



Causal nexus in industrialization, urbanization, trade openness, and carbon emissions: empirical evidence from OPEC economies

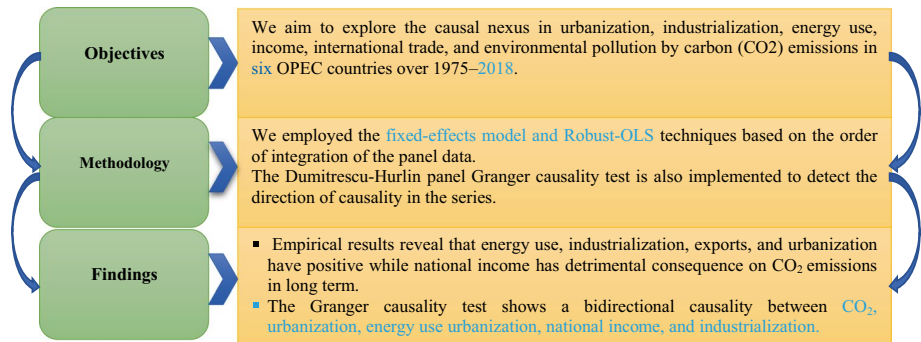
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Abstract

We need a desirable level of sustainable national economic development without environmental degradation. The key objective of this study is to explore the causal nexus in urbanization, industrialization, energy use, national income, international trade, and environmental pollution by carbon dioxide (CO₂) emissions in the six-member countries from the OPEC (Organization of the Petroleum Exporting Countries) over the period 1975–2018. This study is based on the modified empirical model of Kaya Identity introduced by Kaya (Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios, Intergovernmental Panel on Climate Change/Response Strategies Working Group, 1989). After checking the data for stationarity properties, we employed a fixed-effects estimator preferred by the Hausman test. We, in addition, employed the method of robust least squares to confirm the estimates. The empirical estimates reveal that regressors namely urbanization, industrialization, international trade, and energy use increase environmental pollution, while the impacts of income found are opposite. The Granger causality test exhibits a bidirectional causality among national income and CO₂, urbanization and CO₂, energy use and urbanization, national income and urbanization, national income and industrialization, urbanization and industrialization, and exports and urbanization. These findings advise that the management authorities of OPEC countries need to adopt environmentally friendly policies, while regulating environmental pollution to accomplish sustainable economic development in the region.

Graphical abstract



Source: Compiled by authors from the present entire study

Keywords Industrialization · Urbanization · CO₂ emissions · Trade · Energy use · National income · OPEC economies

JEL Classification N5 · P · F1 · Q5

1 Introduction

Achieving sustainable economic development is the chief objective of every economy, where to accomplish the needs of the existing generation without affecting the resources left for the next generation (WCED, 1987). There are numerous factors which significantly contribute to maintain and accomplish sustainable economic development where the vital role played by energy supply cannot be overlooked. A clean and green environment is also a significant factor and undeniably a requisite for sustainable development. Environment quality largely depends on many factors including the use of energy, industrialization, urbanization, and openness to trade, etc. The efficient use of energy is useful because its decline per unit output cost of production and pollution (Dincer & Rosen, 1999). In their study, Azam and Khan (2016) mention that modernization, industrialization, and the swift increased in urbanization were significantly contributed to the pollution, which is painstaking concerned with the environment throughout the world, but most dangerous for low-income countries.

Usually, a polluted environment is considered a key hindrance in the way of sustainable economic development in the modern world. Many studies including Zafar et al. (2020) explicitly highlighted that sustainable development remains unattainable without improving the environmental quality. The essential components for economic growth are rapid urbanization and industrialization, while these increases environmental pollution. There is a possibility of the transformation of labor from agriculture sectors to industrial sectors in many countries due to urbanization (Henderson, 2003). However, the creation of job opportunities and a better standard of living are attached to urbanization, which leads to raising CO₂ emissions. It has been observed that more than 2/3% of the world energy used in the cities and use of 70% energy was the source of CO₂ emissions (IRENA, 2016).

Carbon emissions are the main factor of global warming and damaging the natural environment. The environmental pollution rises since the 1990s, with the rising trend

of industrialization and urbanization (Parveen et al., 2019). There is a close connection between industrialization and urbanization, which has been accepted globally. This connection is based on purpose to attain a higher economic growth level and economic development (Sadorsky, 2013). This interconnection has twofold effects, on one way; it is promoting the scale of production and stimulating gross domestic product (GDP) growth in the advanced and emerging countries. On the second way, a lot of energy was used at household and industrial levels, which was the main cause of environmental pollution such as CO₂ emissions and other greenhouse gas emissions (Nasreen et al., 2018). Industrialization and urbanization are parts of modern society and a high standard of living with severe outcomes in the form of unavoidable health problems (Ahmad & Zhao, 2018).

The relationship between urbanization associated with industrialization and increasing the use of energy and CO₂ emissions was empirically investigated by many erstwhile studies, where these studies (Cole & Neumayer, 2004; Sadorsky, 2013; Yazdi & Dariani, 2019; York et al., 2003) found positive link between urbanization and CO₂ emissions, while the other found a negative relationship between these two variables (Asumadu-Sarkodie et al., 2016; Lv & Xu, 2018). Likewise, many prior studies support that trade openness has contributed to the decrease in environmental pollution (Lv & Xu, 2018; Shahbaz et al., 2011), while several other studies found that trade openness has a harmful effect on the environment (Boulatoff & Jenkins, 2010; Le et al., 2016). Thus, all these erstwhile studies reveal that the effect of industrialization, openness to trade, and urbanization on environmental pollution is yet controversial, and further robust studies required re-exploring the impacts of these variables on the environment.

The environmental problem in the OPEC countries is undeniably crucial due to two dimensions: first, most of the OPEC countries have no precautions to global warming, and secondly, these countries are responsible for the global warming, though these countries officially recognize the importance of the global environmental problem. The oil industry significantly increases environmental credentials, both in production and use for long time. The OPEC countries support always to the development of technologies to capture carbon emission and confiscation methods to diminish climate change. There is no clear evidence regarding the OPEC countries that they also using fossil fuels and CO₂ emissions (Sari & Soytaş, 2009).

The motivation of this study is grounded on the study by Wang et al. (2020) for 18 APEC countries, this study covers nine countries from OPEC, and we use a well-defined empirical model, longer period data and the most suitable estimation strategy based on the series integration order.

The existing studies reveal that urbanization plays detrimental role and contribute in increases CO₂ emissions (Liu & Bae, 2018; McGee & York, 2018), industrialization by (Lean & Smyth, 2010; Liu & Bae, 2018; Shiyi, 2009), and trade openness by (Azam & Ozturk, 2020; Ertugrul et al., 2016). The existing literature shows that the empirical outcomes regarding the relationship among the national income measured by GDP, trade, industrialization, urbanization, and CO₂ emissions are yet hazy. Therefore, to accomplish sustainable development, we intend to explore the influence of industrialization, urbanization, trade openness, and national income on the environmental pollution for six OPEC countries over the period 1975–2018. These six OPEC countries are Algeria, Iraq, Nigeria,

Saudi Arabia, United Arab Emirates and Venezuela.¹ To the best of the authors knowledge, it is the pioneer study exploring the impact of selected variables on the environment in the context of these sample countries from OPEC. We employed the most suitable estimation techniques to explore the unknown parameters by eliminating heterogeneity and exogeneity from the data. This study is important to identify and verify the relationship between these set of variables, and the empirical findings will help the policymakers to minimize the adverse effect of CO₂ emissions because OPEC countries have growing level of CO₂ emissions. The set of variables of this study are broad and covers key variables which yet not considered by prior studies in the context of OPEC countries. Thus, this study is expected to significantly contribute to the existing literature by using the new group of countries and variables and appropriate empirical methodology. The outcomes of this study will increase understating of the undesirable effect of selected regressors on the environment. The outcomes will help the policymakers to increase the industrialization and trade with the minimum cost of pollution.

The remaining study is structured as follows: Relevant literature is given in section two, Section three presents empirical methodology, while section four deals with outcomes and discussions, and section five presents a brief review and conclusion.

2 Review of literature

The ecological modernization theory (Blowers, 1997) claims that environmental quality suffers due to societies move from lower stages to middle stages of development, focus on output growth over a sustainable environment. It is believed that further modernization, decline environmental problems and societies start to highlight technological innovation, environmental sustainability, and transit the manufactured economy to service-based economy (Hajer, 1995). The urban environmental transition theory argues that as the societies move to industrialization-based economy, pollution rises with the nation's wealth (Marcotullio & Lee, 2003). The compact city theory argues that the urbanization expedites economies of scale for the government infrastructure and thus reduces environmental damages and pressure. However, urbanization without the provision of enough urban infrastructure tends to environmental damages (Burgess, 2000). There are two different views about the effect of trade on environmental quality, pollution heaven hypotheses (PHH) and factor endowment hypotheses (FEH). The PHH argues that the developed countries and multinational firms transfer their pollution-intensive production units to developing countries. The developing economies consider heaven for the world's polluting intensive industries. The developed economies are predicted to gain while developing economies are loss in terms of environmental quality. The PEH argues that it's not depends on variances in pollution policy but the disparities in technology or resource endowments determine international trade (Temurshoev, 2006).

The extant empirical literature on the connection between the CO₂ emissions and other factors is yet inconclusive or the empirical results are mixed. For example, Dinda and Coondoo (2006) found that there exist two ways causality between the income and CO₂ emissions and confirmed the validity of the EKC hypotheses for 88 countries from 1960 to 1990. A similar result also observed by Apergis and Payne (2009) using panel data of six Central American economies over 1971–2004 and found that there was long-term relationships between the real output, energy usage, and CO₂ emissions. The energy usage has positively influenced the CO₂ emissions while real output has quadratic connection with

¹ List of OPEC countries taken from https://www.opec.org/opec_web/en/about_us/25.htm.

CO₂ emissions. Shi (2003) found that there are optimistic connection among the population variations and CO₂ emissions for 93 economies from 1975 to 1996. Keho (2015) found that industrialization and trade were paired in deteriorating the quality of the environment in Cote d'Ivoire during 1970–2010.

Cole and Neumayer (2004) observed an encouraging link among CO₂ emissions and urbanization and population, household sizes, energy intensity, for 86 economies from 1975 to 1998. Lean and Smyth (2010) found that there is a positive connection between electricity use and CO₂ and the connection among the real output and CO₂ is nonlinear in the long term for five ASEAN countries from 1980 to 2006. Akin (2014) found that trade openness has an adverse effect on CO₂ in the long term, a unidirectional causality running from CO₂ to trade openness and GDP to CO₂ and use of energy in the short term for 85 countries from 1990 to 2011. Aka (2008) found that trade has improved while economic growth has harmed the environment quality during 1961–2003 for the Sub-Saharan Africa.

In their study, Lv and Xu (2018) found that trade openness has a favorable impact on the environment in the short-term, while has a destructive effect on the environment in the long-term, and urbanization has a detrimental effect on the environment for 55 middle income economies from 1992–2012, while urbanization has a noteworthy and harmful consequence on CO₂ emissions. In their study, Yazdi and Dariani (2019) observed that there are long-term associations among the variables during 1980–2014 of Asian countries. The increase in the urbanization increases CO₂ and then energy use, and also a bidirectional causality among CO₂, urbanization, and output growth were observed. Similarly, Parveen et al. (2019) confirmed that there is a one-way causality turning from CO₂ emissions to urbanization and CO₂ emissions to economic growth of Pakistan from 1975 to 2017. Odugbesan and Rjoub (2020) detected that there is a one-way causality moving from usage of energy to GDP growth in Indonesia and Nigeria, and a bidirectional causality exists between energy and GDP growth in Turkey and Mexico from 1993 to 2017. Overall, the empirical estimate reveals a long-run association from energy usage, economic growth, and CO₂ emissions to urbanization. However, there was long-term connection among the variables in all four economies. The study of Adebayo et al. (2021) found that energy usage, CO₂, and urbanization show positive effect on economic growth in Brazil over 1965–2019, while no significant link between trade openness and economic growth was observed. The empirical findings of Adeneye et al. (2021) study show cointegration between CO₂ emission, energy use, urbanization, and economic growth in 42 Asian countries from 2000 to 2014.

Sari and Soytas (2009) found that long-run cointegration exists only in Saudi Arabia among the variables in five OPEC countries from 1971 to 2012. They also found that output growth and use of energy have no long-term impression on CO₂ emissions. They determined that no need for loss of output growth to lessens CO₂ emissions. Moutinho et al. (2020) discovered that output growth upsurges CO₂ emissions in oil-exporting and oil-producing countries and the energy use has a harmful effect on environment; trade openness has improved the environmental quality in 12 OPEC countries from 1992 to 2015. Saidi and Rahman (2020) suggested that there is bidirectional causality among output growth and the use of energy for all countries and CO₂ emissions and output growth in all countries except Algeria, use of energy and CO₂ emissions in all five OPEC economies from 1990 to 2014 except Venezuela. The linkages among urbanization and industrialization, trade openness, output growth, and CO₂ emissions are still controversial on both theoretical and empirical ground. There are very few studies that are conducted to investigate the relationship among the urbanization and industrialization, output growth, trade openness, and CO₂ emissions and used few countries sample or small time period like Saidi and Rahman (2020) used the panel data for five OPEC economies for period from 1990 to 2014 but they missed the most

important variables, i.e., industrialization and trade openness which are the most significant factors of the CO₂ emissions. Similarly, Moutinho et al. (2020) overlooked the most important variables, i.e., industrialization and urbanization which are the most significant factors of the CO₂ emissions in case of 12 OPEC economies from 1992 to 2015. Most of the prior studies also neglected the use of OLS techniques in case of OPEC countries and also missed important variables. Therefore, we used panel data for six OPEC countries and the Fixed-effects and robust least square techniques and panel Granger causality technique to obtain accurate and more reliable results to generalize for all OPEC countries to reduce the existing gap. The summary of some more relevant studies is given in Table 1.

3 Data and empirical methodology

We used annual balanced panel data of six OPEC countries namely Algeria, Iraq, Nigeria, Saudi Arabia, United Arab Emirates and Venezuela over the ranging from 1971 to 2018.² The environmental quality measured by CO₂ emissions is regressand and urban population (urbanization), energy use (kg of oil equivalent per capita), national income (GDP), industry value added as proxied for industrialization and exports as proxied for international trade are regressors in this study. A brief detail of data and descriptions of variables are specified in Table 2.

3.1 Empirical model

The model of this study is based on the empirical model introduced by Kaya (1989) and used to explore the connection among environmental quality (CO₂ emissions) and human activities. The Kaya introduced empirical model was also used by Lin et al. (2015) to investigate the industrialization effect on CO₂ emissions for Nigeria; Lin and Xie (2014) for China. A similar model was also used by Hossain (2011) for nine recently industrialized economies; Ertugrul et al. (2016) for the top 10 emitters among emerging economies; Ali et al. (2016) for Malaysia; Zafeiriou and Azam (2017) for three Mediterranean countries; Liu and Bae (2018) for China; McGee and York (2018) for 102 developing countries; (Awan et al., 2020) for MENA economies and Azam and Ozturk (2020) for 17 Asian economies. The multivariate regression model is used in this study can be written symbolically as follows:

$$CO_{2it} = \alpha_0 + \alpha_{1,i}UP_{it} + \alpha_{2,i}GDP_{it} + \alpha_{3,i}EC_{it} + \alpha_{4,i}EXP_{it} + \alpha_{5,i}ID_{it} + \mu_{it} \quad (1)$$

where as i , show the number of country, t shows time, μ is the error term and $\alpha_1 - \alpha_5$ are the coefficient.

Based on the nature of the order of integration of panel balanced data, we implemented the traditional panel data analysis technique (fixed-effects) and also robust least square (Robust-OLS) for estimation.

Summary of correlation matrix and basic statistics is given in Table 3. All the variables have greater mean value than CO₂ emissions. The variation in the CO₂ emission series has greater than GDP, industrialization, exports and urbanization while less than in the energy consumption. All the variables are negatively skewed except exports have

² Data used in this study for empirical examination have been obtained from the World Development Indicators (2021), the World Bank database <https://data.worldbank.org/>.

Table 1 Summary of prior empirical studies on the link between urbanization, industrialization, energy use and CO₂ emissions

Author(s)	Data, country(s)/and methodology	Variables used	Results
Zhang and Cheng (2009)	1960–2007, China, Granger causality	CO ₂ emissions, GDP, and energy use	Long-run GDP → energy use and energy use → CO ₂ emissions
Hossain (2011)	1971–2007, Panel Granger causality test	CO ₂ emissions, energy use, urbanization, trade and real GDP per capita (growth)	Found cointegration but no causality between the variables in the long run. In short run, growth → CO ₂ emissions, trade → CO ₂ emissions, growth → energy use, trade and urbanization → growth and trade → urbanization
Omri (2013)	1990–2011, 14-MENA economies 2SLS	CO ₂ emissions, energy use, and GDP	Energy use ↔ GDP and CO ₂ emissions → GDP
Baig and Baig (2014)	1970–2010, Pakistan, ARDL and Granger Causality test	CO ₂ emissions, GDP, energy use, population	GDP → CO ₂ emissions, CO ₂ emissions → population and GDP → CO ₂ emissions
Alshehry and Belloumi (2015)	1971–2010, Saudi Arabia Cointegration, Granger Causality tests	Per capita CO ₂ emissions, GDP per capita, energy prices, per capita energy use	Long-term connection among the variables. In the long run, energy use and energy prices → CO ₂ emissions and per capita GDP and CO ₂ emissions ↔ economic growth. In short run, CO ₂ emissions → per capita GDP and energy use and energy prices → CO ₂ emissions. They confirmed the energy led growth hypothesis
Asumadu-Sarkodie et al. (2016)	1965–2011, Rwanda, ARDL, Granger causality test	CO ₂ emissions, industrialization, population and economic growth	Exists long-run cointegration among the variables. Population → economic growth, population → industrialization and economic growth
Liu and Bae (2018)	1970–2015, China VECM, ARDL techniques	CO ₂ , GDP, energy use, industrialization and urbanization	Exists bidirectional causality among the industrialization and CO ₂ emissions
Shahbaz et al. (2020)	1976–2016, USA ARDL bound and VECM, Granger causality test	CO ₂ emissions, natural resources, GDP, oil prices and education	Long-term connection among the variables. The oil prices and education have adverse effect on energy use and CO ₂ emissions

→ indicates one-way causality and ↔ two-way causality between variables

Table 2 Descriptions of the variables

Variable	Labeled	Units	Sources
CO ₂ emissions (metric tons per Capita)	CO ₂	Metric tons	(World Development Indicators (WDI) (2021))
GDP (Current US\$)	GDP	US\$	WDI (2021)
Urban population	UP	Numbers	WDI (2021)
Industry (including construction), value added (Current US\$)	ID	US\$	WDI (2021)
Energy use (kg of oil equivalent per capita)	EC	Kg	WDI (2021)
Exports of goods and services (Current US\$)	EXP	US\$	WDI (2021)

positively skewed. The series CO₂ emissions and exports are symmetrical, GDP and industrialization are moderately and energy consumption and urbanization are highly skewed. Similarly, the kurtosis values are positive of all variables, which shows that the series CO₂ and exports are platykurtic and rest of the variables are leptokurtic. The correlation between energy use, industrialization, exports and income has positive while urbanization has a negative correlation with CO₂ emissions. The CO₂ emissions increase with energy use, industrialization, income and exports and decrease with urbanization.

3.2 Estimation procedure

3.2.1 Cross-sectional dependency (CD) tests

Due to globalization, financial and economic integration increases among the country's day by day. Like, the economic situation of one country affects the economic

Table 3 Summary of descriptive statistics and correlation matrix. *Source:* Authors calculation

	CO _{2it}	EC _{it}	GDP _{it}	ID _{it}	EXP _{it}	UP _{it}
Mean	1.6103	24.0845	25.0679	24.4747	7.4938	16.2781
Median	1.5824	24.2291	24.9302	24.4624	7.2672	16.5003
Maximum	4.3518	26.7181	27.3909	26.8575	9.4069	18.4067
Minimum	-0.7822	13.4492	19.8263	19.1539	5.4508	12.3078
Std. dev	1.2237	1.9895	1.1919	1.0936	0.9756	1.0818
Skewness	-0.0109	-2.4382	-0.7229	-0.9615	0.4349	-1.2014
Kurtosis	2.3332	13.6211	4.9059	6.4049	2.0837	4.8740
CO _{2it}	1					
EC _{it}	0.4588	1				
GDP _{it}	0.1339	0.7177	1			
ID _{it}	0.1817	0.6992	0.8981	1		
EXP _{it}	0.8643	0.5704	0.3822	0.3208	1	
UP _{it}	-0.7222	-0.1708	0.3854	0.2746	-0.4745	1

situation of other countries (De Hoyos & Sarafidis, 2006). The cross-sectional dependence is also important because the environmental quality of one country affects the other country. We employed four tests to detect the cross-sectional dependence among the countries. The Breusch–Pagan LM test developed by Breusch and Pagan (1980), Bias-corrected scaled LM test introduced by Baltagi et al. (2012) and Pesaran scaled LM test and Pesaran CD test established by Pesaran (2004). The null hypotheses of all these tests are that the residuals of each section independency.

3.2.1.1 Breusch–Pagan LM test The Breusch–Pagan LM test is used in the context of specifically unrelated regression equation with cross section (N) is fixed and time dimension of the panels (T) $T \rightarrow \infty$, to test the null hypotheses that there are zero cross equation error correlations. The equation of Breusch–Pagan LM test as follows:

$$CD_{lm} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2, \tag{2}$$

where $\hat{\rho}_{ij}^2$ is the sample estimate of the pairwise correlation of the residuals. Particularly,

$$\hat{\rho}_{ij}^2 = \hat{\rho}_{ji}^2 = \frac{\sum_{t=1}^T e_{it}e_{jt}}{\left(\sum_{t=1}^T e_{it}^2\right)^{1/2}\left(\sum_{t=1}^T e_{jt}^2\right)^{1/2}}, \tag{3}$$

and e_{it} asymptotically distributed. Unlike the spatial dependence test, this test is more generally applicable and does not need the specific order of the cross-section units. However, CD_{lm} is valid for large T and small N .

3.2.1.2 Pesaran CD test Unlike the Breusch and Pagan (1980), CD_{lm} test due the assumption of fixed N , $T \rightarrow \infty$, and the LM is asymptotically distributed. However, in the empirical analysis, mostly the N is large, and T is finite because the CD_{lm} is not correctly centered for finite T and seems to bias with the large N .

To overcome these issues, Pesaran (2004) proposed the following alternative CD tests.

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right), \tag{4}$$

Indicated that under the null hypotheses of no cross-sectional dependence $CD \rightarrow^d N(0, 1)$ for $N \rightarrow \infty$ and T is large sufficiently. Unlike the LM statistic, the CD statistics has mean at accurately zero for stuck values N and T , under a wide range of panel data models, including heterogenous/homogenous nonstationary and dynamic models. For heterogenous and homogenous dynamic models, the standard random and fixed-effect estimators are biased (Nickell, 1981; Pesaran & Smith, 1995). However, the CD test is still valid because, despite the small sample bias of the parameters, the random and fixed-effect residuals will have exactly mean zero even for fixed T , provided that the error terms are symmetrically distributed.

For the unbalanced panels, the Pesaran (2004) presents the modified version (6),

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \sqrt{T_{ij}} \hat{\rho}_{ij} \right) \tag{5}$$

where $T_{ij} = \#(T_i \cap T_j)$ (i.e., the number of common time series observations between units i and j),

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t \in T_i \cap T_j} (\hat{u}_{it} - \bar{\hat{u}}_i)(\hat{u}_{jt} - \bar{\hat{u}}_j)}{\left\{ \sum_{t \in T_i \cap T_j} (\hat{u}_{it} - \bar{\hat{u}}_i)^2 \right\}^{1/2} \left\{ \sum_{t \in T_i \cap T_j} (\hat{u}_{jt} - \bar{\hat{u}}_j)^2 \right\}^{1/2}}$$

And

$$\bar{\hat{u}}_i = \frac{\sum_{t \in T_i \cap T_j} \hat{u}_{it}}{\#(T_i \cap T_j)}$$

The modified statistics accounts for the fact that residuals for subsets of t are not necessarily mean zero.

3.2.1.3 Bias-corrected scaled LM test In the raw data case, the $n \times 1$ vectors Z_1, Z_2, \dots, Z_T are a random sample drawn from $N(0, \Sigma_z)$. The t th observation Z_t has n components, $Z_t = (z_{1t}, \dots, z_{nt})'$. The null hypothesis of independence between these n components but now to Σ_z rather than Σ_u . In the case of fixed n , and as $T \rightarrow \infty$, the traditional CD_{lm} test statistic converges in distribution to $\chi^2_{n(n-1)/2}$ under the null of independence. The sample correlation r_{ij} is defined as

$$r_{ij} = \left(\sum_{t=1}^T z_{it}^2 \right)^{-1/2} \left(\sum_{t=1}^T z_{jt}^2 \right)^{-1/2} \sum_{t=1}^T z_{it} z_{jt} \tag{6}$$

However, as the dimension n becomes as comparably large as T , this CD_{lm} test becomes invalid.

Then, A scaled LM test statistics is considered.

$$LM_z = \sqrt{\frac{1}{n(n-1)}} \sum_{i=1}^{n-1} \sum_{j=i+1}^n (Tr_{ij}^2 - 1) \tag{7}$$

3.2.2 Panel unit root tests

The estimation with nonstationary variables leads to gives an inconsistent and misleading outcome (Ndiaye & Korsu, 2016). Therefore, it is obligatory to check the order of integration before the estimation. We implemented four-panel unit root tests namely LLC test developed by Levin et al. (2002), IPS W-test developed by Im et al. (2003), the Augmented Dickey–Fuller test–Fisher Chi-square test initiated by Maddala and Wu (1999) and the Cross-sectionally Augmented IPS (CIPS) test introduced by Pesaran (2007) to check stationarities roperties of the data

3.2.3 Panel cointegration tests

To detect that whether the variables are cointegrated or not. This study applies two panel cointegration tests, Johansen Fisher Panel Cointegration formed by Maddala and Wu (1999) and Westerlund cointegration test developed by Westerlund (2007) against the null hypotheses that there are no cointegration in the panel. Maddala and Wu (1999) trusted on the Johansen (1988) cointegration test to reflect the suggestion of Fisher (1934) to combine the max-eigen statistics and trace test to detect the cointegration in the whole panel by merging the individual country for cointegration. Johansen Fisher cointegration test used the aggregates probability value of each individual maximum likelihood cointegration statistics. Unlike the Kao (1999) and Pedroni (2004) which are based on residual. We also applied the Westerlund cointegration test because it can remove cross-section dependence effects between the variables by the bootstrap approach.

3.2.4 Regression techniques

We employed three suitable estimation techniques namely Fixed-effects and Robust-OLS techniques. The main advantage of the Fixed-effects estimators that it remove the impacts of time invariant causes (measured or not), and improve omitted-factor bias in a less than fully specified model and eliminate unknown specification bias (Firebaugh, 2018). The random-effect differs from Fixed-effects to estimate the error term. The fixed-effect treats the error term as fixed for each section while Random-effect treats as randomly varying (Firebaugh et al., 2013). The Hausman's test is used to check the appropriateness that either Fixed-effects or random-effects estimator is suitable for estimation (Hausman, 1978). We also employed the Robust-OLS techniques for confirmation of results.

3.2.5 Granger causality test

To examine the causality among the variables, we also employ the Dumitrescu–Hurlin (2012) (D-H) panel Granger causality test that permits capturing the slope of heterogeneity between each country. The D-H panel Granger causality testis depends on the non-causality heterogeneous panel data test developed by Granger (1969). The null hypothesis of D-H Panel causality test is homogeneously non-causality that there is no causality among the variables for any cross section of the panel. The central advantage of this technique is that it is too easy in the implementation like the standardized mean average Wald statistics are easy to calculate and have a standardized asymptotic normal distribution.

The average statistic $W_{N,T}^{H_{nc}}$ related with the null Homogenous Non-Causality (HNC) hypothesis is defined as:

$$W_{N,T}^{H_{nc}} = \frac{1}{N} \sum_{i=1}^N W_{i,T}, \quad (8)$$

where $W_{i,T}$ indicated the individual Wald statistics for the i th cross-section unit corresponding to the individual test $H_0 = \beta_i = 0$.

4 Results and discussion

4.1 Results of CD tests

The empirical outcomes of cross-sectional dependence (CD) tests are given in Table 4. All the tests' statistics are found significant; therefore, we deny the null hypotheses and concluded that there exists the cross-sectional dependence in the panel.

4.2 Results of panel unit root tests

Panel unit root test outcomes are given in Table 5 which is versus the null hypotheses that there is no unit root problem in the data. The LLC test, IP&S-W, ADF-Fisher χ^2 and CIPS test show that all the variables are stationary at the level and have zero-degree order integration. Therefore, the variables have a same order of integration and we preferred to employ the OLS techniques for estimation purposes.

4.3 The Fixed-effects and Robust least squares estimations

The Fixed-effects and robust-OLS results are given in Table 6. It is evident from Table 6 that consumption of energy has an optimistic and noteworthy consequence on CO₂ emissions. Our result is in line with (Alshehry & Belloumi, 2015; Baig & Baig, 2014; Lin et al., 2015; Liu & Bae, 2018) and dissimilar with (Al-Mulali et al., 2016). If the energy used increases 1% will lead to upsurge the CO₂ emissions by 0.04%. The industrialization has an encouraging and highly noteworthy consequence on CO₂ emissions. Our result was similar to (Asumadu-Sarkodie et al., 2016; Lin et al., 2015) and different with (Keho, 2015). A percent upsurge in industrialization will lead to an upsurge in CO₂ emissions 0.07%. The GDP growth has an adverse and highly noteworthy effect on CO₂ emission. Our result parallels with (Asumadu-Sarkodie et al., 2016) and dissimilar with (Aka, 2008; Baig & Baig, 2014; Lin et al., 2015; Liu & Bae, 2018). The 1% upsurge in GDP growth will bring

Table 4 Cross-section dependence tests results

Variables	Breusch–Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD scaled LM
CO _{2it}	108.3467* (0.0000)	17.0427* (0.0000)	16.9789* (0.0000)	0.4798 (0.6314)
EC _{it}	317.3662* (0.0000)	55.2042* (0.0000)	55.1404* (0.0000)	15.6217* (0.0000)
GDP _{it}	505.129* (0.0000)	89.4849* (0.0000)	89.4211* (0.0000)	22.2102* (0.0000)
ID _{it}	332.931* (0.0000)	58.0460* (0.0000)	57.9822* (0.0000)	17.2314* (0.0000)
EXP _{it}	491.840* (0.0000)	87.0585* (0.0000)	86.9948* (0.0000)	22.0391* (0.0000)
UP _{it}	703.252* (0.0000)	125.657* (0.0000)	125.593* (0.0000)	26.5183* (0.0000)

p value inside the () parentheses

Asterisks * represent 1%, level of significance

Table 5 Panel unit root tests analysis

Variables	LLC test (p value)	IP&S-W Test (p value)	ADF-Fisher χ^2 test (p value)	CIPS	Decision
CO _{2it}	-2.6842* (0.0036)	-3.2620* (0.0006)	30.6839* (0.0022)	-2.499*	I(0)
EC _{it}	-2.7030* (0.0034)	-2.2505** (0.0122)	22.1541** (0.0358)	-2.473*	I(0)
GDP _{it}	-3.5709* (0.0002)	-1.3570*** (0.0874)	21.7879** (0.0400)	-3.247*	I(0)
ID _{it}	-2.1915** (0.0142)	-1.5037*** (0.0663)	21.3405** (0.0456)	-3.047*	I(0)
EXP _{it}	-5.8704* (0.0000)	-4.2264* (0.0000)	40.7438* (0.0001)	-2.648*	I(0)
UP _{it}	-5.0800* (0.0000)	-2.2021** (0.0138)	24.8874** (0.0154)	-2.664*	I(0)

p value inside the () parentheses

Asterisks *, ** & *** represent 1%, 5% and 10% level of significance, respectively

Critical value for CIPS test is -2.19 for 5% and -2.41 for 1% level of significance

0.23% to decrease in CO₂ emission in long term. Exports have a noteworthy and positive consequence on CO₂ emissions in long term. Our results are alike with (Le et al., 2016) and oppose with (Lv & Xu, 2018; Shahbaz et al., 2011). The 1% upsurge in the exports will increase the CO₂ emission by 0.30%. Urbanization has an optimistic and substantial consequence on CO₂ in long term. Our results are the same as (Cole & Neumayer, 2004; Sadorsky, 2013; Yazdi & Dariani, 2019; York et al., 2003) and oppose (Lv & Xu, 2018). A 1% increase in the urbanization will bring an upsurge in the CO₂ emissions by 0.42%. The Hausman test results are found significant and recommend that the Fixed-effects estimator results are appropriate than random-effects.

4.4 Panel cointegration test results

Table 7 shows the Johansen Fisher panel cointegration test result, which shows that there are long-run cointegration among the variables up to third lag indicated by Fisher

Table 6 Regression results

Variables	Fixed-effects	Robust-OLS
	Coefficient	Coefficient
Energy use (EC _{it})	0.0361* [0.0104] (0.0006)	0.0699* [0.0257] (0.0066)
GDP _{it}	0.2339* [0.0323] (0.0000)	0.1432** [0.0716] (0.0453)
Industry value added (ID _{it})	0.0749* [0.0281] (0.0081)	0.3362* [0.0500] (0.0000)
Exports of goods and services (EXP _{it})	0.3020* [0.0380] (0.0000)	0.8548* [0.0395] (0.0000)
Urban population (UP _{it})	0.4200* [0.0289] (0.0000)	0.4753* [0.0422] (0.0000)
Constant	3.0247* [0.2991] (0.0000)	-
Hausman Test- Cross-section random	1356.71 (0.0000)	

Standard-Error and p value inside the [] and () parentheses, respectively

Asterisks * represent 1%, level of significance

Table 7 Panel cointegration test results

Hypothesized no. of CE(s)	Fisher statistic (from trace test)	Probability value	Fisher statistic (from max-eigen test)	Probability value
<i>a. Johansen Fisher panel cointegration test results</i>				
None	201.6*	0.0000	126.9*	0.0000
At most 1	98.03*	0.0000	56.59*	0.0000
At most 2	51.12*	0.0000	30.69*	0.0022
At most 3	28.50*	0.0047	21.15**	0.0483
At most 4	17.93	0.1179	15.39	0.2209
At most 5	17.26	0.1400	17.26	0.1400
<i>b. Westerlund cointegration test results</i>				
	ADF		-1.4362***	0.0755

Asterisks *, ** & *** represent 1%, 5% and 10% level of significance, respectively

Statistic (from trace test) and Fisher Statistic (from max-eigen test). We also confirmed these results through Westerlund cointegration test. The Westerlund cointegration test also rejects the null hypotheses and concluded that there are long-run cointegration among the variables. Sharma (2011) investigates the determinants of CO₂ emissions and used the panel data set of sixty-nine countries and employed random and fixed-effect model for estimation without checking the structural breaks. Similarly, Moutinho et al. (2020) used the panel data of twelve OPEC countries to investigate factors determining Environmental Kuznets Curve and employed the random- and Fixed-effects techniques for estimation but they cannot consider and check the structural breaks in the data. Regarding the structural break in panel data, we also followed (Moutinho et al., 2020; Sharma, 2011).

4.5 Panel causality test results

Table 8 shows the results of Pairwise Dumitrescu–Hurlin panel granger casualty techniques. The D-H panel Granger causality techniques outcome depicted the existence of unidirectional casualty among energy use and CO₂ emissions, running from energy use to CO₂ emissions. Figure 1 also shows direction of causality among the series through a flowchart diagram. Our outcome is alike with (Rahman & Kashem, 2017; Zhang & Cheng, 2009) and dissimilar with (Akin, 2014; Asongu et al., 2020; Saidi & Rahman, 2020). There is a two-way causality among CO₂ emissions and industrialization that the increases in industrialization lead to boost in CO₂ emissions and vice versa. Our outcome is similar to (Liu & Bae, 2018) and different (Gokmenoglu et al., 2015; Hossain, 2011; Wang et al., 2020). The causality analysis also confirmed the two-way causality among consumption of energy and GDP per capita. Our results are similar with (Wang et al., 2020; Zhao & Wang, 2015) and inconsistent with (Chiou-Wei et al., 2008; Wolde-Rufael & Menyah, 2010). The consumption of energy and urbanization also have two-way causality. Our results were in line with (Asongu et al., 2020; Wang et al., 2020) and opposite with (Dogan & Turkekul, 2016). There exists unidirectional causality between exports and GDP, running from GDP to exports. Alike outcome were given by (Chaudhry et al., 2010) and opposite results were given by (Iqbal et al., 2010). There exists two-way causality among the urbanization and GDP. Our results are similar to (Asongu et al., 2020; Wang et al., 2020) and opposite

Table 8 Pairwise Dumitrescu–Hurlin Panel causality tests results

Variables	CO _{2it}	EC _{it}	GDP _{it}	ID _{it}	EXP _{it}	UP _{it}
LCO _{2it}	–	2.5010 (0.1217)	6.8397* (0.0012)	2.7648 (0.4636)	3.7383 (0.6131)	3.6758*** (0.0817)
EC _{it}	5.5978* (0.0001)	–	6.4879* (0.0033)	6.0861* (0.0098)	7.6373* (0.0000)	18.9634* (0.0000)
GDP _{it}	6.2513* (0.0064)	1.3939 (0.1169)	–	4.7387* (0.0035)	4.6705* (0.0045)	5.9043* (0.0000)
ID _{it}	3.8854** (0.0485)	4.9212 (0.1207)	19.2079* (0.0000)	–	4.2941** (0.0153)	7.1719* (0.0000)
EXP _{it}	5.5138** (0.0379)	1.3187 (0.3857)	1.7991 (0.7370)	0.7420 (0.1321)	–	3.7163*** (0.0741)
UP _{it}	5.7594* (0.0000)	7.2325* (0.0003)	4.4916* (0.0082)	4.1450** (0.0238)	4.5128* (0.0076)	–

p value is inside the () parentheses and *, ** &*** represent 1%, 5% and 10% level of significance, respectively. The selected lags vary from 2 to 3

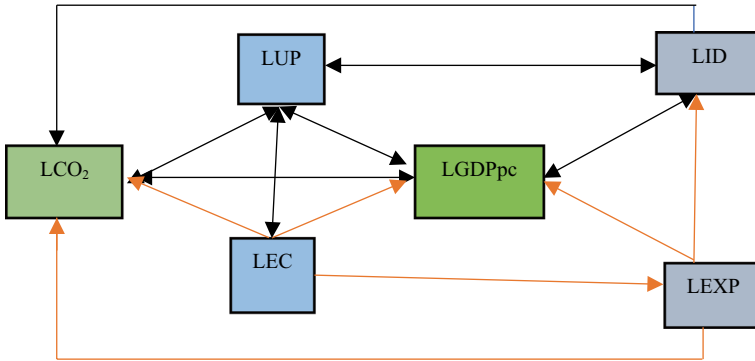


Fig. 1 Pairwise D-H panel causality tests results

with (Zhao & Wang, 2015). The causality test also confirms the two-way causality among exports and urbanization, running from exports to urbanization.

Empirical results of the D-H panel Granger causality test given in Table 8 also confirmed that there is two-way casualty between CO₂ emissions and economic growth. These results are similar to the findings by (Asongu et al., 2020; Yazdi & Dariani, 2019) and the contradictory to the findings by (Zhang & Cheng, 2009). There are also exist the unidirectional causality among CO₂ emissions and exports, running from exports to CO₂ emissions. The results are consistent with the findings of (Akin, 2014) and the opposite to the findings of (Iqbal et al., 2010). There are exist two-way causality among urbanization and CO₂ emissions and our result is similar with (Yazdi & Dariani, 2019) and different with (Alom et al., 2017; Parveen et al., 2019). Similarly, the one-way casualty exists between industrialization and energy use, running from energy use to industrialization. Our results is similar with (Asumadu-Sarkodie et al., 2016) and contradictory with (Asumadu-Sarkodie & Owusu, 2016). There are one-way causality between exports to energy use, running from energy use to exports and our results not consistent with (Shahbaz et al., 2013). There are

two-way causality GDP per capita and industrialization and our results are similar with (Liu & Bae, 2018) and dissimilar with (Asumadu-Sarkodie et al., 2016; Wang et al., 2020). While, one-way causality exists between industrialization and exports, running from industrialization to exports, and exists two-way causality between industrialization and urbanization and our results are different with (Alom et al., 2017; Wang et al., 2020).

5 Concluding remarks

The polluted environment was considered one of the key difficulties in the way of sustainable economic development in the modern world. The main objective of the study is to investigate the connection among urbanization, industrialization, national income, exports, and carbon emissions in six OPEC countries from 1971 to 2018. This study is based on the modified empirical model Kaya Identity introduced by Kaya (1989). We employed Fixed-effects and robust-OLS techniques to estimate coefficient of the variables and Pairwise Dumitrescu–Hurlin panel Granger causality to explore the direction of the causality of the variables.

This study found that variables namely energy use, industrialization, exports, and urbanization have an encouraging and highly noteworthy consequence on CO₂ emissions while economic growth has an adverse and highly noteworthy consequence on CO₂. There exists long-run cointegration among the variables. There is bidirectional causality between national income (GDP) and CO₂, urbanization, CO₂, energy use and urbanization, economic growth and urbanization, economic growth and industrialization, industrialization and urbanization, and exports and urbanization. There is one-way causality running from energy consumption to CO₂, industrialization to CO₂, exports to CO₂, energy use to national income, energy use to industrialization, energy use to exports, exports to GDP, and industrialization to exports.

We concluded that consumption of energy, industrialization, exports, and urbanization have positive while GDP growth has unhelpful consequence on CO₂ emissions. We further concluded that there is bidirectional causality between national income and CO₂, urbanization and CO₂, energy use and urbanization, economic growth and urbanization, economic growth and industrialization, industrialization and urbanization, and exports and urbanization. There is one-way causality running from energy consumption to CO₂, industrialization to CO₂, exports to CO₂, energy use to GDP, energy use to industrialization, energy use to exports, exports to GDP, and industrialization to exports.

These empirical results are according to the theoretical expectation and support the erstwhile studies results. These results may be generalized for all lower-, middle-, and higher-income countries in the world. Empirical findings suggest that each country must improve its national economics with minimum use of energy, and better plan urbanization. The findings of the study suggest that to embolden green and sustainable urbanization, as it upsurges aggregate output but not at the cost of environmental damaging; to expand the efficacy of energy usage and high-tech innovation; to expand the volume of exports but not on the expense of environmental degradation. Moreover, emissions from vehicular can be mitigated in metropolitan areas by encouraging the public urban transportation system. In order to reduce pressure of urban migration, the government of these countries needs to promote sustainable and environmentally friendly Towns, and provide essential services to people living in rural area. The government needs to adopt environment friendly

technology by urban industrial and housing sectors and awareness among people shall be created about reducing environmental degradation.

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