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Co-movements of income and urbanization through energy use and pollution: An investigation for world's leading polluting countries

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ABSTRACT

Economic growth via urbanization helps in the accumulation of capital in the urban area. Again, to meet up the urban demand, energy consumption increases sharply, and consequently as the byproduct, magnitude of carbon emission also increases in the environment. The existing literature did not focus upon the high trajectory of carbon emission following urbanization. There is, thus, an interlink too between income growth and magnitudes of urbanization. Therefore, the co-movements between income and urbanization, and the connotation among income, urbanization, energy use and Green House Gas emissions are an area to be explored for the highly polluting nations. This study thus aims to investigate whether income, urbanization, energy uses and GHG emissions are cointegrated or having co-movements for the world's top 20 polluting nations for the period 1970–2018. The study first underpins a theoretical background for the association among the four indicators and then goes for empirical verifications using time series econometric exercise. Using Johansen cointegration test and Vector Error Correction Model (VECM) for the variables the results show that the variables have long run associations as well as short run causal interplays in mostly the developed countries of the list. Income and urbanization have latent explanatory powers through energy use and GHG emissions. Hence, the policy makers of the concerned countries should focus on controlling the process of urbanization in order to manage energy use and GHG emissions to ultimately reach to the end of sustainable development.

1. Introduction

Economic betterment often characterized in terms of potentiality of economic growth. Economic growth fundamentally describes the economic opportunity in terms of quantitative perspective that actually grabbed by the representative economy in an ex-post manner (Bakhsh et al., 2017; Tipu, 2021). Therefore, more output or higher gross domestic product (GDP) and its rate of increase critically explain and by virtue of it in backyard, a flow of economic commitment in terms of taking place the process of urbanization (Saidi and Mbarek 2017; Hanif, 2018). Although such commitment is not implicit, moreover, its significance is a rising one. Urbanization broadly implies the engagement of working force in urban area and in turn it indicates the share of urban population in the urban area (Yu et al., 2020). Therefore, rapid urbanization progressively affects economic activities either in manufacturing, or in service or in urban informal sectors (Zhu et al., 2012). The other side of the same story is also important, that is, economic growth attracts labours from rural to urban areas following higher remunerations or wages (Lewis, 1954; Harris and Todaro, 1970) and influences urbanization aggressively (Ghosh et al., 2014). Hence, like the generation of urbanization through the channel of economic growth, impact of urbanization on growth issue is quite pertinent and significant.

Again, if we take the following cases, that is, economic growth via urbanization or urbanization owing to growth, in both cases accumulation of capital is realized in order to maintain high trajectory of investment in urban area (Deqing et al., 2022). Consequently, urban output of manufacturing sector rises and consecutively it raises the share of carbon emission within the basket of total emission of pollutants (Fang et al., 2015; Zhang et al., 2021; Zeng et al., 2021). Therefore, rapid urbanization implicitly aggravates the level of pollution in environment via channel of either carbon dioxide emission or through the emission of other GHGs or due to both (Russell, 2020; Das et al., 2022). Moreover, impact of pollution in terms of CO_2 emission cannot be ignored and it is

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tossed in Human Development Report 2019 (UNDP, 2019). Following the latest Sustainable Development Goals (SDG) progress report we find that the developing nations are the poor performer, compared to their developed counterpart in the context of climate action and environment issues (UNESCAP, 2021). As the said economies are still depending majorly upon the fossil fuel-based energies, the following economic growth path may not be able to address environmental sustainability. Consequently, the said economies are still lagging far to standardize the existing policy measures for achieving the objective of the climate action, which actually is mentioned under SDG 13. The lack of effective policies and the need of policy realignment for the said economies constitute the starting point of the present study.

So far, we have discussed the nexus among growth, urbanization and pollution, however, the story remains incomplete unless the incorporation of energy issue is done. Moreover, the aspect of energy use has two different parts; one is related to fossil fuel-based solution and the other one is non-fossil fuel-based solutions (Hanif, 2018; Anwar et al., 2021). It is historically evident that rapid use of fossil fuel-based energy creates immense pressure on environmental quality through emission of CO_2 and other GHGs (Zafar et al., 2021). Energy generated from such resources always harms environment and consequently respective growth path, and urbanization become unsustainable, and it puts forward conflict on the potentiality of SDGs achievements (Jiang et al., 2020; Das et al., 2021). Therefore, the said economies are still lagging far to calibrate the existing policy measures for achieving the objective of the energy solutions to be clean and affordable, which actually falls under SDG 7. Therefore, void of the existing energy and urban related policy measures and urgency of policy realignment in the context of energy, growth and urban development in order to achieve the SDG 7 give us the second relevant point behind the present study.

From the above, it is quite clear that while the developing and developed countries are trying to produce more to capture high growth path, they actually raise the use of fossil fuel-based energy, degrade environment and create unsustainable urbanization. Now from this backdrop, a few questions may arise. First, in which way or at what degree such urbanization affects developing and developed countries? Second, whether policy realignment in the present context can generate sustainable urbanization via the achievement of SDG 7 & and SDG 13? Third, does unsustainable urbanization affect environment and energy consumption to accommodate unsustainable economic growth? These three questions generate the rationale behind the present study and it becomes imperative to analyze each with proper empirical paths.

Given these issues or research objectives, here, we have incorporated 20 most polluting countries (11 developed and 9 developing countries) in the world and the study spans from 1970 to 2018. The interrelationships among the four key variables, urbanization, GDP (or income), energy use and GHG emissions, are analyzed here using a basic theoretical model supported by the empirical investigations using the time series econometric techniques. Thus, our study is contributing in the following manner. First, the nexus between economic growth and pollution is either explained in terms of energy uses or via the channel of urbanization. It is to be noted that the issue related to growth, urbanization, energy use and pollution has been of major concern during the last decades. However, unlike others, the present study makes an environment of juncture where the mentioned nexus is analyzed via channel of both urbanization and energy uses simultaneously. Second, incorporation of such hitherto untested issue like the co-movements of economic growth indicator and the indicator of urbanization for a long panel, where the representation from both developed and developing countries are present, is scarce in the literature. Therefore, in this study we test a novel methodology in which the co-movement analysis is performed by exploring both long run association and short-run dynamics among the variables of interest. Third, instead of a specific policy measure, we propose a wide variety of more balanced strategies with options to achieve SDGs 13 and 7 greater sustainability.

The paper is organized in the following ways. Section 2 reviews theexisting literature on the issues in which the present study is focused. Section 3 reveals the possible theoretical underpinnings and compatible empirical model, while Section 4 presents the empirical results and offers a possible policy analysis. Conclusions are made in Section 5.

2. Literature review

2.1. Income and pollution

In the literature, economic growth is described as one of the main driving forces behind the enhancement of CO_2 emission (Alam et al., 2007; Al-Mulali et al., 2015; Anwar et al., 2021; Shahbaz and Sinha, 2019; Zafar et al., 2019). Rapid growth often augmented with the high-end use of fossils fuel. More use of fossils fuel generates CO_2 to the environment, as consumption of fossils fuels is a big source of CO_2 emission (Tipu, 2021). However, the effect of environmental degradation on economic growth via health issues remains a question of research. In this context the following studies, that is, studies conducted by Pao and Tsai (2011), Baek (2016), Bakhsh et al. (2017), Hanif (2018) and Koengkan (2018) put significant contributions[1]. Apart from these, there are a few studies which have significant contributions in order to explain the association between income and pollution. By using a panel data of 43 developing economies for the period of 1980 to 2004, Narayan and Narayan (2010) examine the nexus between pollution and income. They have shown that pollution in terms of CO_2 emission decreases in South Asian and Middle East countries as income increases. Again, Miah et al. (2011) use a data set for a study of Bangladesh for the period 2008 to 2009 and claim that pollution in terms of waste, emissions from waste, and suspended particle matter increases with increase in income but after reaching the threshold income level it starts declining. Dewan et al. (2012) focus only upon Dhaka Metro area with revelations of primary data on the impact of urbanization upon water pollution, land use and some air pollutants. However, in a similar study, Ghosh et al. (2014) find that there exist no significant association between pollution and income growth in Bangladesh. In that study Ghosh et al. (2014) use the data set for Bangladesh for the period 1972 to 2011. In a comparison of the results for Bangladesh, Ghosh et al. (2014) used Johansen and Juselius (1990) cointegration method on income, energy use and carbon emission while Dewan et al. (2012) focused only upon Dhaka Metro area with revelations of primary data on water pollution, land use and some air pollutants. Miah et al. (2011) studied the relationship between income and waste and particulate matter to test whether Environmental Kuznets curve worked for Bangladesh. The differences in methodologies as well as areas of studies led to the differences of the results. Interestingly, Deqing et al. (2020) have proposed that quality of green growth can accommodate economic development, social inclusiveness, and eco-environmental protection in case of developing countries.

2.2. Urbanization and pollution

Now, by shifting our focus from growth and pollution to urbanization and pollution via growth, we find several studies which have already researched the nexus between urbanization and pollution and evidently acknowledged the impact of rapid urbanization combined with economic growth on pollution, both in terms of theory and empirics (Liag et al., 2019; Grimm et al., 2008; Poumanyvong and Kaneko, 2010; Xu et al., 2021; Das et al., 2021; Das and Ivaldi, 2021;). Moreover, such argument, that is, urbanization affects pollution and environmental health significantly has been shown by Parshall et al. (2010) in case of USA and China. With special reference to China, Fang et al. (2015)

[1] For detail review of literature one can go through articles written by Dinda (2004) and Shahbaz and Sinha (2019).

establish the adverse effect of urbanization on pollution in terms of rapid increase in surface temperature on Earth, and also claims adverse effect on human health following the same reason. Similarly, Zeng et al. (2021) describe global worming mainly following massive carbon emission via the channel of fossil fuel consumption owing to different human activities. Again, in a similar study Hossain (2011) has claimed significant influence of urbanization on pollution in case of USA and newly industrialized countries. In a more recent work Akomolafe et al. (2021) have also shown similar significant impact of urbanization on carbon emission in case of an emerging economy like Nigeria. In an interesting study, Ribeiro et al. (2022) have described the effect of pollution and urbanization on chronic stresses in Brazilian birds. This study has shown that birds of urban area possess higher chronic stresses compared to rural area. Moreover, the adverse influence of urbanization on pollution via the energy consumption of fossil fuel-based solutions is also researched in the literature especially in case of developing and less developed economies (Al-Mulali et al., 2012; Xie et al., 2020; Yu et al., 2020). Furthermore, Al-Mulali et al. (2012), Sufeng et al. (2020) and Yu et al. (2020) have closely monitored the case of China and revealed that the pace of urbanization aggravated more labor supply, which in turn increases overall energy consumption and affects environment through carbon emissions. Li et al. (2020) take 30 provincial regions in Mainland China for the period of 2003–2016 as their reference. In this study Li et al. (2020) have claimed that sustainable urbanization in the presence of carbon emission can be achieved following the process rapid urbanization under reasonable carbon emission reduction regime. In addition to the earlier studies, Zhu et al. (2012) have used the data for twenty emerging economies around the world to check the possible nexus between urbanization and pollution and they have found an inverted U-curve association between carbon emission and urbanization. Again, Ali et al. (2017) have chosen Singapore for their study for a given span of 1970–2015 and claim the same adverse impact of urbanization on pollution and interestingly they have treated the Singapore's environmental policies as the main culprit behind the said nexus. In a recent study, Chen et al. (2022) incorporate China's regional coordination and green low-carbon development strategy to examine the association between industrial clustering and carbon emissions. To examine this, the study uses provincial panel data for the period 1998–2017, and the study claims improvement of industrial clustering can reduce the carbon emission via spatial functional division. Again, Lin et al. (2021) have shown that healthy urban design in the form of three-dimensional building structure can help the policymakers to restrict the emission of CO_2 in the environment, and through their experiment they have suggested to implement the said structure in an earlier stage of urbanization. However, in a similar study, Saidi and Mbarek (2017) have chosen nineteen emerging economies and suggest that there exist no significant association between urbanization and pollution, and specifically urbanization is not a responsible factor behind pollution. Similar finding has also been explored in panel study of 69 countries and the panel claims that there is no significant relationship between the said duos. Furthermore, Sridhar (2018) has also examined the association between urbanization and pollution in India's cities. The study has found no significant impact of urbanization on pollution. However, it has been suggested that the said association depends upon the city's urban form, and argued in favor of development of more compact cities in India.

2.3. Pollution and energy

Al-Mulali et al. (2012), Xie et al. (2020) and Yu et al. (2020) have established the negative effects of urbanization on carbon emission following increased consumption of fossil fuel-based energy in case of less developed economies. Waheed et al. (2018) have taken Pakistan as their case study and they have revealed that, even though agriculture out affects pollution adversely, however, uses of non-renewable energy affect pollution negatively. Similarly, in case of developed nations, the negative effect of green energy on pollution level owing to strict environmental regulations or policies has also been endorsed by Le et al. (2020). Dogan and Seker (2016) have chosen European Union for a span of 1980–2012 and explore pollution abatement mechanism in terms of reduction in carbon emission following the usage of green energy. Again, Cheng et al. (2019) have exercised the same objectives for BRICS nations during 2000–2013 and found that higher incorporation of green energy within energy basket reduces the volume of carbon emission. Furthermore, Nathaniel and Iheonu (2019) have found the existence of unidirectional causality running from green energy to carbon emission in case of African continent.

2.4. Urbanization, energy consumption and pollution

In case of China, it is evident that degree of urbanization insists labour suppliers to supply more labour hour and which in turn accelerate the overall energy consumption, and thereby affects environment adversely owing to more usage of carbon emission (Xiaoyang et al., 2022; Cui et al., 2019; Yu et al., 2020). In Pakistan's case, Ahmed and Long (2012) have explored the nexus between energy consumption, CO_2 emission and urbanization. For this study they have used cointegration analysis using auto regressive distributed lags bound testing approach for the period 1971–2008 and find that joint force of urbanization and energy affect pollution adversely. In a similar study with special reference to Pakistan, Nasir and Rehman (2011) have found energy consumption, rather than urbanization, to be a reason behind the increase in pollution levels. To obtain this result, they used the battery of Johansen method of cointegration for the period 1972–2008. Sahibzada (1993) has shown for developing nations that urbanization can affect environment in the following three ways, namely, through industrialization, transport and energy, and poverty. This study claims that policy realignment regarding pollution control occurs only due to significant presence of urbanization. Similarly, Dewan et al. (2012) take Bangladesh as their reference and have found an adverse influence of rapid urbanization on pollution via increased usage of fossil fuel-based solutions. Again, Silva et al. (2017) have illustrated that even though major proportion of energies are consumed by cities, and following the same cities are also responsible for more than 65 percentage of total GHG emission, however, better, and healthy urban planning can control the carbon emission. Wang et al. (2020, 2018) have also claimed similar set of results by analysing the association among urbanization, pollution and energy consumption. More precisely, Wang et al. (2020) have found the outcomes by employing a panel of 136 countries, whereas, Wang et al. (2018) have explained the association among the trios in presence of economic growth. Nematchoua et al. (2020) have shown that urban land use in terms of vertical building affects the energy consumption, and which in turn affects CO_2 emission. In this study author(s) have taken Madagascar as their reference area, and have suggested to implement better and efficient urban land use strategy to control carbon emission via energy consumption. In a similar context, Xu et al. (2020) explore that in case of emerging economies height of the highest skyscraper and the number of skyscrapers can't be used to foresee the uses of vertical building structure in order to tackle the carbon emission. Except Wang et al. (2018), none of the above-mentioned studies relate income with urbanization in the presence of issues such as carbon emission and fossil fuel-based energy consumption. However, Wang et al. (2018) have also missed the scope of analysing the co-movements between urbanization and income via the channel of energy consumption and pollution.

From the above review we find following lacunas in the existing literature. First, in simple words, studies relating income and pollution via the channel of energy consumption and urbanization is relatively scarce. Moreover, the presence of ambiguity within the pollution-income nexus also gives us a space to research the nexus in the presence of urbanization and energy consumption from fossil fuel. Second, the relationship between pollution and urbanization is not clear in the existing literature. Hence, to avoid such ambiguity, rigorous research is needed to explore the nexus between pollution and urbanization, and at the same time, the ways of causation between the duos is also needed to understand. Third, even though the above-mentioned literature review is clearly illustrated, the positive impact of green energy uses on pollution, however, how and in which way the co-movement between income and urbanization can be affected in the presence of overall energy use and pollution on top polluting nations have not been researched yet. The present article shall try to eliminate the gap. Finally, we find that apart from Wang et al. (2018), none of the prevailing studies relate income with urbanization in the presence of the issues such as carbon emission and fossil fuel-based energy consumption. Further the short-run dynamics inherent with the said association is also absent in the literature, and similarly, long-run analysis for top polluting nations is also less researched.

3. Theoretical underpinning

To have growth of an economy, it needs to analyze the role of urbanization (U) in its structural changes. At this very point we implicitly augment the role of economic expansion in terms of increase in GDP which attracts labour or civil society towards urban world. The preference may be due to either better standard of living owing to high income or following higher probability of getting urban jobs, however, it only generates the presence and potentiality of urbanization (Bechle et al., 2011; Hanif, 2018). It can be depicted as

$$U = U(Y); U/ > 0 \tag{1}$$

Again, amalgamation of economic expansion with urbanization leads to increase in demand for energy consumption (E). Moreover, non-renewable energy consumption exploits the environment adversely (Imai, 1997; Salim and Shafie, 2014). Following these arguments, we observe

$$E = f_E(U); f_E/ > 0, f_E^{//} < 0 \tag{2}$$

and

$$P = f_P(E); f_P/ > 0, f_P^{//} < 0 \tag{3}$$

In fact, rapid urbanization usually exploits the economy by means of rapid pollution (P) and equations (2) and (3) are also depicting the same (Das et al., 2021). Hence, mathematically we can express it as

$$P = P(U); P/ > 0, P^{//} < 0 \tag{4}$$

Expression (4) entails that as the urbanization increases it also exploits environment more aggressively. However, adaptation of green technology and other environment related measures enhances the possibility of decreasing the rate of exploitation of environment (Deqing et al., 2020). Equations (1) to (4) illustrates that economic expansion in terms of economic growth generates urbanization, and in turn, urbanization affects both E and P aggressively. Graphically we can explain the role of U on E and P in the following manner.

Fig. 1 explains that, for given Y (in figure it refers to Y_1), if U increases due to some exogenous shocks, then a leftward shift of U-Y schedule to $(U\text{-}Y)_2$ (explained in terms of equation (1)) will happen. As a consequence, we find an increase in pollution level (from P_1 to P_2) for a given level of Y. Therefore, it implies even if Y or level of economic expansion remains unchanged, after initial level of economic growth P may increase owing to urbanization and following equation (2) energy consumption may also rise (E_1 to E_2) from U. From the other side of the coin we find that such increase in E and P following U may enhance the Y indirectly (in the figure it is illustrated in terms of Y_3), that is, in order to enjoy the dividend from natural resources, economies may pursue higher growth trajectory (Dinda, 2004). It can be expressed in terms of following equation.

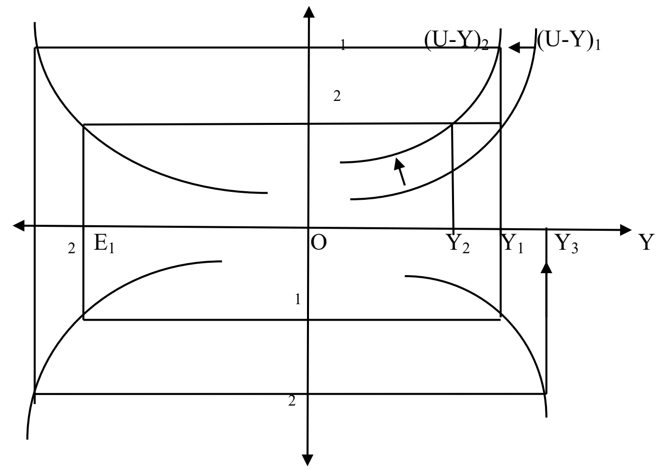

Fig. 1. Interrelationships among Y, U, E and P. Source: Sketched by the authors.

$$Y = Y(E, P); Y_E/ > 0, Y_P/ > 0 \tag{5}$$

Again, equation (2) and (4) give us the scope to rewrite equation (5) in the following form

$$Y = \psi(U); \psi/ > 0 \tag{6}$$

Equation (6) is the inverse form of equation (1) with which we have started our theoretical understanding. It shows both way causality and interrelationships among Y, E, U and P, which is rational from the angle of the above theory. In the next sub-section we take care of it from the angle of empirical analysis.

3.1. Data and empirical methodology

The study uses four variables, namely, urbanization, GDP (or income), energy use and GHG emissions. Urbanization is measured by the total number of urban population measured in lacs. There are several criteria of urbanization depending upon the laws/acts of different countries; thus a general consensus is difficult to make. We have followed a popular work of Tacoli (2015) where total number of urban population has been considered as the indicator of urbanization. GDP is the proxy of income measured in billion USD at constant 2015 prices (GDP and income will thus be used interchangeably in the entire paper), energy use is measured in billion Kg of oil equivalent by the urban people, and GHG emissions are measured by Kt of CO2 equivalent as measured by the World Bank. The data of all the variables are collected from the World Bank database (www.worldbank.org) for the world's top 20 polluting countries. The selection of the number of countries are on the basis of the total pollution generated by these top 20 countries. The target of reducing GHGs by the 2030 is mostly surrounded by these countries. These countries also contribute hugely to the world's total urban population and energy uses.

As the purpose of the study is not to compare the four indicators across the countries but only to see their trends over the time and to make comparisons across the indicators in a same country, the units of the said indicators are not standardized to any common unit to avoid changes in the natures of the indicators without making the loss of generality. The large values of the indicators on GDP, energy use and population have been converted into some bigger units as mentioned above.

To do time series econometric analysis for the existence of long run relations among the variables it is desirable to have long length data set as far as possible. Since the data on GHG are available from 1970's for all the listed countries of the study, we focused on data from 1970 (as starting year of study) to 2018 (the latest data available at that moment).

The highly 11 polluting developed countries in the group of 20 are USA, Canada, UK, Germany, France, Italy, Japan, Australia, Saudi Arabia, South Korea and Poland. On the other hand, the highly 9 polluting developing countries in the group are China, India, Russia, Brazil, Indonesia, South Africa, Mexico, Turkey and Iran.

Since there are long lengths of the four data series it is a common phenomenon that the series will be nonstationary in nature. It is thus required to test for stationarity or unit roots of the four series for all the selected countries to avoid any sort of spurious results. We have tested for the unit roots by Augmented Dickey-Fuller (ADF) (1979) by following a linear regression set up,

$$\Delta y_t = \alpha + \delta t + \beta y_{t-1} + \sum_{j=1}^{p} \gamma_j \Delta y_{t-j} + u_t \tag{7}$$

If β = 0 is rejected by the ADF statistic then we say that the series is stationary. If this property holds for all the four indicators then we can run regression without the chances of getting spurious results. If not, we need to test whether the series are integrated of order one (I(1)) or first difference stationary. If we get the result that all the series are I(1) (that is integrated of same order), or nonstationary at levels then we can test for cointegration between the series to establish long run associations. Since we have four endogenous variables we can run vector auto regression (VAR) model and if we find cointegration among them then we apply vector error correction model (VECM). If VECM provides usual signs and statistically significant results then there are long run causal influences running from any three independent endogenous variables to any one rest dependent endogenous variable. Also we test for short run causal interplay among the four variables in line with the Wald test. If we get significant causality results then we test for the fitness of the model. We test for residuals to justify whether there is any serial correlation exists among the error terms Jarque-Bera test. A high value of probability in each of the investigations indicates that the null hypothesis is accepted and the errors qualify all the diagnostic checking.

The structure of the VAR model for four endogenous variables, urbanization (URB), GDP, energy use (ENR) and GHG emissions (GHG) is as follows-.

$$URB_t = \alpha_1 + \sum_{j=1}^{n}\beta_{1j}URB_{t-j} + \sum_{j=1}^{n}\gamma_{1j}GDP_{t-j} + \sum_{j=1}^{n}\delta_{1j}ENR_{t-j} + \sum_{j=1}^{n}\theta_{1j}GHG_{t-j} + u_{1t} \tag{8}$$

$$GDP_t = \alpha_2 + \sum_{j=1}^{n}\beta_{2j}URB_{t-j} + \sum_{j=1}^{n}\gamma_{2j}GDP_{t-j} + \sum_{j=1}^{n}\delta_{2j}ENR_{t-j} + \sum_{j=1}^{n}\theta_{2j}GHG_{t-j} + u_{2t} \tag{9}$$

$$ENR_t = \alpha_3 + \sum_{j=1}^{n}\beta_{3j}URB_{t-j} + \sum_{j=1}^{n}\gamma_{3j}GDP_{t-j} + \sum_{j=1}^{n}\delta_{3j}ENR_{t-j} + \sum_{j=1}^{n}\theta_{3j}GHG_{t-j} + u_{3t} \tag{10}$$

$$GHG_t = \alpha_4 + \sum_{j=1}^{n}\beta_{4j}URB_{t-j} + \sum_{j=1}^{n}\gamma_{4j}GDP_{t-j} + \sum_{j=1}^{n}\delta_{4j}ENR_{t-j} + \sum_{j=1}^{n}\theta_{4j}GHG_{t-j} + u_{4t} \tag{11}$$

where α_1, β_{1j}, γ_{1j}, δ_{1j}, θ_{1j}stand for the intercept and slope coefficients when URB is the dependent endogenous variable. The notations with numbers will change accordingly from 2 to 4 for GDP, ENR and GHG as the dependent endogenous variables. Once the optimum lag is selected then the VAR model will have to be modified.

Using the four variables the study uses Johansen technique for investigating the existence of cointegration among the four for the study period. Once it is tested that the series are cointegrated, we will go for modelling the VECM. VECM is a restricted VAR model and it has cointegrating relation built into the specification so that it restricts the long run behaviours of the endogenous variables to converge to their long run equilibrium relations while allowing for the short run dynamics. The cointegrating term is the error correction (EC) term. Here the primary task is to add estimated error terms with lagged values as the error correction terms in the set of VAR equations. The VECM is given by the following set of equations-

$$\Delta URB_t = \alpha_1 + \sum_{j=1}^{n}\beta_{1j}\Delta URB_{t-j} + \sum_{j=1}^{n}\gamma_{1j}\Delta GDP_{t-j} + \sum_{j=1}^{n}\delta_{1j}\Delta ENR_{t-j} + \sum_{j=1}^{n}\theta_{1j}\Delta GHG_{t-j} + \sum_{i=1}^{m}\eta_{1i}\widehat{e_{1,t-i}} + \varepsilon_{1t} \tag{12}$$

$$\Delta GDP_t = \alpha_2 + \sum_{j=1}^{n}\beta_{2j}\Delta URB_{t-j} + \sum_{j=1}^{n}\gamma_{2j}\Delta GDP_{t-j} + \sum_{j=1}^{n}\delta_{2j}\Delta ENR_{t-j} + \sum_{j=1}^{n}\theta_{2j}\Delta GHG_{t-j} + \sum_{i=1}^{m}\eta_{2i}\widehat{e_{2,t-i}} + \varepsilon_{2t} \tag{13}$$

$$\Delta ENR_t = \alpha_3 + \sum_{j=1}^{n}\beta_{3j}\Delta URB_{t-j} + \sum_{j=1}^{n}\gamma_{3j}\Delta GDP_{t-j} + \sum_{j=1}^{n}\delta_{3j}\Delta ENR_{t-j} + \sum_{j=1}^{n}\theta_{3j}\Delta GHG_{t-j} + \sum_{i=1}^{m}\eta_{3i}\widehat{e_{3,t-i}} + \varepsilon_{3t} \tag{14}$$

$$\Delta GHG_t = \alpha_4 + \sum_{j=1}^{n}\beta_{4j}\Delta URB_{t-j} + \sum_{j=1}^{n}\gamma_{4j}\Delta GDP_{t-j} + \sum_{j=1}^{n}\delta_{4j}\Delta ENR_{t-j} + \sum_{j=1}^{n}\theta_{4j}\Delta GHG_{t-j} + \sum_{i=1}^{m}\eta_{4i}\widehat{e_{4,t-i}} + \varepsilon_{4t} \tag{15}$$

where $\widehat{e_{t-i}}$ is the lagged value of the estimated residuals and η $\widehat{e_{t-i}}$ is the error correction term. 'η' indicates coefficient of EC, the rate of adjustment. It is desirable to be negative and statistically significant to establish the long run associations among the variables. Further, a negative and significant 'η' signifies long run causality.

Short run causality, say in equation (13), from GDP, ENR and GHG to URB can be examined on the basis of null hypothesis, H_0: $\gamma_{1j} = \delta_{1j} = \theta_{1j} = 0$. If the null hypothesis is accepted with probability values less than 0.05 then there is no causality running from GDP, ENR and GHG to URB. Wald test ensures the results.

4. Analysis of empirical results

4.1. Descriptive statistics

Before entering to the rigorous econometric exercises in order to investigate the co-movements between income (measured in GDP) and urbanization (measured in total number of urban population) through the energy use and GHGs emission the study presents the trends of the variables in diagrams (Figs. 2 to 5) and then presents the principal measures of descriptive statistics, the mean and standard deviation (SD), for the entire period of study (Table 1).

In Fig. 2 it is observed that the trends of GHGs were rising in the first phase (up to 1990′s) and then falling. Mostly the developed countries in the list had these features. But for the developing economies there are rising trends in the GHG emissions levels. China is the leader in this respect.

The magnitude of urbanization as measured by the number of urban population is also increasing for all the countries in the list (Fig. 3). China is the leader followed by India.

With respect to energy use, Fig. 4 shows that all the countries are using it at the rising levels. USA and China are the leaders in this head followed by Russia. Iran is at the bottom level.

It is observed from Fig. 5 that the trends of GDP at the constant prices are rising for all the countries in the list with USA being the leader followed by China, Japan etc. Here again Iran is in the bottom level. All the four diagrams provide scattered information on the four variables. To get some concrete statistical figures the study goes for presenting descriptive statistics.

Regarding the descriptive statistics, with respect to GDP, the highest average value is for UK followed by USA and the lowest value is for S. Africa followed by Poland. On the other hand, the variance measured in

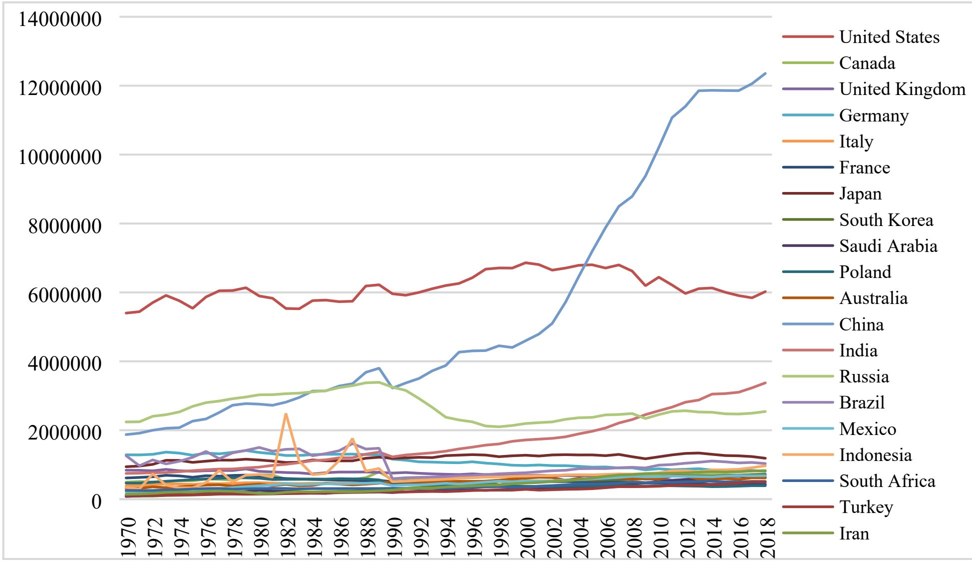

Fig. 2. Trends of GHGs emissions of the countries (in kt of CO2 equivalent). Source: Drawn by the authors.

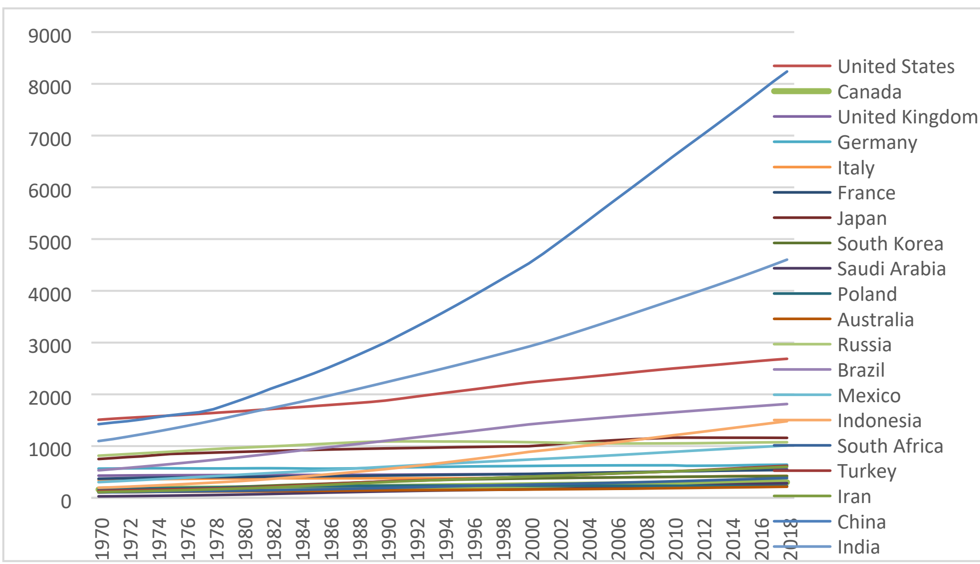

Fig. 3. Trends of urban population of the countries (in lacs). Source: Drawn by the authors.

SD is the maximum for India followed by USA and the minimum variance is for S Africa followed by Iran.

For Urbanization, the maximum average urban people are in China followed by India as the total number of populations in these two countries are much higher compared to the rest of the countries in the list and minimum average urban people is in Poland followed by Australia. But in percentage form, the highest rates of urbanizations are for the developed countries (of around 78%) and moderate in case of the developing countries (of around 48%). Hence, there is a positive association between average volume of GDP and average rate of urbanization in the selected countries. There are highest variations in the urban populations for China and India as well.

With respect to the average figure of energy use, the maximum value is for China followed by USA, and the minimum value is for Poland followed by Turkey. The variations or fluctuations are also highest for China and USA. Finally, with respect to GHG emissions, the maximum average value is for USA followed by China and the minimum average value is for Turkey followed by S Africa. But the maximum variations in GHG emissions are observed for the countries from the developing block.

The information as given in Table 1 show that USA leads the list in terms of mean values of GDP, GHGs and energy use followed by China, but in terms of urbanization, China leads the countries followed by India as their total population figure are very high. The variations in GHGs and urbanization are highest for China followed by the USA. The table thus depicts the associations among the four selected variables for the countries in both the developed and developing blocks. It thus provokes us to investigate through empirical exercise whether these variables have some long run and short run relationships in these two groups of countries.

4.2. Unit root test results

Since the data length is very long, the movements of the concerned variables over time will have the high probability of being non stationary in nature. The study, thus, has tested the stationarity of the series

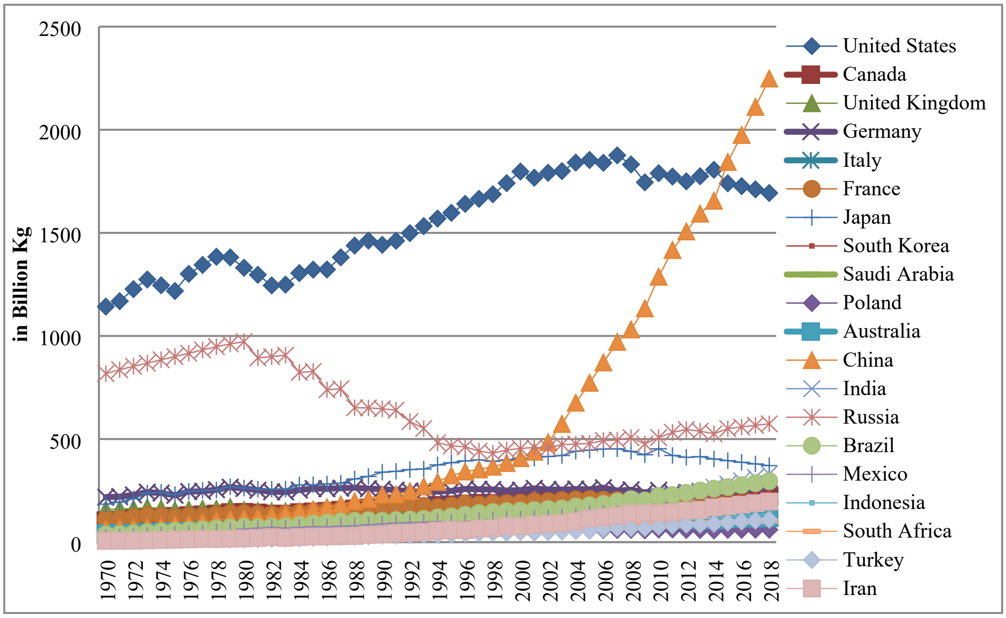

Fig. 4. Trends of total energy use (in billion kg) of the countries. Source: Drawn by the authors.

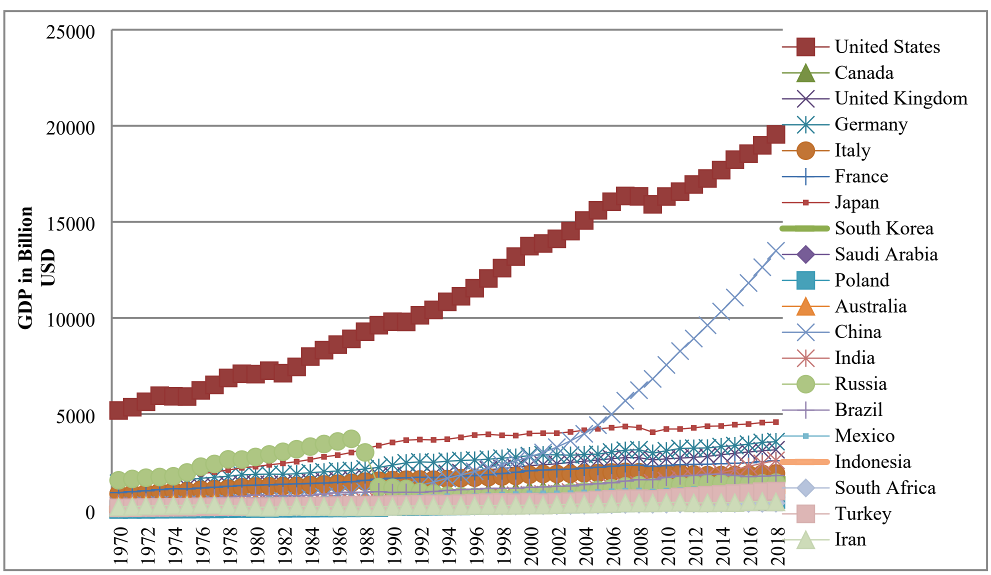

Fig. 5. Trends of GDP (billion USD) of the countries. Source: Drawn by the authors.

using ADF test. The results show that the concerned four series are non-stationary at their levels across all the twenty countries. However, many of the series for some countries are stationary when their first differences are taken. But the remaining series are stationary at the second differences. Table 2 shows the unit root test results.

All the four series are I(1) for Canada, UK, Germany, Italy, France, Japan, S Arabia, Australia, China, Brazil and Iran. For the remaining nine countries, not all the four series at a time are I(1), rather some of them are I(2). Therefore, the study has converted all of these I(1) series to I(2) to make parity in the orders of integrations to do the econometric exercises for these ten countries.

4.3. Cointegration test results

In order to investigate whether the four variables, GDP, urbanization, energy use and GHG emissions, maintain long run relationships for the period of study, the study uses Johansen cointegration technique and presents those results where cointegration is found. The results are given in Table 3.

It is observed that all the four series are cointegrated for eleven countries. There is at least one cointegrating equation involving the four variables for all these eleven countries which are mainly developed in nature. Out of the countries from the group of the developing nations the results for the world's two highly populated countries, China and India, are important to mention here. The overall urbanization process in these countries, not related to any cities therein, has got tremendous boost due to their outstanding performance in increasing their GDPs and as a result, the volume of energy use and environmental pollution got increased strikingly. It is claimed that economic growth promotes the expansion of modern industries and an increase in the urban population; in turn, urbanization also promotes economic growth to some extent (Chen et al., 2014). Besides, the level and pace of urbanization in a country depend on the urban–rural income gaps or income inequality (Ha et al., 2019). Once there is such inequality there will be the scopes of

Table 1
Mean and SD of the variables across countries.

Developed Countries					Developing Countries				
Country	GHGs	Urban	Energy	GDP	Country	GHGs	Urban	Energy	GDP
USA	6,134,747	2055	1546	11,541	China	5,439,570	4025	580	3383
	(413492)	(376)	(230)	(4426)		(3457406)	(2143)	(626)	(3832)
Canada	631,361	227	175	830	India	1,643,519	2617	119	824
	(73183)	(41)	(37)	(494)		(771149)	(1041)	(84)	(6643)
UK	708,839	468	162	2010	Russia	2,635,846	1023	649	1656
	(111747)	(35)	(10)	(633)		(374165)	(785)	(183)	(887)
Germany	1,102,161	597	248	2468	Brazil	1,043,306	1204	138	1098
	(193508)	(26)	(11)	(637)		(282585)	(402)	(73)	(443)
Italy	474,026	384	99	1548	Mexico	479,260	654	96	734
	(44778)	(19)	(16)	(355)		(139753)	(209)	(40)	(279)
France	540,318	450	169	1771	Indonesia	745,926	735	52	386
	(80223)	(49)	(30)	(498)		(346521)	(404)	(41)	(257)
Japan	1,193,163	990	342	3348	S Africa	367,667	224	57	217
	(94444)	(122)	(80)	(990)		(87829)	(84)	(24)	(74)
S Korea	385,950	313	107	654	Turkey	252,165	353	42	395
	(210323)	(93)	(80)	(496)		(112329)	(146)	(29)	(242)
S Arabia	310,621	142	75	369	Iran	421,340	343	71	264
	(164476)	(75)	(61)	(144)		(235167)	(151)	(58)	(87)
Poland	464,202	221	61	228					
	(91226)	(19)	(84)	(154)					
Australia	502,408	154	79	778					
	(101478)	(30)	(22)	(343)					

Notes: Mean and SD of GDP are in billion USD; population in lacs and energy use in billion kg. Figures in the parentheses are for standard deviations.
Source: Authors' own calculations.

Table 2
Unit root test results for all the four indicators at their first differences.

Developed Countries					Developing Countries				
Country	ADF(Prob) GHGs	ADF(Prob) Urban	ADF(Prob) Energy	ADF(Prob) GDP	Country	ADF(Prob) GHGs	ADF(Prob) Urban	ADF(Prob) Energy	ADF(Prob) GDP
USA	−6.26(0.00)	−4.1(0.00)*	−5.25(0.00)	−4.36(0.00)	China	−4.56(0.00)	−5.23(0.00)	−3.99(0.03)	−6.35(0.00)
Canada	−8.32(0.00)	−5.46(0.00)	−6.07(0.00)	−5.37(0.00)	India	−5.3(0.00)*	−5.6(0.00)*	−5.3(0.00)*	−7.5(0.00)*
UK	−8.73(0.00)	−3.31(0.00)	−7.95(0.00)	−4.54(0.00)	Russia	−3.05(0.05)	−3.6(0.01)*	−2.92(0.05)	−4.52(0.00)
Germany	−6.91(0.00)	−3.49(0.00)	−8.12(0.00)	−6.50(0.00)	Brazil	−8.12(0.00)	−3.05(0.05)	−9.06(0.00)	−4.89(0.00)
Italy	−5.47(0.00)	−3.15(0.00)	−3.18(0.00)	−4.91(0.00)	Mexico	−7.53(0.00)	−3.9(0.00)*	−6.39(0.00)	−6.41(0.00)
France	−7.45(0.00)	−2.96(0.00)	−7.52(0.00)	−5.23(0.00)	Indonesia	−7.05(0.00)	−6.4(0.00)*	−5.26(0.00)	−3.03(0.03)
Japan	−5.64(0.00)	−2.96(0.05)	−6.13(0.00)	−5.28(0.00)	S Africa	−7.09(0.00)	−3.1(0.04)*	−6.38(0.00)	−4.18(0.00)
S Korea	−6.61(0.00)	−5.7(0.00)*	−6.27(0.00)	−5.06(0.00)	Turkey	−6.76(0.00)	−4.1(0.00)*	−5.08(0.00)	−4.67(0.00)
S Arabia	−5.18(0.00)	−2.93(0.04)	−2.96(0.05)	−5.35(0.00)	Iran	−3.93(0.00)	−2.99(0.04)	−8.14(0.00)	−4.65(0.00)
Poland	−4.81(0.00)	−9.9(0.00)*	−4.97(0.00)	−7.08(0.00)					
Australia	−7.93(0.00)	−4.63(0.02)	−7.63(0.00)	−3.40(0.01)					

Note: * marks are for second difference stationary results.
Source: Authors' own calculations.

more urbanization. The situation fits well for China and India where the huge economic growths led to increasing income inequalities during the phase of globalization (Bardhan, 2007; Bhaduri, 2008). The relations show that the key variables of urbanization effect due to GDP growth, energy use and pollution, have long run associations for the period of study. The economies' expansion leading to GDP increase influences people to move to urban areas, and making use of more energy and generating its related by-product, GHG emission, to move side by side. Hence, the goal of sustainable development could be hard to achieve if the long run associations between the four would not be broken.

4.4. VECM test results

Existence of long run associations among the four variables does not necessarily mean that there should not be any sort of dynamics in the short run around the equilibrium relation. If there arises any such deviation from the equilibrium, which is called the error in the long run relation, then it is required to test whether the error is corrected shortly or the error prevails perpetually. If the first one happens then it is called 'error is temporary and the series converge to the original long run relation', and on the other hand, for the second situation, it is called 'error is permanent and the series diverge from the original long run relation'. Having four variables with optimum lag intervals VECM captures this phenomenon for analysing short run dynamics and finds out the coefficient of the error component with its statistical significance values. A negative and statistically significant value of the error term justifies convergent result. Besides, it demonstrates the existence of long run causality from the set of three exogenous variables to the one endogenous variable. The results are given in Table 4. The study makes the VECM for the nine countries having significant cointegration results excepting Germany.

The results show that there are six countries, Canada, UK, S Arabia, Australia, China and Iran, where the errors are not corrected, making the deviation away from the long run relation. Also there are no causal relations in the long run from any of the group of three variables to the rest one in these five countries.

On the other hand, there are five countries in the list where significant error corrections happened in some ways. In case of Italy, France and Japan, the errors are corrected significantly when energy use and GHG emissions play the role of dependent endogenous variables. This means, GDP, Urbanization and GHG emissions make a cause to energy use in the long run, and, GDP, Urbanization and energy use make a cause

Table 3
Johansen Cointegration test results.

Country	HypothesizedNo. of CE (s)	Trace Statistics (Prob)	Remarks
Canada	None *	73.655(0.00)	Variables are cointegrated and there are 2 cointegrating equations at 0.05 level
	At most 1 *	29.79(0.00)	
UK	None *	50.25(0.02)	Variables are cointegrated and there is1cointegrating equation at 0.05 level
	At most 1	25.03(0.16)	
Italy	None *	50.25(0.02)	Variables are cointegrated and there is1cointegrating equation at 0.05 level
	At most 1	25.03(0.16)	
France	None *	51.05(0.02)	Variables are cointegrated and there is1cointegrating equation at 0.05 level
	At most 1	24.71(0.17)	
Japan	None *	61.27(0.00)	Variables are cointegrated and there are2cointegrating equations at 0.05 level
	At most 1 *	34.21(0.01)	
S. Arabia	None *	52.37(0.01)	Variables are cointegrated and there is1cointegrating equation at 0.05 level
	At most 1 *	26.36(0.11)	
Australia	None *	67.63(0.00)	Variables are cointegrated and there are2cointegrating equations at 0.05 level
	At most 1 *	37.53(0.00)	
China	None *	57.93(0.00)	Variables are cointegrated and there is 1 cointegrating equation at 0.05 level
	At most 1 *	22.05 (0.29)	
India	None *	58.85 (0.00)	Variables are cointegrated and there is 1 cointegrating equation at 0.05 level
	At most 1 *	28.55 (0.06)	
Brazil	None *	69.63(0.00)	Variables are cointegrated and there is1cointegrating equation at 0.05 level
	At most 1	28.53(0.07)	
Iran	None *	63.63(0.00)	Variables are cointegrated and there are2cointegrating equations at 0.05 level
	At most 1 *	36.53(0.00)	

Note: * mark denotes rejection of the 'no cointegration' hypothesis at the 0.05 level.
Source: Author's own calculations.

to GHG emissions in these three countries. There are co-movements as well as causal relations among the concerned variables for these three countries. GDP, Urbanization and GHG emissions play the role of demand following factors which influence energy use, and GDP, Urbanization and energy use become the supply leading factors which lead to more GHG emissions. The behaviours of the time series variables are however seemed similar in these three developed countries. This particular part of the results points out that the sustaining economic growth pattern is directly or indirectly responsible for the rise in GHG emissions in these three nations. This piece of the empirical evidence reverberates with the outcomes of Koengkan (2018), Zafar et al. (2019) and Das et al. (2021). But for Brazil, there are one way causal relations in the long run which justifies significant error corrections as well. Urbanization in Brazil is caused by the combined effects of the two years' lagged values of the interlinked variables, GDP, energy use and GHG emissions. This evidence partially suggests that persisting demand pattern through growth and corresponding incorporations of both high end GHG emissions and energy uses can push the flow of urbanization further in developing countries. Again, this outcome echoes with the results of Saidi and Mbarek (2017), Das et al. (2021) and Zafar et al. (2021). But there is an all-possible results of error corrections as well as long run causal relations in case of India. All the four variables acting as the endogenous dependent variables are getting caused by the remaining three sets of independent endogenous variables. For example, GHGs in India is caused by GDP, urbanization and energy use; energy use gets caused by GDP, urbanization and GHGs, etc. Once the economy expands by means of GDP, tendency of more urbanization increases leading to more energy use which ultimately emit more GHGs in the air. Hence, economic expansion may be a threat to the environment. The results go in part with that of Saidi and Mbarek (2017), Das et al. (2021) and Zafar et al. (2021), though it slightly differs to that of Sridhar (2018) because of the differences in the variable selections and spatial representations in the studies.

4.5. *Short run causality test results*

Even if there are the presence or absence of long run associations among the variables, there can have short run causal interplays among the variables. Here the VAR model is estimated using the four variables using optimum lags. Once the model is estimated block exogeneity test (or Wald test) is carried out to find the effect or influence of the combined three variables with their optimum lags upon the current value of the rest one variable behaving as endogenous dependent variable. Table 5 depicts the results.

The results show that there are five countries in the list where there are no causal interplays observed in the short run. They are France, Japan, China, India and S Africa. The four variables are not with significant interplay relations in these countries.

Energy use is caused by GDP, urbanization and GHG in case of Canada, UK, Italy, S Arabia, Poland, China and Mexico, the countries are mainly developed in nature. Again, GHG emission is influenced by GDP, urbanization and energy use in case of Germany, Poland, Mexico and Turkey. GDP is caused by GHG, urbanization and energy use for UK, Australia, Russia, China, Mexico and Iran. For China, the study does not find any short run stable dynamics around the long run relation, though there are certain causal interplays in the short run. GHG emission in China is not caused by urbanization and other two variables even in the short run. This finding is in line of Sridhar (2018) if we consider that development of compact cities dominates over the sprawl for a nation. Further, urbanization is caused by GDP, energy use and GHG for USA, Germany, Italy, Poland, Russia, Brazil and Indonesia. Finally, there is only one country, S. Korea, where each of the three variables re making a cause to the rest one dependent variable. For this country, the true interlinkage effects are observed. But for India, having a good level of urbanization and income generating activities like China, there is no causal interplay in the short run; its ambient air quality degradation cannot be blamed by growing urbanization like the countries such as Germany, Poland, etc. There are the instances of low per capita GDP, energy use and urban area out of total land, and relatively more greeneries in case of China and India which lead to the non-influential GHG emissions.

4.6. *Discussions and policy caveats*

From the above results we obtain two specific categories of ways of causations, one belongs to the long-run activities and the second one tells us the story of short-run. In long-run, we find that in case of selected developed countries, that is, Italy, France and Japan, and developing countries like China and India, GDP, Urbanization and GHG emissions play the role of demand following factors which influence energy use.

Table 4
Long run causality test results through VECM.

Country (Optimum lag)	Dependent Variables	Independent Variables	EC term(η)	Prob.	Remarks
	GDP	Remaining three	1.787	0.05	No LR causality
Canada (2)	Urbanization	Remaining three	0.0000	0.85	No LR causality
	Energy	Remaining three	0.271	0.002	No LR causality
	GHGs	Remaining three	0.000	0.01	No LR causality
	GDP	Remaining three	1.093	0.003	No LR causality
UK (3)	Urbanization	Remaining three	0.0000	0.81	No LR causality
	Energy	Remaining three	0.098	0.04	No LR causality
	GHGs	Remaining three	0.0000	0.75	No LR causality
Italy (2)	GDP	Remaining three	−3.726	0.07	No LR causality
	Urbanization	Remaining three	1.69	0.03	No LR causality
	Energy	Remaining three	−0.88	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	−0.000002	0.04	GDP, URB, ENG → GHG
France (2)	GDP	Remaining three	−0.163	0.65	No LR causality
	Urbanization	Remaining three	2.51	0.53	No LR causality
	Energy	Remaining three	−0.553	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	−0.000001	0.04	GDP, URB, ENG → GHG
Japan (2)	GDP	Remaining three	−0.008	0.68	No LR causality
	Urbanization	Remaining three	−0.000001	0.63	No LR causality
	Energy	Remaining three	−0.024	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	−0.000004	0.04	GDP, URB, ENG → GHG
S Arabia (3)	GDP	Remaining three	−0.207	0.08	No LR causality
	Urbanization	Remaining three	0.000003	0.67	No LR causality
	Energy	Remaining three	0.050	0.02	No LR causality
	GHGs	Remaining three	0.000002	0.01	No LR causality
Australia (1)	GDP	Remaining three	0.71	0.00	No LR causality
	Urbanization	Remaining three	0.000003	0.00	No LR causality
	Energy	Remaining three	0.033	0.44	No LR causality
	GHGs	Remaining three	0.000001	0.02	No LR causality
China (2)	GDP	Remaining three	0.26	0.00	No LR causality
	Urbanization	Remaining three	0.007	0.43	No LR causality
	Energy	Remaining three	0.157	0.02	No LR causality
	GHGs	Remaining three	0.04	0.66	No LR causality
India (2)	GDP	Remaining three	−2.08	0.02	ENG, GHG,URB → GDP
	Urbanization	Remaining three	−0.00002	0.00	GDP, ENG, GHG → URB
	Energy	Remaining three	−0.33	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	−0.00004	0.05	GDP, URB, ENG → GHG
Brazil (2)	GDP	Remaining three	0.09	0.79	No LR causality
	Urbanization	Remaining three	−0.000002	0.00	GDP, ENG, GHG → URB
	Energy	Remaining three	0.07	0.03	No LR causality
	GHGs	Remaining three	0.000009	0.57	No LR causality
Iran (2)	GDP	Remaining three	0.38	0.00	No LR causality
	Urbanization	Remaining three	0.000006	0.71	No LR causality
	Energy	Remaining three	−0.03	0.11	No LR causality
	GHGs	Remaining three	0.000001	0.03	No LR causality

Source: Authors' own calculations.

Again, GDP, Urbanization and energy use become the supply leading factors which lead to more GHG emissions for the same set of countries. This particular piece of the result indicates that the sustaining economic growth pattern is directly or indirectly responsible for the rise in GHG emissions in these three nations. But there are all four possible results of long run causal relations in case of India. All the four variables acting as the endogenous dependent variables are getting caused by the remaining three sets of independent endogenous variables. The problem of urbanization, though earlier faced by the so called developed countries of the world, is now becoming the headache to the highly developing countries like China and India due to their incapability of managing the urban–rural income gaps which appeared after the phase of globalization. Huge number of rural people have shifted their earning venues from the rural to the urban areas, the density of slum population increased, energy uses as well as GHG emissions got increased as the resultant. The results thus do not resemble to the study of Sridhar (2018) in respect of China and India.

However, in case of Brazil, there are one-way causal relations in the long run which justifies significant error corrections as well. Urbanization in Brazil is caused by the combined effects of the two years' lagged values of the interlinked variables, GDP, energy use and GHG emissions. This fact moderately suggests that persisting demand pattern through growth and corresponding incorporations of both high end GHG emissions and energy uses can push the flow of urbanization further in developing countries. Again, in the short run, we find multiple ways of causation following the structure of each cross-section and hence, country-specific policy realignment is quite important for both long-run and short-run. Depending upon the ways of causation we categorically divide policy options into four forms for different nation. Each panel of following representation (Fig. 6) describes a policy option and we explain as follows. Panel A explores the influence of GDP (or Y), urbanization (or U) and GHG emission (or P) on energy uses (or E), and under such background policymakers of such economies must provide more attention towards sustainable energy consumption. In fact, without making harm on persisting growth path, policy makers should convince the lawmakers to move on the path of sustainable development through the channel of high-end uses of green energy and less uses of fossil-fuel based energy. We refer such policy option as Policy A. Again, from panel b we see that, if P is caused by Y, U and F, policy makers must impose strict environmental regulations either in terms of taxes or standards in order to control the environmental damage by maintaining the trajectory of sustainable development. We label such policy option as Policy B. Similarly, if Y is influenced by U, P and E, growth specific policy realignment is needed via inclusiveness and green technology and we call such policy realignment in terms of Policy C. Moreover, the fourth policy option is labeled as Policy D. The policy D should be

Table 5
Short run causality test results (Wald test).

Country (Optimum lag)	Dependent Variables	Independent Variables	Chi Square Value	Prob.	Remarks
USA*	GDP	Remaining three	2.468	0.480	No SR causality
	Urbanization	Remaining three	7.768	0.051	GDP, ENG, GHG → URB
	Energy	Remaining three	3.722	0.293	No SR causality
	GHGs	Remaining three	4.035	0.257	No SR causality
Canada (2)	GDP	Remaining three	13.34	0.147	No SR causality
	Urbanization	Remaining three	5.564	0.473	No SR causality
	Energy	Remaining three	15.72	0.01	GDP, URB, GHG → ENG
	GHGs	Remaining three	5.478	0.485	No SR causality
UK (3)	GDP	Remaining three	15.032	0.001	URB, ENG, GHG → GDP
	Urbanization	Remaining three	8.723	0.46	No SR causality
	Energy	Remaining three	24.39	0.003	GDP, URB, GHG → ENG
	GHGs	Remaining three	13.51	0.14	No SR causality
Germany (2)	GDP	Remaining three	3.316	0.768	No SR causality
	Urbanization	Remaining three	14.02	0.02	GDP, ENG, GHG → URB
	Energy	Remaining three	10.62	0.103	No SR causality
	GHGs	Remaining three	27.31	0.001	GDP, URB, ENG → GHG
Italy (2)	GDP	Remaining three	6.55	0.36	No SR causality
	Urbanization	Remaining three	14.35	0.02	GDP, ENG, GHG → URB
	Energy	Remaining three	14.95	0.02	GDP, URB, GHG → ENG
	GHGs	Remaining three	6.06	0.41	No SR causality
France (2)	GDP	Remaining three	1.97	0.92	No SR causality
	Urbanization	Remaining three	4.54	0.60	No SR causality
	Energy	Remaining three	4.439	0.61	No SR causality
	GHGs	Remaining three	5.68	0.45	No SR causality
Japan (2)	GDP	Remaining three	1.016	0.98	No SR causality
	Urbanization	Remaining three	7.30	0.29	No SR causality
	Energy	Remaining three	10.02	0.12	No SR causality
	GHGs	Remaining three	5.98	0.42	No SR causality
S Korea (2)*	GDP	Remaining three	21.69	0.00	URB, ENG, GHG → GDP
	Urbanization	Remaining three	18.96	0.00	GDP, ENG, GHG → URB
	Energy	Remaining three	19.14	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	20.33	0.00	GDP, URB, ENG → GHG
S Arabia (3)	GDP	Remaining three	9.48	0.39	No SR causality
	Urbanization	Remaining three	15.66	0.07	No SR causality
	Energy	Remaining three	21.54	0.01	GDP, URB, GHG → ENG
	GHGs	Remaining three	13.54	0.13	No SR causality
Poland (2)*	GDP	Remaining three	10.84	0.09	No SR causality
	Urbanization	Remaining three	16.20	0.01	GDP, ENG, GHG → URB
	Energy	Remaining three	18.29	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	32.59	0.00	GDP, URB, ENG → GHG
Australia (1)	GDP	Remaining three	8.34	0.05	URB, ENG, GHG → GDP
	Urbanization	Remaining three	5.01	0.17	No SR causality
	Energy	Remaining three	1.59	0.66	No SR causality
	GHGs	Remaining three	1.98	0.92	No SR causality
China (1)	GDP	Remaining three	12.27	0.05	URB, ENG, GHG → GDP
	Urbanization	Remaining three	6.37	0.38	No SR causality
	Energy	Remaining three	14.70	0.02	GDP, URB, GHG → ENG
	GHGs	Remaining three	6.15	0.40	No SR causality
India* (2)	GDP	Remaining three	6.59	0.39	No SR causality
	Urbanization	Remaining three	10.23	0.11	No SR causality
	Energy	Remaining three	7.47	0.28	No SR causality
	GHGs	Remaining three	6.57	0.36	No SR causality
Russia* (1)	GDP	Remaining three	10.95	0.01	URB, ENG, GHG → GDP
	Urbanization	Remaining three	18.71	0.00	GDP, ENG, GHG → URB
	Energy	Remaining three	3.16	0.36	No SR causality
	GHGs	Remaining three	4.83	0.18	No SR causality
Brazil (2)	GDP	Remaining three	4.70	0.58	No SR causality
	Urbanization	Remaining three	12.38	0.05	GDP, ENG, GHG → URB
	Energy	Remaining three	4.02	0.67	No SR causality
	GHGs	Remaining three	5.81	0.12	No SR causality
Mexico* (4)	GDP	Remaining three	50.24	0.00	URB, ENG, GHG → GDP
	Urbanization	Remaining three	9.67	0.64	No SR causality
	Energy	Remaining three	57.84	0.00	GDP, URB, GHG → ENG
	GHGs	Remaining three	23.68	0.02	GDP, URB, ENG → GHG
Indonesia* (2)	GDP	Remaining three	6.07	0.91	No SR causality
	Urbanization	Remaining three	123.38	0.00	GDP, ENG, GHG → URB
	Energy	Remaining three	2.89	0.99	No SR causality
	GHGs	Remaining three	7.94	0.78	No SR causality
S Africa* (2)	GDP	Remaining three	3.70	0.68	No SR causality
	Urbanization	Remaining three	2.38	0.75	No SR causality
	Energy	Remaining three	1.93	0.92	No SR causality
	GHGs	Remaining three	7.47	0.10	No SR causality
Turkey* (2)	GDP	Remaining three	5.19	0.51	No SR causality

(*continued on next page*)

Table 5 (*continued*)

Country (Optimum lag)	Dependent Variables	Independent Variables	Chi Square Value	Prob.	Remarks
	Urbanization	Remaining three	2.63	0.85	No SR causality
	Energy	Remaining three	4.01	0.67	No SR causality
	GHGs	Remaining three	12.76	0.04	GDP, URB, ENG → GHG
Iran (2)	GDP	Remaining three	12.35	0.05	URB, ENG, GHG → GDP
	Urbanization	Remaining three	4.40	0.62	No SR causality
	Energy	Remaining three	3.41	0.75	No SR causality
	GHGs	Remaining three	7.04	0.31	No SR causality

Note: * mark indicates test results for I(2) series for the concerned countries.
Source: Authors' own calculations.

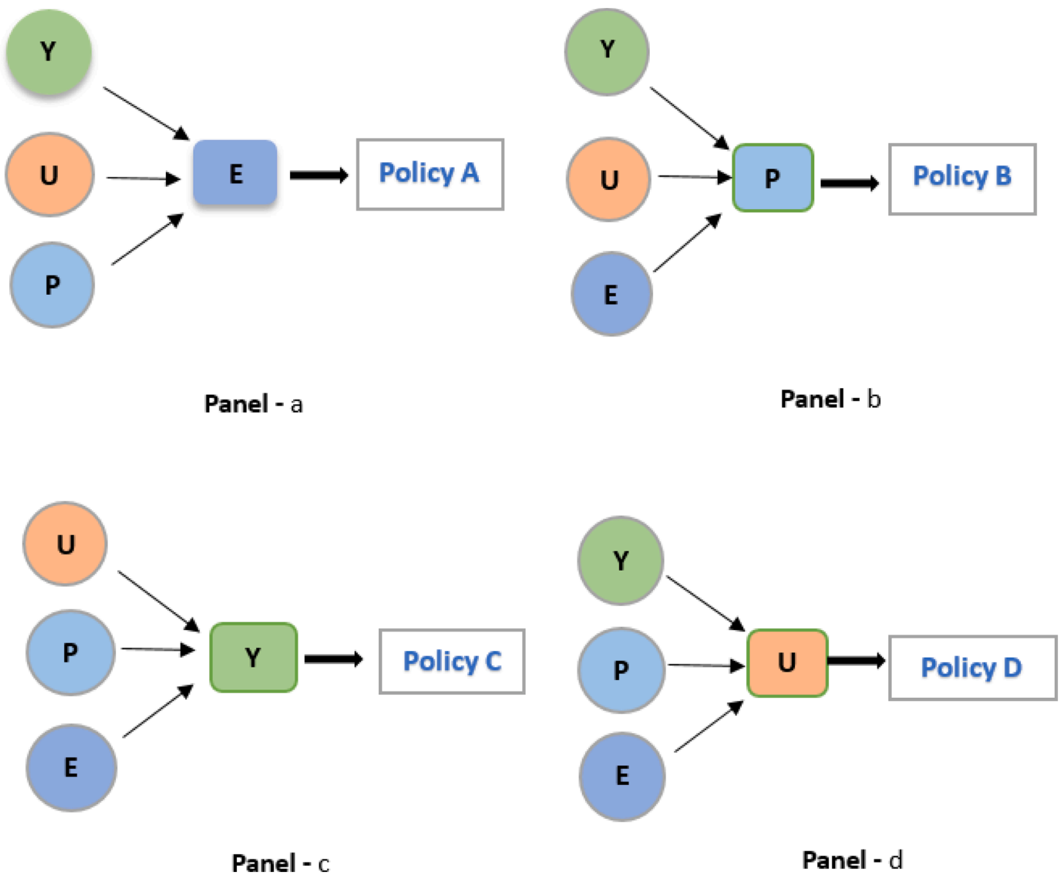

Fig. 6. Illustration of alternative policy options. Source: Authors' own deliberations.

introduced by the policy makers when urbanization is supposed to be affected by Y, E and P. In fact, it suggests that the corresponding nation must follow a path of sustainable urbanization following adaptation of Policy D.

From the long-run perspective we find that other things remaining same for the developed countries like Italy, France and Japan Policy A and Policy B must put together to achieve sustainable path of development, while in case of the developing nations like Brazil Policy D must be implemented in an isolated manner. However, short-run ways of causation is relatively complicated. For instance, our empirical results suggest that Mexico and Poland must implement both policies A and B together, and in addition to that Mexico and Poland are also asked to adopt Policy C and policy D respectively. It is to be noted from the empirical outcomes that Iran should adopt Policy B and Policy D together, while Germany is asked to implement both Policy B and Policy D simultaneously. Similarly, UK, Russia and Italy should implement Policies A and C, Policies C and D and policies A and D respectively in the short-run. Interestingly, we find that Policy A can be adopted by Italy and Policy D can be implemented in Brazil irrespective of short-run and long–run issues.

So, without loss in generality, we can argue that, in order to achieve the high growth as well as sustainable development, the nations should control the fossil fuel energy use by making substitutions with the non-fossil fuel, mainly the alternative energy sources like solar, electrical, hydro and wind power energy, etc. The governments in the countries should incentivize the use of the non-fossil fuels as the source of energy by means of subsidy first and then by enactment of laws in these regards. It is also to be added that all the countries should move in the similar way to bring the earth back to its in-situ natural power. The global monitoring authorities in these fields should take such initiatives to enforce the users of the countries to shift out their focus from fossil fuel use to the environment friendly non-fossil fuel uses.

5. Conclusion and policy prescriptions

The study examines whether income, urbanization, energy uses and GHG emissions are cointegrated or having co-movements for the world's top 20 polluting nations for the period 1970–2018. Here we first emphasize upon a theoretical background for the association among the four indicators and then go for empirical corroborations using time series econometric exercise. Moreover, using the battery of Johansen cointegration test and VECM for the variables the results show that the variables have long run associations as well as short run causal interplays in mostly the developed countries of the list.

The causal relationships unfold that Income and urbanization have latent explanatory powers through energy use and GHG emissions. It is thus now non-deniable that the so-called high polluting countries in the world are making the global environment into high risks through the growths of their income, urbanization, energy use and pollutants. They should be at the helm of operations in controlling environmental pollution through their mode of industrial as well as other economic activities. Hence, the policy makers of the concerned countries should focus on controlling the process of urbanization in order to manage energy use and GHG emissions to ultimately reach to the end of sustainable development. The sets of policy tools may be the following-

- Shifting the focus of energy use from fossil-fuels to natural friendly non-fossil fuels such as solar energy, hydroelectrical energy, wind energy, natural gas, tidal energy, geo thermal energy, etc.
- Switching of the traditional urban practices to smart urban practices by means of the provisioning of the smart urban facilities.
- Both the public and private entrepreneurs should actively participate in this noble mission. Both the forward and backward linkage effects should be allowed to work in order to get high growth of output as well as to have better environmental quality.
- Governments may subsidize the private sectors in initiating the investments in these energy sources.
- There may be green taxes imposed by the governments in the countries to finance their environment friendly project expenses
- The governments should make the awareness programs to alert the users in terms of cost and benefits.
- The governments may frame laws to make the compulsory use of the environment friendly fuel to make a balance between economic growth and environmental degradation to attain the goal of sustainable development.

The scope of this study is limited to world's top 20 polluting countries (including 11 developed and 9 developing countries) and only a limited number of variables are included. As the roles of developing countries are enlarging in order to tackle environmental degradation and hence its share within the list of countries must increase. Future studies can extend the empirical model by incorporating other relevant variables along with a greater number of cross-sections of the countries.

CRediT authorship contribution statement

Ramesh Chandra Das: Writing – review & editing. **Tonmoy Chatterjee:** Writing – review & editing. **Enrico Ivaldi:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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