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Research paper

Industrialization, urbanization and CO₂ emissions in Saudi Arabia: Asymmetry analysis

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ABSTRACT

Keeping a sustainable environment is always a massive challenge for oil-exporting countries, and in that situation, industrialization and rapid growth of urbanization can add fuel to the fire. We investigate the effects of industrialization and urbanization on the CO₂ emissions per capita in Saudi Arabia, utilizing an annual period 1968–2014. The results show that both industrialization and urbanization impede the environment with the inelastic effect of industrialization and elastic effect of urbanization on the emissions. An asymmetry in the relationship of industrialization and emissions is also found. The increasing industrialization has larger environmental effect than decreasing industrialization. We recommend the Saudi government to design tighter urban and industrial–environmental policies to put a halt on increasing CO₂ emissions.

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1. Introduction

With global competition in all domains of life getting an exponential pace, countries are longing to find ways to compete with an upper hand. For many countries, growth and development are synonymous with industrialization, and that is primarily because once the industry of a country starts to grow, economic ease and urbanization are inevitable. It the debate of industrialization, one factor that must be considered is ensuring that the growth rate in this segment is sustainable and the net impact on the overall economy is positive. In many capacities, when the industry is at a faster growth pace, ensuring that it is inclusive of other sectors is not an easy task. Hence, in some instances, urbanization and industrialization can turn out to be destructive for the wider population considering their net impact.

Growth of industrialization eventually means the utilization of more natural resources. While boosting up the industrial activities and focusing on production so that the country can become self-sufficient, the environment can turn out to be the last that comes into consideration in that growth strategy spectrum. One of the significant aspects of an economy that are prone to get affected by industrialization is the environment and overall carbon footprint of the country. With increased industrialization, natural resources seem to deplete at a faster pace, and that influences the overall wellbeing of the wider population. Both rural and

urban habitats in a community get affected, and there is a lot of pressure on these habitats in terms of shrinking of the resources that nature has provided (Dubey and Narayanan, 2010). These adverse effects ultimately raise questions on activities that are aimed at ensuring rapid industrial growth.

There is also a debate on the fact that as countries start getting more advanced, people considering moving to the urban areas, which may be a cause of the higher deteriorating environmental condition. Yuan et al. (2019) conducted a study on the association between urban environment and how the higher density of the population can lead to environmental degradation. The results of the study suggested that noise pollution is a significant issue in urban areas, and as the population of these areas starts to expand, the rate of higher environmental risk increases. It is so because a higher population leads to congestion in terms of housing and traffic as well that eventually affects the overall environment.

There are many examples of countries where industrialization has worsened the air, water, and soil quality and became clear evidence that industrialization leads to environmental degradation. For instance, Li et al. (2019) mentioned in their study that there seems to be an association between industrialization and environmental quality. The study was focused on China, and data from 2003–2017 was analyzed over 31 regions of the country. Throughout this period, activities of industrialization seemed to have affected the air quality in China constantly, which means that industrialization and environmental quality do not go hand in hand. It indicated that at the beginning, the environment gets worse as industrialization improves, but after a certain level,

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emissions decrease. However, this effect does not stay for long, and as the country becomes more industrialized, emissions start to rise that make the environment degrade again. Considering this in a longer term, it can be said that industrialization is not good for the environment in the first place because no matter what pace of industrialization the country adopts, the final impact on the environment may be negative.

To understand the aspects of industrialization, it is essential to know the factors that are responsible for this phenomenon, and that is how its effects and consequences can be broken down. In their research, Haraguchi et al. (2019) analyzed the driving factors for industrialization. They used 1970–2014 data from developing countries and explored how organizational, technological, and political changes in these nations led to growth or decline in industrialization. The results of the study revealed that industrialization is not a single-faceted concept, and many mechanisms play a role in its formation. These factors might include the country's initial economic condition before the phase of industrialization takes place, the political and strategic profile of the country, demography, and geography of the country and policy formation activities considering the current situation of the nation. While many countries are looking at enhancing their industrialization index, it is not surprising to miss out on the tough consequences of these activities on the economy and when the focus of a country is entirely on being more industrialized, looking at the subsequent environment might not be the first thing that is considered. Hence, it is crucial to understand the role industrialization plays in impeding the environmental quality of a country and what must be done to avoid it.

For countries in the Middle East, the need to analyze this topic is even more crucial since countries in this region are focusing a lot of improving their industrial growth and with the discovery of oil in the countries, there is a lot of focus on developing and sustaining that industry as a significant source of income. In those operations, exploration, drilling, and extraction and production of oil require activities that can lead to functions that increase CO₂ and other emissions in the environment. Further, growing oil revenues are investing for more urbanization by increasing spending on the infrastructure. Because of these facts, there is a need to explore how much industrialization and urbanization influence the environmental portfolio of these countries.

In the case of Saudi Arabia, road transportation seems to have emitted a large number of greenhouse gases that influence the environment in a negative way (Rahman et al., 2017). Another study that indirectly links carbon emissions with oil consumption was presented by Alkhatlan and Javid (2015) in which they narrated that being a major oil-producing country, higher oil consumption in Saudi Arabia, especially in the transport industry leads to higher CO₂ emissions. Additionally, as income in the country increases, so do CO₂ emissions. In their work, Mahmood and Alkhateeb (2017) mentioned that trade and environment in Saudi Arabia has a secure connection and provided evidence that with higher income in the country, CO₂ emissions start to rise. Still, as the income keeps increasing, the emissions start going backward, which indicates the existence of the environmental Kuznets curve (EKC). Another study corroborated this finding that EKC exists in the Kingdom, and with more financial development, the country consumes more energy, which eventually leads to higher CO₂ emissions (Mahmood et al., 2018). This impact can get influenced by other macroeconomic, industrial, and related aspects of an economy. For instance, Mahmood et al. (2020) argued that in oil-abundant economies, oil prices could lead to an acceleration in urbanization. Therefore, urbanization as a result of oil prices can have a positive effect on the CO₂ emissions in the Saudi Arabia. Similarly, Algarini (2020) found the Granger causality from income, energy consumption and energy production to the CO₂ emissions.

Samargandia (2017) conducted a study on the value addition in any sector, technological development, and the consequences of these improvements in the form of CO₂ emissions in Saudi Arabia. Contrary to the above studies, he mentioned that EKC does not exist in Saudi Arabia. Because EKC does not seem to prevail, considering the effects of industrialization on the environment is even more necessary because the environment is not prone to get better with more economic growth. It means that as the country gains more economic growth, it does not mean that the installation of new, advanced, and greener technology will lead to a reduction in CO₂ emissions. In fact, both technological advancement and emissions seem to grow in a linear way, which indicates that a faster industrial growth results in a quicker CO₂ emissions rate.

Further, the environmental effects of faster and ever-growing urbanization as a result of industrialization and economic growth are neglected in Saudi literature. It leaves space to research how much industrialization and urbanization impede environmental sustainability. To answer, we combine the industrialization and urbanization in a CO₂ emissions model and also care about the possible asymmetry in the relationships for an empirical contribution in Saudi environment literature. Conducting a consolidated study on industrialization and urbanization is crucial because these two concepts seem to be closely related. When economies start making industrial progress, which leads to economic prosperity, people start moving from rural areas to urban ones. Since these urban areas have a limited space to cater to the needs of residents, the result will be downward pressure on the available resource. Eventually, the environment has to take a hit, and water, air, noise, and other types of pollution start to become more common.

2. Literature review

Studies talk about how industrialization can lead to higher emission rates and hence, pollution. Hong et al. (2019) conducted a study on the carbon, nitrogen, and other toxic substances and pollution created by these in the industrialized environment of South Korea. The purpose of the study was to analyze how severe contamination can take place in industrialized areas and the ways this pollution can influence the overall environment portfolio of a locality. Industrialization was seen to affect not just air pollution but water and its quality as well. It leaves space to implement practical policies that can influence reduce the negative impacts of these chemicals so that the adverse impacts of industrial activities can be contained. Something similar was analyzed in China by Li et al. (2019) that argued about the fact that industrialization can have a substantial impact on the air quality of a country. Using 2003–2017 data over 31 regions in China, the results of the study were to evaluate the effect of industrialization on the environment of China. The findings made it pretty evident that no matter how contained the activities of industrialization are, the environment does not negatively impact that makes it a dire need to keep these activities in check and ensure that greener practices are used on a larger scale.

To justify the need for industrialization and its benefits, advocates usually use the argument of the EKC. According to the curve, there is always a level of convergence. As a country becomes more advanced, more environment-friendly technologies are involved in the system, which makes the emission rate and pollution generation go down. However, there are still skeptics that argue that EKC does not apply in some countries. For instance, Friedl and Getzner (2003) proved the N-shaped association between growth and emissions, which indicates that with more growth, emissions might start to fall, but there comes a time when they start to grow back again and then keep growing exponentially. A

similar N-shaped curve was argued to exist in China by [Du et al. \(2018\)](#), and they mentioned in their study that this relationship was seen in 27 capital cities in the country, and the results are valid for haze pollution from 2003–2017.

[Du and Xie \(2019\)](#) discussed the process of deindustrialization into consideration. Unlike other studies, the study did consider the existence of EKC. Nevertheless, the analysis did agree with the fact that when a country is making progress towards reducing its emissions and making the environment cleaner, the process is easier and smoother for countries that are deindustrializing compared to the ones that are still on the path of industrialization. The results of the study indirectly support ideas provided by other studies ([Dubey and Narayanan, 2010](#); [Hong et al., 2019](#); [Friedl and Getzner, 2003](#)) that industrialization does not play an essential role in keeping the environment cleaner. While these studies directly or indirectly talk about industrialization affecting the environmental condition of a country, there is not enough extensive research available on the Middle Eastern region that can provide a concrete finding of the association between the industrialization and emissions.

The results of industrialization can be mixed for countries depending on the economic sector they already have in place. Talking about the effects of industrialization on the environment, the outcome cannot only vary depending on the national economic condition but also on the smaller economic profiles within a country. [Liu et al. \(2016\)](#), for instance, mentioned in their study that industrialization and environment have a negative relationship and as industrialization grows in a country, the environment gets deteriorated. Nevertheless, it does not mean that industrialization is all bad for an economy since some benefits need to be considered. Especially talking about rural China, industrialization leads to higher off-farm employment opportunities for the people, which can offset the negative impacts that the environment has to deal with. This idea leaves space in the literature to analyze whether any other types of segregation are affected differently by industrialization in a country.

In their research, [Leveque and Saleh \(2018\)](#) did talk about the differences in the effects of industrialization on various segregated groups in a country. Moreover, [Ullah et al. \(2020\)](#) investigated the asymmetric effects of industrialization on the CO₂ emission in Pakistan. They found positive effects of industrialization, deindustrialization, urbanization, and income on CO₂ emissions. The asymmetry was also corroborated through a different magnitude of the impact of deindustrialization and industrialization. [Sbia et al. \(2017\)](#) found the inverted U-shaped relationship between urbanization and electricity consumption in the UAE. Hence, urbanization had a positive impact on energy consumption, but after some threshold, it helped to reduce electricity consumption. [Shahbaz et al. \(2014\)](#) found that urbanization had a positive impact on energy emissions in the UAE. But, exports and electricity consumption were reduced the energy emissions. [Al-Mulali et al. \(2015\)](#) found that urbanization, income, and financial development had positive effects on the CO₂ emissions in Europe. On the other hand, trade openness and renewable electricity were helped to reduce CO₂ emissions.

In the urban-environment study, [Dong et al. \(2019\)](#) found that there is a double-threshold impact of urbanization on emissions in developed countries. However, when these countries are on the lower scale of urbanization, there is not much sensitivity in the environment to these activities. As the country starts moving towards the middle stage of urbanization, the effects on the environment start getting more intense and harmful. Industrialization has some obvious impacts on an economy, and as a country starts focusing on improving its industry, the rate of emissions increase, which eventually degrades the environment. In higher-income countries, the ultimate impact might not be as destructive since

they have strong financial and technological systems to make up for the loss. However, it does not mean that the overall effect of industrialization becomes positive on the environment.

According to [Yuan et al. \(2019\)](#), urbanization can be a significant source of noise pollution in the areas which eventually affects the environment in an adverse way. The situation can get worse when more people start moving to the urban areas and tackling the issue of congestion; high-rise residential buildings are constructed, which can eventually increase noise pollution. The idea caters to the concept of increasing urban population and urbanization at the same time since both are interrelated in many ways. The study provided a policy implication for residential building owners to consider spatial building designs to tackle the issue of environment, and there must be a ratio of business, industrial and residential urbanization that can help mitigate the harmful effects of higher population and urbanization on the environment. [Farhani and Ozturk \(2015\)](#) found that financial development and urbanization have positive impact on CO₂ emissions, and trade openness helped to reduce CO₂ emissions in Tunisia.

Urbanization has an impactful role in the development of the environmental profile of a country, and it can make or break the entire concept of a green environment for a nation. A study was conducted by [Martinez et al. \(2018\)](#) to observe the understanding of urbanization about the idea of environment and mitigation of environmentally degrading activities. The results of the study suggested that urbanization does have an understanding of climate change and also believe that it is real. Although the results of the study do not directly indicate the role that this population plays in the environment of a country, the underlying factors assist in realizing that this population can play a strong role in the mitigation policies for a better and cleaner environment.

[Chernwchan \(2012\)](#) argued that as an economy develops, there are clear and intense impacts of industrialization on the environment that cannot be ignored. Using data from 157 countries from 1970–2000, it was found that 1% increase in industrialization activities can lead up to over 11% emissions per capita in a country. [Liu and Bae \(2018\)](#) provided a similar analysis and mentioned in their research that industrialization can lead to short and long-term effects on the environment. They mentioned that there is a causal relationship between urbanization, industrialization, and CO₂ emissions. Based on the result, there is a need to strategize activities of industrialization so that an optimal level of industry-related activities and environmental structure can be found. It would assist in improving energy efficiency while ensuring innovation and technological advancement at the same time.

In the environment literature, the testing of asymmetry is also fashionable nowadays. For the first time, [Shahbaz et al. \(2016\)](#) studied the determinants of CO₂ emissions of Pakistan in asymmetrical settings and also found the asymmetry in the relationships. Further, they talk about the fact that inefficiency in the use of technology can increase CO₂ emissions and degrade the environment. Although financial market development (FMD) and economic growth can degrade the environment, efficient energy-saving technologies can be used to reduce the harmful consequences for the environment. Moreover, a study linked the asymmetrical relationship between trade and energy consumption in Egypt and found the asymmetrical positive effect of trade on energy consumption ([Alkhateeb and Mahmood, 2019](#)), which may have environmental effects as well. On the other hand, [Mahmood et al. \(2019\)](#) found the asymmetric impact of trade openness on emissions, and with increased trade leading to higher CO₂ emissions, they also proved the existence of EKC in Tunisia.

A vast literature is available in the relationship of industrialization, urbanization, and pollution emissions, but such literature

is missing in the oil-exporting countries or Middle East countries' case. Considering the fact that Saudia is a largest oil exporting nation and is putting a lot of focus on developing its oil industry, there is a need to refine the search on Saudia to explore the possibility of this relationship between industrialization, urbanization and the environment.

3. Theoretical framework and methods

Before comprehending the extent to which urbanization and industrialization have an impact on any economy, it is crucial to understand the ways these two segments play a role in the macroeconomic structure of a country. Once the scope and intensity of this role are understood, it becomes pertinent to analyze how and why the environment would be affected through higher emission rates. When it comes to getting a maximum benefit out of industrialization and ensuring that the environment also stays in the most optimal situation, the level of energy consumption and the proportion of renewables and non-renewables must be taken into account as well (Amri, 2019). Hence, it is up to the country to decide how much benefit it wants to gain from the industrialization and how far it wants to go to streamline energy consumption for better trade relations while still considering the environment.

Theoretical explanation of how industrialization can lead to affecting the environment in a negative way has been explored in the literature (Dubey and Narayanan, 2010; Li et al., 2019; Hong et al., 2019; Liu and Bae, 2018). In many instances, the idea is associated with countries turning towards using more natural resources and increasing their energy consumption to be able to improve the industrial profile of the country. To get ahead in the game of economic and strategic competition, countries usually rely a lot on their industries and business operations are designed around enhancing the industry (Liu et al., 2018). Something similar is taking place in the Middle East and especially Saudi Arabia as well. In the region, countries are focusing on improving their income, trade, production, and financial stability (Shahbaz et al., 2019). Since oil is a significant commodity discovered in the country a few decades ago, there is a lot of focus on making sure that this industry reaches its maximum potential.

The role of urbanization and industrialization in environmental degradation is theoretical and practically sound in many ways. Additionally, there is also a possibility that these factors are interlinked that supports the argument of their co-existence. Once a country explores the routes of economic progress and starts moving towards focusing on the industry more often, the result is a higher level of industrialization. As a result, more and more fuel is burnt in the industry so the country can develop its industrial sector to become not only self-sufficient in industrial material but also be able to export products to other countries and improve its export portfolio. As the people in the country start seeing this growth in the industry and most of the activities in the more advanced part of the country, a higher inflow of population can be expected to the urban areas which are essential because of people looking for jobs in the industrial sector and exploring their contribution opportunities. As more people keep moving to the urban areas, urbanization improves, and more and more natural resources are used in the form of energy because of growing urbanization. Eventually, the final result of a focus on the industry, urbanization increases that can subsequently put negative pressure on the environment, leading to potential reasons for global warming (Wang and Wang, 2017).

However, the intensity of impacts industrialization and urbanization have on the environment throughout the country is still scant in the literature. To meet a certain level of urbanization and industrialization, it becomes inevitable for a country to avoid

energy consumption since most activities do require the involvement of energy and natural resources. In this pursuit of improving the industrial profile of the country, there is no evidence that the environmental profile gets unaffected. The eventual effects, however, can vary depending on where the country starts from in the beginning and how long is the journey to meeting that goal (Li and Lin, 2015). Nevertheless, the environment does seem to have a prominent role in that journey to industrialization and urbanization. To analyze their environmental role, below equation is hypothesized:

$$COPC_t = f(IND_t, URB_t) \tag{1}$$

$COPC_t$ is CO_2 emissions per capita, a proxy of pollution emissions, and taken in natural logarithm form. IND_t is a natural logarithm of industrial value-added per capita, a proxy of industrialization. URB_t is urban population percentage of total population and converted into a natural logarithm. t is a maximum available period 1968–2014. Both industrialization and urbanization are anticipated to have a positive influence on emissions. All series are sourced from the World Bank (2019). At first, the unit root test of Ng and Perron (2001) will be employed to verify the stationarity of the series. Then, a cointegration will be tested to validate the long and short-run relations using Pesaran et al. (2001) linear ARDL methodology as follows:

$$\begin{aligned} \Delta COPC_t = & \gamma_0 + \gamma_1 COPC_{t-1} + \gamma_2 IND_{t-1} \\ & + \gamma_3 URB_{t-1} + \sum_{j=1}^{m1} v_{1j} \Delta COPC_{t-j} \\ & + \sum_{j=0}^{m2} v_{2j} \Delta IND_{t-j} + \sum_{j=0}^{m3} v_{3j} \Delta URB_{t-j} + e_t \end{aligned} \tag{2}$$

Eq. (2) will be first tested for cointegration through bound testing on a H_0 of $\gamma_1 = \gamma_2 = \gamma_3 = 0$, and rejection of it using critical values of Kripfganz and Schneider (2018) can prove cointegration. Further, the short-run relationship can also be corroborated by introducing and capturing negative parameters of error correction term (ECT_{t-1}) in the above equation. Moreover, long-run and short-run impacts can be discussed through normalized γ and v respectively. Keynes (1936) argued that macroeconomic variables do not behave in the same way during the rises and falls. The increasing trend shifted into a decreasing trend suddenly and sharply. Therefore, the rise and fall of the explanatory variable do not have the same influence on the dependent variable; hence, asymmetry can be anticipated in the relationship. We have two independent variables in the analysis. Where, urbanization has a continues increasing trend throughout the sample period. However, industrialization has a mix of ups and downs. So following, Shin et al. (2014), we convert the series IND_t into $INDP_t$ and $INDN_t$ in the following equations:

$$INDP_t = \sum_{i=1}^t \Delta IND_i^+ = \sum_{i=1}^t \max(\Delta IND_i, 0) \tag{3}$$

$$INDN_t = \sum_{i=1}^t \Delta IND_i^- = \sum_{i=1}^t \min(\Delta IND_i, 0) \tag{4}$$

$INDP_t$ and $INDN_t$ are partial sums of only positive and only negative deviations in IND_t , respectively. Now, we replaced $INDP_t$ and $INDN_t$ with IND_t in Eq. (2), and nonlinear ARDL has the following shape:

$$\begin{aligned} \Delta COPC_t = & \theta_0 + \theta_1 COPC_{t-1} + \theta_2 INDP_{t-1} + \theta_3 INDN_{t-1} \\ & + \theta_4 URB_{t-1} + \sum_{j=1}^{m1} \lambda_{1j} \Delta COPC_{t-j} \\ & + \sum_{j=0}^{m2} \lambda_{2j} \Delta INDP_{t-j} + \sum_{j=0}^{m3} \lambda_{3j} \Delta INDN_{t-j} + \sum_{j=0}^{m4} \lambda_{4j} \Delta URB_{t-j} + \xi_t \end{aligned} \tag{5}$$

Table 1
Unit root analysis.

| Variable | MZa | MZt | MSB | MPT |
|-----------------|------------|-----------|----------|----------|
| $COPC_t$ | -5.8845 | -1.7106 | 0.2907 | 15.4784 |
| IND_t | -5.1139 | -1.5843 | 0.3098 | 17.7524 |
| $INDP_t$ | -1.9495 | -0.8104 | 0.4157 | 36.1237 |
| $INDN_t$ | -4.4698 | -1.3842 | 0.3097 | 19.5026 |
| URB_t | -1.0016 | -0.4978 | 0.4970 | 52.1812 |
| $\Delta COPC_t$ | -22.4021** | -3.3298** | 0.1486** | 4.1702** |
| ΔIND_t | -22.2526** | -3.3261** | 0.1494** | 4.1525** |
| $\Delta INDP_t$ | -22.0935** | -3.3234** | 0.1504** | 4.1262** |
| $\Delta INDN_t$ | -19.3069** | -3.1025** | 0.1607** | 4.7475** |
| ΔURB_t | -21.9684** | -3.3133** | 0.1508** | 4.1538** |

**Is showing stationarity on 5% level of significance.

Now, Eq. (5) will be estimated, as discussed in Eq. (2).

4. Results and discussions

Table 1 epitomizes the results using Ng and Perron (2001). It is cleared from the results that considering all statistics; all variables are level non-stationary and differenced stationary. Yet, the integration level is one, and we continue for cointegration.

For the long run and short run results, we regress both linear and nonlinear ARDL models following procedures discussed before and present the results in Table 2. Bound test corroborated the cointegration by rejecting the H_0 of no-cointegration at 1% level of significance for both models as estimated F-values are larger than upper bound value. Bound test signifies the superiority of nonlinear model over linear as the estimated F-value of nonlinear mode is higher than the linear model. The diagnostic tests reported in the last four rows of Table 2 are showing p-values are more than 0.1, and both models' results are econometrically sound. Further, the results of CUSUM in Fig. 1 show that both models' parameters are stable. However, CUSUMsq corroborated stability only for the nonlinear model. Hence, nonlinear models' estimates are stable and preferred by CUSUMsq test and showed superiority over the linear model, which is partially stable. The parameters of ECT_{t-1} are negative and are showing that both models have adjusted on the long run steady path at 45.94% and 59.11% per year respectively after any short-run disequilibrium.

Long-run results of linear ARDL in Table 2 show that industrialization has a positive impact on the emissions, and 1% rise/fall in IND_t has 0.4148% rise/fall effect on the $COPC_t$. Further, the urbanization is adding fuel by a positive elastic effect on the emissions, and 1% increase in URB_t has 5.9035% increase in the $COPC_t$. The effect of decreasing urbanization cannot be discussed as the urbanization has only positive trend during the sample period. In the short run, industrialization has again positive influence on the emissions even same positive effect is also coming from one-year lag. Further, the urbanization has a positive effect on the emissions. Both short-run positive effects of urbanization and industrialization are found larger than the long run effects.

Both increasing and decreasing industrialization variables ($INDP_t$ and $INDN_t$) have positive effects on the emissions in the nonlinear model results. However, the magnitude of $INDP_t$ is found greater in volume and statistically more significant than that of $INDN_t$. It means that the positive effect of increasing industrialization is more consistent throughout the sample period with lesser standard error than that of the effect of decreasing industrialization. The elasticity parameter shows that 1% increasing industrialization is responsible for 0.8288% increase in emissions, and 1% decreasing industrialization can reduce only 0.1771% of emissions. The results indicate that when industrialization is increasing in a country, the environment is more likely to get negatively affected compared to the positive effects when it

Table 2
ARDL and non-linear ARDL models.

| Variable | ARDL | Nonlinear ARDL |
|---------------------|--|--|
| Long run | | |
| IND_t | 0.4148 (0.0046) | |
| $INDP_t$ | | 0.8288 (0.0000) |
| $INDN_t$ | | 0.1771 (0.0960) |
| Wald Test | | 6.1016 (0.0179) |
| URB_t | 5.9035 (0.0006) | 2.6659 (0.0054) |
| Intercept | -27.7881 (0.0007) | -10.5265 (0.0098) |
| Short run | | |
| ΔIND_t | 0.4982 (0.0000) | |
| ΔIND_{t-1} | 0.1788 (0.0925) | |
| $\Delta INDP_t$ | | 0.4899 (0.0000) |
| $\Delta INDN_t$ | | 0.1047 (0.1406) |
| Wald Test | | 12.4874 (0.0011) |
| ΔURB_t | 26.2986 (0.0001) | 29.7814 (0.0008) |
| ECT_{t-1} | -0.4594 (0.0002) | -0.5911 (0.0000) |
| Diagnostics | | |
| Bound Test | F-value = 5.4276 At 1% 4.0934–4.9199 At 5% 3.0836–3.8155 At 10% 2.6175–3.2969 | F-value = 7.9064 At 1% 3.6031–4.5632 At 5% 2.7620–3.6167 At 10% 2.3688–3.1663 |
| F-Hetro | 0.8297 (0.5544) | 1.7730 (0.1450) |
| F-Serial | 0.3355 (0.7172) | 0.0918 (0.9125) |
| F-RESET | 0.9097 (0.3464) | 1.6919 (0.2010) |
| χ^2 -Normality | 4.0649 (0.1310) | 2.9030 (0.2342) |

Note: () shows probability value.

is decreasing. The results have theoretical significance as well since Li et al. (2019), Hong et al. (2019) and Dong et al. (2019) and many more suggested how technological advancement and industrial growth in a country can lead to higher emission rates which eventually negatively affect the environment. Moreover, this asymmetry in the magnitude of effects of $INDP_t$ and $INDN_t$ is corroborated by the Wald test as it rejects the H_0 of symmetry at 1% level of significance. Further, the urbanization has a positive impact, but this effect in the nonlinear model is found lesser than that of the linear model's result. The linear model's result can be considered as biased because asymmetry has been proved statistically significant, and ignoring asymmetrical effects of industrialization in the linear model can be claimed for a specification biasness. Further, 1% increase in urbanization is responsible for 2.6659% increase in emissions. This result is also supported by other studies, e.g. Yuan et al. (2019), and Wang and Wang (2017) in which urbanization is expected to lead to environmental degradation. Nevertheless, like Martinez et al. (2018) suggested, the urbanization can also play a role in tackling the climate change issue since there is a higher awareness in this population.

5. Conclusions

Industrialization is growing due to diversification policies of Saudi Arabia, which have environmental consequences in turn.

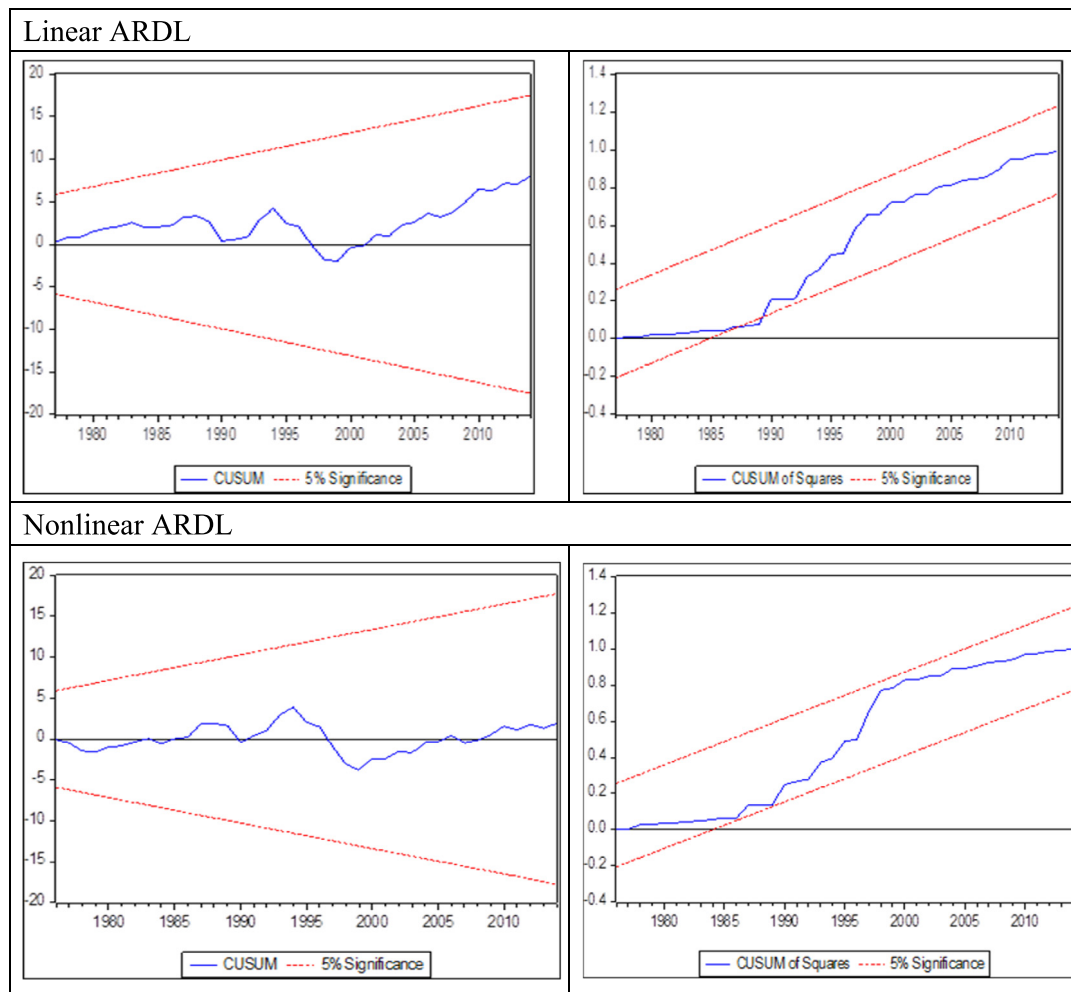


Fig. 1. CUSUM and CUSUMsq tests.

The growth of industrialization and urbanization are pertinent for economic well-being, but its environmental effects cannot be ignored. This article tests the effects of industrialization and urbanization on the CO₂ emissions per capita using a period 1968–2014 in the linear and nonlinear setting. We found the cointegration and short-run relationships in the models, and both industrialization and urbanization are found responsible for environmental degradation through increasing CO₂ emissions in the linear and nonlinear analyses. The elasticity of increasing industrialization is found less than one but larger than that of decreasing industrialization.

The asymmetrical impact of industrialization is tested in the Saudi context through the Wald test, and asymmetry is proved valid by rejecting the symmetrical effect. As a country becomes more industrialized, there is a higher possibility of using natural resources that can lead to many types of environmental degradations. Additionally, the results indicated that a higher rate of urbanization tends to have negative impacts on the environment due to the exploitation of natural resources. The elasticity of urbanization is found more than one in both linear and nonlinear models. Considering the findings of the study, it is suggested that the Saudi government devises a more inclusive environment plan in the coming years and make the environment policies more stringent to avoid any future inconveniences. While focusing on industrialization and urbanization, the government must consider how they might impact the environment and produce a negative net impact.

Saudi Arabia is committed to contribute to the Sustainable Development Goals (SDGs) set up by the United Nations. The

country also provided a [First Voluntary National Review \(2018\)](#) to explore how close the country is to meeting these SDGs. Multiple participations, including Paris Climate accord, Koyoto Protocol, Montreal Protocol, and Vision 2030, are prioritizing a sustainable climate where sustainable sources of energy are used. Under the National Action Plan, the country is aiming to cut down its CO₂ emissions by 130 million tonnes by 2030. To achieve that goal, the findings of this study can play a useful role since policymaking can be directed using these results. The country can try to focus more on spreading the network of energy-efficient public transport across the country so that people prefer those options other than fossil-fuel vehicles with a rapid urbanization. Removing subsidies from gas and other high-emission can be another way. Additionally, it is crucial that too much emphasis on urbanization and industrialization needs to be reconsidered since their effects might not always be positive for the long-run environmental health. In the SDGs, Saudi Arabia has planned to move to the cleaner energy use but could not achieve a satisfactory level of cleaner energy use till now. Therefore, the use of fossil fuel energy, because of increasing industrialization and urbanization, should be taxed to avoid its environmental consequences.

5.1. Limitation and future direction

The present research focused on investigating the asymmetric effect of industrialization and the symmetric impact of urbanization on CO₂ emissions. A practical limitation of this paper is that the sample period closes in 2014 due to an operation cease of

Carbon Dioxide Information Analysis Center. Therefore, a future study on this subject should develop an alternative pollution emissions' proxy to update the sample. Secondly, this present study ignores the market-based regulation or policy variables in the pollution emissions model due to un-availability of Saudi data on variables. However, excess to such kind of data can be a useful contribution to the future study. Lastly, a future study may consider the role of industrialization on CO₂ emissions of the entire Gulf Cooperation Council (GCC) region, if data of a reasonable time sample can be obtained from all GCC countries.

CRedit authorship contribution statement

Haider Mahmood: Conceptualization, Methodology, Software, Writing - original draft. **Tarek Tawfik Yousef Alkhateeb:** Data curation, Visualization, Investigation. **Maham Furqan:** Software, Validation, 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

The dataset analyzed during the current study is available in the Dataverse repository: <https://doi.org/10.7910/DVN/WEEPP0>

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