	Vector Error Correction Mechanism (VECM) and long-run causality	Section 4.3
4	Short-run causal interplays	Section 4.4

Source: Prepared by the authors.

4.1. Panel Unit Roots

If there are data in a time series format across different cross-sections, then the results of the unit root test for the individual cross-sections face a power problem that will generate spurious regression outcomes. The problem can be overcome by a panel unit root test, which provides more powerful results. A unit root test can be visualized through correlograms, but a quantitative measurement through tests such as the Augmented Dickey–Fuller (ADF) test offers a better measure than the one shown by correlograms. Thus, the present study used the panel unit root test to check whether the time series data were stationary.

Let us consider the following linear regression model for the panel unit root test in line with the ADF(p)(1979) [50] regression—viz., for the data series of a variable "x" ($x_{i,t}$, i = 1, 2,. . . , N (here N = 20 = 11 + 9) and t = 1, 2,. . . ,T (here T = 28):

$$\Delta x_{i,t} = (\rho_i - 1)x_{i,t-1} + \sum_{j=1}^{p} \gamma_j \Delta x_{i,t-j} + Z'_{i,t}\alpha_i + \varepsilon_{i,t} \quad (11)$$

where Z_{it} stands for the set of variables with exogeneity property in the model, including any fixed effects or trends across the individuals. The test criteria for this model are set by the null hypothesis as $\rho_i = 1$ against the alternative hypothesis $\rho_i < 1$. Equation (11) can be revised as

$$\Delta x_{i,t} = \beta_i x_{i,t-1} + \sum_{j=1}^{p} \gamma_j \Delta x_{i,t-j} + Z'_{i,t}\alpha_i + \varepsilon_{i,t} \tag{12}$$

The revised null hypothesis for the model is $\beta_i = 0$ against the revised alternative hypothesis of $\beta_i < 0$.

Two approaches to test for unit roots in the panel are available in time series econometrics, which depend on the conditions of homogeneity or heterogeneity of the coefficients of the regression. In the first one, the test procedures for the panel unit roots have coefficients ($\beta_i s$) that are bound to be homogeneous across all the individual units of the panel [51,52]; in the second one, heterogeneous coefficients are considered [53–56]. The homogeneity assumption ($\beta_i s = \beta$, say) is clearly limiting and is conditioned upon the possible homogeneity bias of the fixed effect estimator.

The models as given in [50,51] are presented by the Equation (13), which follows $\beta_i s = \beta$:

$$\Delta x_{i,t} = \beta x_{i,t-1} + \sum_{j=1}^{p} \gamma_j \Delta x_{i,t-j} + Z'_{i,t}\alpha + \varepsilon_{i,t} \tag{13}$$

On the other hand, Maddala and Wu test [55] statistics, based on the proposition of Fischer, apply the following formula:

$$\chi^2 = -2\sum_{i=1}^{N}(log\ p_i) \tag{14}$$

(where i takes the values 1, 2, ..., N). The test follows the chi-square distribution against the null hypothesis, $p_i = 0$ for all the "i_s". The simulations suggest that the said test is more powerful than the Im, Pesaran and Shin test, which in turn is more powerful than the Levin, Lin and Chu test under a diversity of conditions.

4.2. Test for Panel Cointegration

Three tests are usually performed with dynamic panel data for testing the existence of cointegrating relationships among the variables. Two of these [57–59] are based on Engle–Granger [60] two-step residual-based *cointegration* tests and the other one is the Fisher test, which is a combined Johansen test. The current study applied all three tests to obtain better comparative results.

The panel *cointegration* test [60] is founded upon an investigation of the residuals of a counterfeit regression executed upon the variables with I (1) feature. If the residuals of the linear combinations of both the variables follow I (0) or they are first differenced stationary, then the variables are said to be *cointegrated*. Conversely, if the residuals are I (1), then the variables are not *cointegrated*. In the Pedroni test technique, there are several tests for *cointegration* under different configurations across the cross-sections. In order to present it, the following regression with "no intercept constant" and "trends" is considered:

$$y_{i,t} = \beta_i x_{i,t} + v_{i,t} \tag{15}$$

where the two variables y and x are assumed to be integrated of order one. The general procedure is to derive residuals from Equation (15) and then test whether residuals follow I (1) by proceeding with the following supplementary regression for each of the cross-sections:

$$e_{i,t} = \rho_i e_{i,t-1} + \sum_{j=1}^{p} \gamma_{ij} \Delta e_{i,t-j} + \varepsilon_{i,t} \tag{16}$$

There are various methods Pedroni proposes for constructing statistics in order to test the null hypothesis, $\rho_i = 1$, signifying no *cointegration*. There are thus two hypotheses: the homogenous one, $(\rho_i = \rho) < 1$ for all i (which is the within-dimension test), and the heterogeneous one, $(\rho_i < 1)$ for all i (which is the between-dimension). The residuals of Equation (16) form the Pedroni panel cointegration statistic $\aleph_{N,\,T}$.

The other residual based method [59], in line with Kao, offers two tests for cointegration in panel data: the DF and ADF type tests. It considers the special case where cointegration vectors are assumed to be homogeneous between individuals. Kao applies the models as shown in Equations (15) and (16). The estimate of ρ applying the OLS technique is given by:

$$\hat{\rho} = \frac{\sum\limits_{i=1}^{N}\sum\limits_{t=2}^{T} \hat{e_{it}}\hat{e}_{it-1}}{\sum\limits_{i=1}^{N}\sum\limits_{t=2}^{T} \hat{e_{it}}\hat{e}^{2}{}_{it-1}} \tag{17}$$

The ADF test statistic for cointegration is founded upon the above-mentioned expression.

Under a different test procedure, as noted in [61], two more statistics are proposed for the purpose of determining the existence of cointegration vectors in the non-stationary time series: the likelihood ratio trace statistics and the maximum eigen value statistics. Through the Johansen test, the new test [55] combines individual tests to suggest a substitute for the two earlier tests.

4.3. Vector Error Correction Mechanism (VECM)

When the series are found to be cointegrated, it is required to examine whether the errors due to the short-run deviations from the long-run relations are amended and the series moves for converging to the equilibrium relation. VECM manages this phenomenon. It is a restricted vector autoregressive model that is envisioned for use with the cointegrated series. The cointegration term is called the *error correction* term.

In order to offer a mathematical presentation of the VECM, a two-variable model is considered to have one cointegrating equation. In addition, there will be no lagged differenced terms. The equation involving cointegration for no intercept and trend is presented below:

$$y_t = \beta x_t + \varepsilon_t \tag{18}$$

Hence, the derived error term in the first difference form is

$$e_{t-1} = y_{t-1} - \beta x_{t-1} \tag{19}$$

Thus, the equivalent structure of the VEC model is

$$\begin{aligned} \Delta y_t &= \alpha_y (y_{t-1} - \beta x_{t-1}) + \varepsilon_{yx} \\ \Delta x_t &= \alpha_x (x_{t-1} - \beta y_{t-1}) + \varepsilon_{xy} \end{aligned} \tag{20}$$

The variable on the right-hand side stands for the error correction (EC) term, which is zero in the equilibrium relation. Nevertheless, if “y” and “x” deviate from the equilibrium relation, the EC term will then be nonzero, leading each of the variables to adjust partially to reinstate the equilibrium relation. The speed of adjustment of the ith endogenous variable on the way to the equilibrium is captured by the coefficient “α”. A negative and significant (with probability at least less than or equal to 0.05) error correction term signifies that the errors in the short term are corrected, and the series converge to their long-run relation. Moreover, this result allows the existence of long run causal interplays from “x” to “y” to be concluded and vice versa.

4.4. Short-Run Causal Interplays

Lastly, in this VECM set up, the causal interplays in the short run can be verified by applying the Wald test under the head of coefficient diagnosis.

5. Analysis of Empirical Results

5.1. Results of the Panel Unit Root Test

Founded on the theoretical model and empirical methodology, the study proceeded with empirical verification of whether urbanization (measured as urban population), non-agricultural output and environmental pollution (measured in CO_2 emissions) follow long-run relations or are cointegrated in the separate panels of developed and developing economies. The primary task was to test whether the three series, urbanization, non-agricultural output and pollution, of the two panels of countries were non-stationary at their levels. If not, their orders of integrations were to be found. The tests of the panel unit root were of two specifications, which were followed by Equations (11)–(14), with individual unit root process and common unit root process. The derived results show that none of the series of the panels were stationary at their levels in both unit root processes (the results are not shown in the Table 2), but in the majority of the test statistics they were I (1). The respective probability values of the test statistics were well below the 0.05 level of significance. However, there are two instances for the panel of developing economies under the individual unit root process in the case of urbanization where the results were not significant. Since there is one test (e.g., MW-ADF—Fisher chi-square) that supports the stationarity of the series for urbanization, the study considered the series as stationary in a broad sense, in order to keep a balance in the results of the other two series.

Table 2. Results of the panel unit root test for urban population, non-agricultural output and CO_2 levels at their first differences.

Method	Null Hypothesis	Test Statistics with Intercept (Prob.) for Developed Countries			Test Statistics with Intercept (Prob.) for Developing Countries		
		Urban	Non-Agri	CO_2	Urban	Non-Agri	CO_2
Levin, Lin and Chu	Unit roots (under common unit roots process)	−3.9 (0.00)	−7.3 (0.00)	−6.7 (0.00)	−2.23 (0.01)	−4.54 (0.00)	−6.12 (0.00)
Im, Pesaran and Shin	Unit roots (under individual unit roots process)	−2.5 (0.00)	−8.1 (0.00)	−8.7 (0.00)	−0.18 (0.4)	−5.8 (0.00)	−7.8 (0.00)
MW-ADF—Fisher chi-square	Unit roots (under individual unit roots process)	40.2 (0.00)	105.2 (0.00)	113.7 (0.00)	29.96 (0.03)	69.15 (0.00)	93.1 (0.00)
MW-PP—Fisher chi-square	Unit roots (under individual unit roots process)	31.2 (0.08)	114.9 (0.00)	200.8 (0.00)	9.56 (0.9)	87.06 (0.00)	172.7 (0.00)

Note: Automatic lag length selection is based on AIC: 0 to 6. Probabilities for Fisher tests were computed using an asymptotic chi-square distribution. All other tests assume asymptotic normality. Source: Authors' calculations.

The derived results as given in the table show that all three selected series are stationary in their first differences because the values of the probability of the selected test statistics are well under 0.05, and hence there is no chance of getting spurious regression results.

5.2. Results of the Panel Cointegration Test

As we explained in the methodology section, there are three commonly used sets of tests for cointegration in a model with panel data. The Engel–Granger framework of residual panel cointegration test is followed in Pedroni and Kao, and the Fisher test follows the combined Johansen test. Table 3 presents the Pedroni test results under three different configurations, and in each of the configurations, there are the results for both "within dimension" and "between dimension".

Table 3. Pedroni's residual cointegration test for both panels of developed and developing economies.

Hypotheses→ Test Criteria↓	***Null Hypothesis: No Cointegration***		**Statistic (Prob.)**	**Weighted Statistic (Prob.)**
No deterministic trend	Alternative hypothesis: Common AR coefficients (within-dimension)	Panel v-Statistic	−0.51 (0.69) [0.90 (0.18)]	0.16 (0.43) [−0.07 (0.53)]
		Panel rho-Statistic	0.77 (0.78) [0.44 (0.67)]	−0.02 (0.49) **[−2.1 (0.01)]**
		Panel PP-Statistic	0.49 (0.69) [−0.21 (0.41)]	−0.95 (0.17) **[−3.63 (0.00)]**
		Panel ADF-Statistic	−0.18 (0.42) **[−1.9 (0.03)]**	−0.62 (0.26) **[−3.20 (0.00)]**
	Alternative hypothesis: Individual AR coefficients (between-dimension)	Group rho-Statistic	0.83 (0.79) [−0.52 (0.30)]	-
		Group PP-Statistic	−0.58 (0.27) **[−3.06 (0.00)]**	-
		Group ADF-Statistic	−0.29 (0.38) **[−2.26 (0.01)]**	-
Deterministic intercepts and trends	Alternative hypothesis: Common AR coefficients (within-dimension)	Panel v-Statistic	**8.60 (0.00)** [0.57 (0.28)]	0.13 (0.46) [−1.69 (0.95)]
		Panel rho-Statistic	**−1.42 (0.08)** [2.21 (0.98)]	−0.12 (0.45) [−0.85 (0.19)]
		Panel PP-Statistic	**−3.61 (0.00)** [2.31 (0.98)]	**−1.92 (0.02) [−3.52 (0.00)]**
		Panel ADF-Statistic	**−3.72 (0.00)** [−0.07 (0.46)]	**−1.35 (0.09) [−3.57 (0.00)]**
	Alternative Hypothesis: Individual AR coefficients (between-dimension)	Group rho-Statistic	0.75 (0.77) [0.65 (0.74)]	-
		Group PP-Statistic	**−1.72 (0.04) [−2.36 (0.00)]**	-
		Group ADF-Statistic	−1.21 (0.13) **[−2.13 (0.01)]**	-
No deterministic intercepts and trends	Alternative Hypothesis: Common AR coefficients (within-dimension)	Panel v-Statistic	0.31 (0.36) **[1.88 (0.02)]**	−0.94 (0.82) [−0.19 (0.57)]
		Panel rho-Statistic	0.33 (0.63) [−0.62 (0.26)]	0.28 (0.61) **[−1.50 (0.07)]**
		Panel PP-Statistic	−0.25 (0.39) **[−1.52 (0.07)]**	−0.38 (0.35) **[−2.41 (0.00)]**
		Panel ADF-Statistic	−0.19 (0.42) **[−2.08 (0.01)]**	−0.39 (0.34) **[−3.10 (0.00)]**
	Alternative hypothesis: Individual AR coefficients (between-dimension)	Group rho-Statistic	1.32 (0.90) [−0.69 (0.24)]	-
		Group PP-Statistic	−0.36 (0.35) **[−4.02 (0.00)]**	-
		Group ADF-Statistic	−0.49 (0.31) **[−3.83 (0.00)]**	-

Note: The figures in the third bracket [.] indicate the cointegration results for the developing economies. The figures in bold indicate significant results of cointegration. Source: Authors' calculations.

The results of the Pedroni test show no signs of cointegration among the three variables of urbanization, non-agricultural output and CO_2 emission in the panel of developed countries. However, the results for the panel of developing countries show signs of cointegration in most cases. Hence, there are long-run or equilibrium relations among the three variables only for the panel of developing economies as far as Pedroni test is concerned.

The derived results of Kao test are presented in Table 4, where it can be observed once more that the panel of developed countries does not have an equilibrium relation among the three variables since the values of probability are far greater than the standard value of 0.05. However, the panel of developing countries shows cointegrations among the variables as the ADF statistic of the residual generated from the regression of one variable upon the two remaining variables has less than 0.05 probability.

Table 4. Results of Kao residual cointegration test.

Null Hypothesis: No Cointegration	**Developed**	**Developing**
	t-Statistic (Prob.)	*t*-Statistic (Prob.)
ADF	−0.99 (0.16)	−2.77(0.00)

Source: Authors' calculations.

Furthermore, the results of the Fisher–Johansen cointegration test (Table 5) show that there are weak cointegrating relations among the selected three indicators for the panel of developed countries since the corresponding probability values of the trace statistic and max-eigen statistic are between 0.05 and 0.10. However, we find cointegrating relations among the three selected indicators for the panel of developing economies since both the statistics and their corresponding probability values are within the desirable limits. The results of VECM for both panels of countries are presented in Table 6.

Table 5. Results of Fisher–Johansen cointegration test.

Fisher Statistics (Developed)	Fisher Statistics (Developing)	Fisher Statistics (Developed)	Fisher Statistics (Developing)
(From trace test) (Prob.)	(From trace test) (Prob.)	(From max-eigen test) (Prob.)	(From max-eigen test) (Prob.)
At most 1 > 28.8 (0.14)	64.11(0.00)	24.2 (0.33)	42.51 (0.00)
At most 2 > 35.16 (0.07)	58.90 (0.00)	35.91 (0.07)	58.90 (0.00)

Source: Authors' calculations.

Table 6. Results of VECM.

	Dependent Variables	EC Terms	Probability	Whether Errors Corrected	Remarks
Developed	D(Urban)	C(1) = −0.002	0.87	No	No long run causal link from Non-agri GDP and CO_2
	D(Non-agriGDP)	C(1) = 141,586	0.00	No	No long run causal link from Urban and CO_2 to Non-agri GDP
	D(CO_2)	C(1) = 14.07	0.00	No	No long run causal link from Urban and Non-agri GDP to CO_2
Developing	D(Urban)	C(1) = 0.003	0.07	No	No long run causal link from Non-agri GDP and CO_2 to Urban
	D(Non-agriGDP)	C(1) = −12,432	0.00	Yes	Long run causal link from Urban and CO_2 to Non-agri GDP
	D(CO_2)	C(1) = 2.21	0.00	No	No long run causal link from Urban and Non-agri GDP to CO_2

Note: Optimum lag is computed as 2 for the developed and 3 for developing according to SIC. Source: Authors' calculations.

The results of error corrections for the developed countries show that the errors are not corrected in any of the three variables acting as dependent endogenous variables, and hence, there is no long-run causation by any two pairs of variables of the third variable as endogenous. On the contrary, with respect to the outcome of the panel of developing countries, the errors are corrected when non-agricultural activity becomes the endogenous dependent variable. Finally, there are no error corrections when the other two variables, urbanization and CO_2, become the endogenous dependent variables. The results of short-run causal interplays are given in Table 7 following Wald test.

Table 7. Short-run causality results through the Wald Test.

	Dependent Variable	Chi Square	Probability	Remarks
Developed	D(Urban)	22.13	0.00	Non-agri and CO_2 $\rightarrow$ Urban
	D(Non-agriGDP)	19.68	0.00	Urban and CO_2 $\rightarrow$ Non-agri
	D(CO_2)	237.42	0.00	Urban and Non-agri $\rightarrow$ CO_2
Developing	D(Urban)	10.92	0.02	Non-agri and CO_2 $\rightarrow$ Urban
	D(Non-agriGDP)	31.98	0.00	Urban and CO_2 $\rightarrow$ Non-agri
	D(CO_2)	20.39	0.00	Urban and Non-agri $\rightarrow$ CO_2

Source: Authors' calculations.

The Wald test results for both the panel data of developed and developing countries show unambiguously that there are significant causal interplays between any two sets of variables and the remaining one variable. The results support the outcome of the studies by Jones [39], Parikh and Sukhla [40], Imai [41] and Salim and Shafiei [42].

6. Discussion

The flow of the methodologies as given in the flow chart (Table 1) shows the tests that were carried out sequentially: stationarity test of the panels of developed and developing countries across the three indicators of urbanization, non-agricultural output and air pollution; panel cointegration; VECM for long-run and short-run causality tests. The derived results show that all three selected series are stationary in their first differences because the values of the probability of the selected test statistics are well under 0.05, and hence, there is no chance of getting spurious regression results. The study then performed the tests for cointegration to examine whether there were equilibrium relations among urbanization, non-agricultural output and pollution in the two separate panels of the selected developed and developing countries.

The results of Pedroni test show no signs of cointegration among the three variables in the panel of developed countries. Indeed, the required statistics in most cases were well below their desired levels and the corresponding values of the probability were greater than the 5% level of significance. On the contrary, the results for the panel of developing countries indicate signs of cointegration in most cases. The required values of the statistics were well above the desired levels and the corresponding values of probability were well below the 5% level of significance. Therefore, there are long-run relations among the three variables only for the panel of developing countries as far as Pedroni test is concerned. The Kao test also produced the same results of cointegration as the Pedroni test. Thus, the two techniques of cointegration based on Engle–Granger residual—namely, Pedroni and Kao—did not produce any co-movements of the three selected variables for the panel of developed countries, while they did so for the panel of developing countries.

Moreover, the Fisher–Johansen test produced weak cointegration results for the panel of developed countries and strong results for the panel of developing countries. Combining all three results of cointegration it can be concluded that there are no equilibrium relations among the three indicators of urbanization, non-agricultural output and CO_2 emissions in the panel of the so-called developed countries. This means that there may not be sustainability issues in the urbanization process of the developed countries. On the other hand, there may be structural breaks in the series of the data set for all the three variables that could have been tested. The study could not capture the issue and preserves it for the future agenda. Additionally, there may be other related factors that affect the sustainability issues of these countries in the modern world. It falls outside the scope of the present study to take all these other factors into account in the analysis of any unsustainability issues that may be present in the developed countries. Nonetheless, the results show that all three indicators maintain long-run associations for the panel of developing countries, which means there can be unsustainable urban planning in these economies.

After identifying the presence of long-run associations among the three selected variables, it is required to study short-run interplays within the equilibrium relations. In specific terms, it is important to identify whether the errors that might be present through the deviations from the long-run relations are corrected or not. Keeping in mind the weak cointegration results for the developed countries as well as the strong cointegration results for the developing countries, the study proceeded with the analysis of short-run dynamics in both panels by means of VECM. The results of error corrections for the panel of developed countries show that the errors were not corrected in any of the three variables acting as dependent endogenous variables and hence there was no long-run causation by any two pairs of variables of the third variable as endogenous. On the contrary, with respect to the outcome of the panel of developing countries, the errors were corrected when non-agricultural output became the endogenous dependent variable. This further means that in the long run, CO_2 emissions and urbanization are a cause of the industrial and tertiary activities in the economies. Developing economies are facing rising urbanization, which becomes unsustainable from the point of view of pollution effects. Finally, there were no error corrections for the other two variables, urbanization and CO_2, when considered as the other endogenous dependent variables.

The last point to discuss concerns the existence of causal interplays among the three variables with optimum lags. Following Table 6, the chi square values were derived on the basis of the regression of any of the three variables in I (1) form upon its own lagged values and those of the other two remaining variables in I (1) forms. The Wald test results show unambiguously that there were significant causal interplays between any two sets of variables and the remaining one variable for both the panel data of developed and developing countries. For example, non-agricultural output and CO_2 emissions were a cause of the urbanization process in both groups of economies. Furthermore, urbanization and non-agricultural economic activities led to more pollution. This means that a higher population pressure on the urban area and the related non-agricultural activities surrounding the urban areas generate more pollution, which is a concern for sustainable urban planning. The results support the outcomes of the studies by Jones [39], Parikh and Sukhla [40], Imai [41] and Salim and Shafiei [42].

Planners in both the developed and developing economies are therefore advised to be careful in increasing urbanization, at least in the short run, and are advised to promote sustainable urbanization instead. Taking into account together the effects in the short and in the long run, the developing countries in particular should be more cautious in planning for increasing and more intense urbanization.

7. Conclusions

Urbanization in the wake of economic growth may generate concerns for sustainability. In fact, it is commonly argued that environmental degradation in the form of pollution questions the sustainable nature of growth. In developed countries, industrialization generates pollution while pursuing high economic growth, but strict regulation and proper implementation of environmental policies usually diminish the intensity of the unsustainability of growth. On the other hand, developing economies are often described as the carriers of pollution, which has been justified by the famous pollution haven hypothesis. Specifically, population explosion along with pollution makes the nature of growth unsustainable in developing nations. This suggests the plausibility of sustainable urbanization, however elusive the way to achieve it proves to be.

Growing urbanization offers excellent opportunities for development, especially if supported by smart and sustainable technologies. Indeed, smart cities have great potential for improving the conditions in developing economies. However, this potential cannot be fully realized in most of the developing economies. Some prevailing structural factors could also have widened the gap between potential and reality. For example, developing economies are inclined to accept policy frameworks supplied by and tested in developed economies, with the risk of promoting the interests of the supplying countries over local interests. Finally, the Smart City initiatives in developing countries are carried out by the governments rather than local entrepreneurs: This is a potential problem of local relevance and sustainability.

Empirical findings show the absence of equilibrium relations among urbanization, non-agricultural output and CO_2 emissions in the panel of developed countries and suggest that there may not be sustainability issues in the urbanization process of the developed economies. However, the present study unambiguously shows that all three indicators maintain long-run associations for the panel of developing countries, which indicates the possible presence of unsustainable urban planning in these emerging economies. On the other hand, short-run interplays among the variables we considered exist for both developed and developing economies.

These findings have some critical implications for policymaking. First, the present study urges policy makers from both of the developed and developing economies to be cautious before encouraging urbanization, at least in the short run. Second, the findings recommend that policymakers of developing countries, in the backdrop of population explosion, be more cautious before encouraging urbanization both in the short and long run. By contrast, policymakers of developed economies should be concerned only in the short run before implementing urbanization.

The study established that there was no cointegrating relation among the three selected variables in the panel of developed countries. One possible explanation, as mentioned, may be the presence of breaks in the series of the three variables. The present study could not test this but signals it as one important element for future policy agendas.

To conclude, we point to some limitations of the present study. First, we only used CO_2 emissions to measure urban pollution; however, other measures of pollution such as SO_2 emissions or methane emissions etc. could also be used to check the robustness of our study. Second, in the present study we considered 20 countries (including 11 developed and 9 developing countries) to examine the sustainable form of urbanization in the presence of pollution and population. A wider sample including a larger number of selected countries may provide efficient estimates through the same panel data technique. These limitations, in turn, provide us future a research agenda on related topics.

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