INDUSTRIAL CARBON FOOTPRINTS AND HUMAN LONGEVITY IN SAUDI ARABIA, IMPLICATIONS FOR ACHIEVING SUSTAINABLE DEVELOPMENT GOAL 3

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Abstract. This study examined the nexus between industrial carbon footprints and human life span in Saudi Arabia over the period from 1990 to 2023. In estimating the collected data, Canonical Cointegrating Regression and Pairwise Granger Causality Tests were utilized, which led to the following findings. Electric power consumption and human life span have a significant positive relationship. Industrial carbon footprints showed a significant positive impact on human life span. Further evidence from the Granger causality test revealed that a uni-directional causality flows from industrial carbon footprints to human life span. A one-way directional causality flows from industrial carbon footprints to electric power consumption. The above results show These results indicate that industrial carbon footprints are a key driver of human life span in Saudi Arabia in Saudi Arabia. In view of these findings, this study recommends that the policymakers in Saudi Arabia should sustain a robust ecological balance and industrial expansion while promoting human health at all ages. This will further enhance the country`s commitment towards the achievement of the SDG 3- ensuring healthy lives and well-being for all at all ages without in the phase of the industrial revolution.
Keywords: *CO_2, life span, SDG3, industries, Saudi Arabia*

Introduction

Life expectancy (LE) is a key indicator used globally to determine the overall health, well-being, and development status of populations. In Saudi Arabia, life expectancy has gradually increased over the past few decades mainly due to the improvements in healthcare provision, expanded access to healthcare services, heightened public health awareness, and increased government expenditure on the health sector. Improved surgical practices, medical technology, and control over disease have also contributed to this trend. According to Sibai et al. (2017) and Basheikh et al. (2021), the Kingdom’s life expectancy is estimated to exceed 80 years by 2030. These estimates align with Saudi Arabia’s Vision 2030 targets for enhancing quality of life and public health outcomes.

However, despite significant contributions by medicine, research tends to emphasize how population health is not solely determined by health systems. As Irandoust et al. (2024) point out, no more than 25% of health outcomes are the result of healthcare, the other 75% determined by non-medical factors which in the past have been called the social determinants of health (SDoH). Income, education, diet, housing, and most importantly, environmental quality are among these. Of the environmental determinants, air pollution, most notably in the forms of carbon emissions and particulate matter, has a

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well-documented history of heightening respiratory and cardiovascular diseases, both of which are significant predictors of life expectancy (Wirayuda et al., 2025; Heuveline, 2022).

In this regard, Saudi Arabia presents a paradoxical example. While it has achieved significant progress in promoting health care and longevity, it is also a leading per capita carbon emitter in the world. Saudi Arabia emits more than 19 tons of CO_2 per capita annually, compared to the global average of approximately 4.8 tons, according to Aziz et al. (2022). Much of this environmental expense is attributable to the Kingdom's highly industrialized economy, high consumption of fossil fuels, and rapid urbanization. While industrialization is a cornerstone of economic growth, it generally comes with a significant environmental cost—one that might eradicate the very health benefits gained through medical progress (Chikezie Ekwueme et al., 2023; Omri et al., 2023).

Environmental deterioration, measured by variables such as carbon emissions, ecological footprint, and air quality, can degrade ecosystems and human health. Jarallah et al. (2024) argue that mounting environmental pressure not only threatens biodiversity but the human situation, namely through disease and reductions in life expectancy. Industrial processes like the oil, gas, petrochemical, and manufacturing industries form Saudi Arabia's carbon footprint. In addition to affecting the climate, such emissions also increase ambient air pollution, thus increasing risks of chronic respiratory diseases, premature mortality, and reduced quality of life.

Although the theoretical link between quality and environmental health is obvious, empirical studies on the immediate impact of carbon emissions from industries on Saudi Arabian life expectancy are not easily found. A lot of current studies either touch upon air pollution in general terms or do not break down the industrial sources' effects. Thus, this study is an important knowledge lacuna, particularly when it comes to the trade-off between economic growth and human health.

This study seeks to fill that gap by analyzing the connection between Saudi Arabia's industrial carbon footprint and life expectancy over time. Employing empirical trends and observations, the study seeks to present evidence-based recommendations for policymakers to weigh economic growth and environmental sustainability and long-term public health consequences. In so doing, it aligns with Saudi Arabia's Vision 2030 programs of enhanced environmental stewardship and a healthier and more sustainable population. In view of the above, this study sets this hypothesis.

H_0: Industrial carbon footprints do not contribute significant impact to human longevity in Saudi Arabia

H_1: Industrial carbon footprints do contribute significant impact to human longevity in Saudi Arabia

Literature review

The section reveals the past insight from previous studies on the current topic so as to draw inferences on what has been done such as the lapses and gap that is yet to be filled with respect to recent happenings around the world and most especially within the Asia region. This review is highly significant because it will help to contribute to the body of academic literature in Asia.

Wang et al. (2016) conducted a study on the relationship between urbanization, energy use and carbon emissions: evidence from a panel of Association of Southeast Asian Nations (ASEAN) countries from 1980–2009. The study used a panel data and the fully

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modified ordinary least analysis technique to analyze the data. The findings from the study revealed that a 1% increase in urban population will lead to 0.20% increase on carbon emissions. Furthermore, the study also disclosed a unilateral short-run causal relationship that exist between urbanization to energy and urbanization to carbon emissions given sequel to the granger causality test results.

Lee (2019) in his opinion examined the Lagged effect of exports, industrialization and urbanization on carbon footprint in Southeast Asia from 1970-2017. The purpose of the study is to look at the lagged causal effect between carbon footprint and economic development policies in South Asia. Given the purpose of the study, panel data was used which cut across five nations in South Asia with 240 observations. The study used several analysis techniques such as the unit root test and cointegration test for analysis. Based on the outcome of the analysis, the findings from the study revealed that economic growth, urbanization, industrialization and (1) exports all have a lagged negative effect on carbon footprint in the short run whereas in the long run, (2) the variables under review for the study thus have a long-run relationship with carbon foot print. Sequel to the findings and discovery, the study therefore concluded that economic growth, industrialization, urbanization and exports are substantial reasons for the increase of carbon foot print within the Southeast Asia region. Additionally, based on the findings, the study therefore opined that the environmental policy with respect to export led growth on the countries in the region have not been effective as result of the fact that the growth that has been achieved so far was at the detriment of harming the environment due to high cost.

Tan et al. (2020) carried out a study on same subject like Lee (2019) and Wang et al. (2016) on economic growth, urbanization and carbon emissions: evidenced from selected ASEAN countries. However, just like other researchers mentioned above, the study of Tan et al. (2020) undertook a different purpose which has to do with assessing and comparing the growth pattern between five different selected ASEAN countries which include Vietnam, Thailand, Philippines, Malaysia and Indonesia. The findings from the study based on the assessment revealed that all the countries have achieved and recorded a minimum of 4% growth in 2018. On the basis of individual country, the findings revealed that Indonesia emerged as the country with the largest growth in terms of total value added within the manufacturing sector while Vietnam emerged as the second largest economic growth in terms of value added in the same industry as mentioned above (manufacturing). Furthermore, the findings revealed that from all the countries that was examined, Indonesia urban population is the largest but Malaysia emerges as the country having the highest growth rate in terms of urbanization and carbon emissions per capital.

Rehman and Rehman (2022) also contributed to the subject under review by looking at the nexus between energy consumption, population growth, urbanization, carbon emission and economic growth in Asia. The study took a different approach so as to fill the gap from previous studies such as the study of Wang et al. (2016) and Lee (2019) who examined all the countries within region, and Hong et al. (2020) who selected some countries within the region. Given the gap from previous study, Rehman and Rehman (2022) decided to use a different method of analysis "Grey relational analysis" to analyze the impact of energy use, gross domestic product per capita, population growth, urbanization on carbon emission with respect to some selected countries which include Bangladesh, Pakistan, Indonesia, India and China just as the study of Hong et al. (2020) with different set of countries.

Following the choice of countries under review, the integrated impact of the explanatory variables was examined using weight and ranking for the year 2001-2014.

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However, in order to determine which country contribute more of carbon emission by ranking, the conservative minimax technique was used based on the second synthetic grey analysis. Furthermore, in determining the optimization by looking at which of the explanatory variable have the greatest influence on CO_2 emissions, the preference by similarity to ideal solution (G-TOPSIS) analysis technique was employed. Prior to the outcome of the various analysis techniques that was used by the researchers, the findings revealed that India serves as a major player contributing most of carbon emission in the Asia region which is a resultant effect of increase in population growth and economic development whereas for China and Pakistan, urbanization and use of energy are determinant of carbon emission. Moreover, the (G-TOSIS) analysis technique revealed that the unsustainable growth of population and CO2 emissions does have a positive and direct causal relationship which leads to environmental damage.

Chopra et al. (2022) in the same year like Rehman and Rehman (2022) analyzed the role of natural resources and renewable energy for sustainable agriculture in ASEAN countries in order to probe and verify if carbon emissions and deforestation affect agricultural productivity. The study used the Mean Group (MG) class estimators, to mitigate and curtail the cross-sectional dependence issues the data. The findings from the study unraveled a dynamic but concise discovery. To start with, the outcome of the analysis revealed that carbon emission emanating from environmental degradation does affect and reduces the productivity of agriculture within the region. Furthermore, variables such as forest area and natural resources portrayed a negative impact on the productivity of the agricultural but renewable energy exhibited a positive impact on agricultural productivity. Additionally, the result from the causality test disclosed a bi-directional causal relationship from renewable energy to agricultural productivity whereas other variables exhibited a uni-directional relationship.

Raihan (2023) in his view also contributed to the body of literature given that previous studies such as Hong et al. (2020) and Rehman and Rehman (2022) has examined selected countries within the region and all the countries in the region, decided to streamline his study to a particular country so as to fill up the gap in literature by examining the relationship that exist between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in Philippines by using a different analysis techniques such the Autoregressive Distributed Lag (ARDL) and the Dynamic Ordinary Least Squares (DOLS) to analyze the data from the period of 1990-2020. Given the outcome of the analysis, the findings revealed that a unit increase among the variables under review will proportionately increase CO_2 emissions by 0.16%, 1.25%, 0.06%, and 0.02% in the Philippines, respectively. Also, a 1% increase in renewable energy consumption, agricultural productivity, and forest area will result in CO_2 emissions reductions of 1.50%, 0.20%, and 3.46%, respectively.

Naseem et al. (2020) assessed the linkage between that exists between energy usage, farming, food availability and greenhouse gases in Pakistan between 1970 and 2019. The authors made use of an asymmetric Autoregressive Distributed Lag (ARDL). From findings of the study, farming activities caused an unbalance influence on greenhouse gases in both the immediate and long periods. Golasa et al. (2021) investigated how the sources of pollution from carbon dioxide pollution and farming alongside identification of the kinds of farmlands where there was a possibility of minimizing carbon dioxide pollution via efficient consumption of power. It was discovered from the study that when various sources of pollution were analyzed, pollution originated from the manufacturing

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of power has a moderate effect. The emissions from power plant were the major source of GHG emissions only emanated from the horticulture crop category. The largest emissions were coming from the manufacturing of cattle. In another study, Sibanda and Ndlela (2020) appraised the network between greenhouse gases, manufacturing production and crop production in South Africa from 1960 to 2017. While estimating the bivariate Autoregressive Distributed Lag method, the authors demonstrated that outputs from agriculture and industry had insignificant impact on greenhouse gases. However, manufacturing production and greenhouse gases contributed a major impact on crop production. Further findings in the study indicated that declining agricultural productivity due to global warming had an adverse effect on food availability.

Having utilized the Mean Group (MG) class estimators, Chopra et al. (2022) interrogated the benefits of biodiversity and green power for agricultural sustainability in ASEAN nations. The study argued that agricultural output was lowered by deterioration of the environment in the area under investigation. Further evidence in the study showed that the employment of clean power sources aided crop production, both environmental factors and the forest area caused a detrimental impact on the industrial outputs. The results proved that ASEAN markets' exposure to globalization did not metamorphose to a rise in farming output, although this region of the world represents one of the most connected markets to the globe. The causality analyses indicated a bidirectional causality running from agricultural output to green power use. Nugroho et al. (2023) conducted a study focusing on the connection between agrarian output and global warming in both advanced and emerging markets between 1990 and 2020. In the process of the research, data from twenty-four advanced markets and seventy-one emerging markets were utilized with the application of the three-stage least squares technique. From the study, it was evident from the study that farming output caused humidity to expand in emerging markets but decline in advanced nations. Climate change influenced a decline in farming outputs in both emerging and industrialized markets. However, products from farming activities were more vulnerable to temperature variations in advanced nations.

Methodology

This section explains technique of estimation adopted, nature of data, scope of the study and operational definition of various variables of interest in the study (*Fig. 1*).

Model specification

This study follows Aderemi et al. (2022, 2021) and Osabohien et al. (2021) in specifying the appropriate model required to address the objective of the study. The model is therefore specified as follows.

$$\text{Human Life Span} = \text{F (Industrial Carbon Footprints)} \qquad \text{(Eq.1)}$$

Introducing a control variable - electric power consumption to enhance the robustness of the model, the equation is restated is stated in this form as.

$$\mathrm{HLS_t} = \alpha_0 + \alpha_1 \mathrm{ICF_t} + \alpha_2\ \mathrm{ELC_t} + \mathrm{u_t} \qquad \text{(Eq.2)}$$

where HLS means human life span, ICF represents industrial carbon footprints and ELC shows electric power combustion and u stands for error term.

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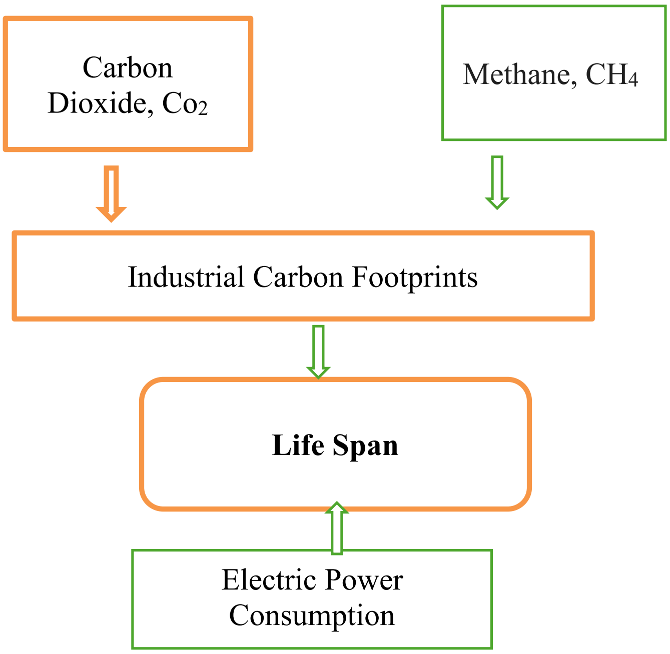

Figure 1. *A schematic graph of the nexus among industrial carbon footprints and human life span in Saudi Arabia (Source: Authors, 2025)*

Estimation procedures

The appropriate method of estimation for the study is Canonical Cointegrating Regression (CCR). This technique of analysis is used to determine unknown parameters in the study. In this regression, deterministic variables, integrated processes and their powers are included as regressors. Across equations, the errors are allowed to be correlated in the process of time and with the regressors as well. Also, the structure of the regression is set in such a way that the usual asymptotically efficient estimators are produced by the least squares procedure. Descriptive statistics as well. Descriptive statistics shows how variables under consideration were distributed over the periods of the analysis, and the mean value was estimated by summing up all the observations from 1990 to 2023 and divided by the number of the years, which is 34. Moreover, Eviews 10 econometrics software was used to run the analysis.

Furthermore, to estimate the direction of causality between industrial carbon footprints and human life span in Saudi Arabia, the principle adopted in the works of Lawal et al. (2022) and Opele et al. (2022) was followed in this study. The specification of the principle is included in model 4-7 as follows.

$$HLS_{it} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \, HLS_{2it-i} + \sum_{j=1}^{n} \beta_j \, ICF_{it-j} + \sum_{k=1}^{n} \delta_k \, ELC_{it-k} + U_{1it} \quad \text{(Eq.3)}$$

$$ICF_{it} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \, ICF_{2it-i} + \sum_{j=1}^{n} \beta_j \, HLS_{it-j} + \sum_{k=1}^{n} \delta_k \, ELC_{it-k} + U_{1it} \quad \text{(Eq.4)}$$

$$ELC_{it} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \, ELC_{2it-i} + \sum_{j=1}^{n} \beta_j \, HLS_{it-j} + \sum_{k=1}^{n} \delta_k \, ELC_{it-k} + U_{1it} \quad \text{(Eq.5)}$$

Table 1 shows the operation definition of the study variables.

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***Table 1.** Measurement and operation definitions of variables*

Abbreviations	Description of variables	Unit	Source
HLS	Human life span. This is measured as life expectancy	Years	World Development Indicators
ICF	Industrial carbon footprints. This measured as CO_2 from industrial combustion energy	(Mt CO_2e)	World Development Indicators
EPC	Electric power combustion. This is measured as electric power consumption per capita	kWh per capita	World Development Indicators

"t" is the time frame of the study, spanning between 1990 and 2023. It important to stress that the a priori expectation is as follows $\alpha_1 < 0$ and $\alpha_2 > 0$

Results

Table 2 reveals the result of the summary statistics for the study which provides a valuable insight in explaining the variability and characteristics of the variables under consideration. Human life span, HLS ranges between 78.7 years and 68.8 years with a mean value of 74.4 years. This implies that in the past three decades (1990-2023), average human life span in Saudi Arabia is above 74 years. Consequently, electric power consumption, EPC possesses a minimum value of 6129.583 kWh per capita and maximum value of 12069.98 kWh per capita with a mean value of 8782.418 kWh per capita. This shows that electric power consumption is very high in Saudi Arabia. Also, industrial carbon footprints possess a minimum value of 28.16950 Mt CO_2e and maximum value of 118.7875 Mt CO_2e respectively. The variable has a mean value of 72.91756 Mt CO_2e.

***Table 2.** Descriptive statistics of the data for the study*

Descriptive statistics	HLS (Yrs)	EPC (kWh per capita)	ICF (Mt CO_2e)
Mean	74.47688	8782.418	72.91756
Median	74.91400	7814.253	76.09770
Maximum	78.75000	12069.98	118.7875
Minimum	68.87400	6129.583	28.16950
Std. Deviation	3.022461	2028.776	28.05434
Skewness	-0.222002	0.448329	0.103275
Kurtosis	1.856014	1.586943	1.713328
Jargue-Bera	2.133279	3.967692	2.405766
Probability	0.344163	0.137539	0.300327
Sum	2532.214	298602.2	2479.197
Sum Sq. Dev.	301.4639	1.36E + 08	25972.52
Observations	34	34	34

Source: Authors (2025)

Table 3 presents the outcome of the Canonical Cointegrating Regression (CCR) analysis of the nexus between industrial carbon footprints and human life span in Saudi Arabia. From the table, the following findings emerged. Industrial carbon footprints did not follow the a priori expectation. Meanwhile, electric power consumption follows the a priori expectation. The R-squared value of 0.927 obtained indicates that over 92% of the

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overall variability observed in the dependent variable was accounted for by the selected independent variables incorporated within the model. This suggests that the econometric model exhibits a favorable level of goodness-of-fit. Therefore, the adopted model is very robust. Meanwhile, electric power consumption and human life span have a significant positive relationship. A unit change in electric power consumption leads to 0.08% rise in human life span. In the same vein, industrial carbon footprints caused a significant positive impact on human life span. A unit change in industrial carbon footprints leads to 5% rise in human life span. This shows that industrial carbon footprints do not pose a danger to human life span in Saudi Arabia. This finding is contrary to the a priori expectation. It is important to stress that sustainability practice such as the usage of clean energy in the country`s industrial sector might fuel this result. This reinforces the fact that Saudi Arabia has been maintaining ecological balance and industrial outputs in ensuring human welfare in the country. This is a confirmation of the country`s commitment towards the achievement of the SDG 3- promotion of healthy lives and well-being for all at all ages without in the phase of the industrial revolution.

***Table 3.** Industrial carbon footprints and human life span in Saudi Arabia*

Regressors	Coefficient	t-stat	Prob
EPC	0.000806*	4.667803	0.0001
ICF	0.055487*	4.567796	0.0001
C	63.51790	67.88653	0.0000
R-squared	0.927735		

Dependent variable: HLS. Method: canonical cointegrating regression (CCR). Source: Authors (2025). *Significant at1%, **Significant at 5%, ***Significant at10%

Table 4 shows the estimated results of direction of causality between industrial carbon footprints and human life span. From the above finding, a uni-directional causality flows from industrial carbon footprints to human life span. Similarly, electric power consumption unidirectionally Granger causes human life span and one-way directional causality flows from industrial carbon footprints to electric power consumption. The above results show that a strong linkage exists among the principal variables in this study. This is an indication that industrial carbon footprints are a driver of human life span in Saudi Arabia.

***Table 4.** Pairwise Granger causality tests for industrial carbon footprints and human life span in Saudi Arabia*

Null hypothesis	Obs.	F-Statistic	Prob.
ICF ↔HLS	31	3.11126	0.0452
HLS ↔ICF	31	0.28826	0.8334
EPC ↔HLS	31	6.47038	0.0023
HLS ↔EPC	31	0.84421	0.4832
EPC ↔ICF	31	1.47702	0.2459
ICF ↔EPC	31	4.59933	0.0111

Sample: 1990-2023; Lags: 3; ↔ does not homogeneously cause. Source: Authors (2025)

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Discussion

This study examined the nexus between industrial carbon footprints and human life span in Saudi Arabia over the periods of 1990 and 2023. In estimating the collected data, Canonical Cointegrating Regression and Pairwise Granger Causality Tests were utilized, which led to the following findings. Human life span, HLS ranges between 78.7 years and 68.8 years with a mean value of 74.4 years. This implies that in the past three decades (1990-2023), average human life span in Saudi Arabia is above 74 years. Consequently, electric power consumption, EPC possesses a minimum value of 6129.583 kWh per capita and maximum value of 12069.98 kWh per capita with a mean value of 8782.418 kWh per capita. This shows that electric power consumption is very high in Saudi Arabia. It is an indication of availability and affordability of electric power in the country. Also, industrial carbon footprints possess a minimum value of 28.16950 Mt CO_2e and maximum value of 118.7875 Mt CO_2e respectively. The variable has a mean value of 72.91756 Mt CO_2e.

Furthermore, electric power consumption and human life span have a significant positive relationship. A unit change in electric power consumption leads to 0.08% rise in human life span.

Further evidence from the Granger causality tests revealed that a uni-directional causality flows from industrial carbon footprints to human life span. Electric power consumption unidirectionally Granger causes human life span and one-way directional causality flows from industrial carbon footprints to electric power consumption. This shows that consumption of electric power has been beneficial to the improvement of life span in Saudi Arabia. This attests to an important role an electric power plays in elongating lives of human beings.

In the same vein, industrial carbon footprints caused a significant positive impact on human life span. A unit change in industrial carbon footprints leads to 5% rise in human life span. This shows that industrial carbon footprints do not pose a danger to human life span in Saudi Arabia. This finding is contrary to the a priori expectation. It is important to stress that sustainability practice such as the usage of clean energy in the country`s industrial sector might fuel this result. This reinforces the fact that Saudi Arabia has been maintaining ecological balance and industrial outputs in ensuring human welfare in the country. This is a confirmation of the country`s commitment towards the achievement of the SDG 3- promotion of healthy lives and well-being for all at all ages in the phase of the industrial revolution. In view of these findings, the policymakers in Saudi Arabia should sustain a robust ecological balance and industrial expansion while promoting healthy human life span. In another words, this finding could be attributed to Saudi Arabia`s resilience to the disastrous effect of industrial carbon footprints which is a menace in the majority of countries in the global south. In the same page, in mitigating hazardous effects of industrial carbon footprints, Saudi Arabia`s continuous commitment towards the usage of advanced technologies in health sector in enhancing healthy lives and well-being for all and sundry could be major contributory factor.

Summary, conclusion and policy implications of the study

This study examined the nexus between industrial carbon footprints and human life span in Saudi Arabia over the periods of 1990 and 2023. In estimating the collected data, Canonical Cointegrating Regression and Pairwise Granger Causality Tests were utilized, which led to the following findings. electric power consumption and human life span have

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a significant positive relationship. Industrial carbon footprints caused a significant positive impact on human life span.

Further evidence from the Granger causality tests revealed that a uni-directional causality flows from industrial carbon footprints to human life span. Electric power consumption unidirectionally Granger causes human life span and one-way directional causality flows from industrial carbon footprints to electric power consumption. The above results show an indication that industrial carbon footprints are a driver of human life span in Saudi Arabia. In view of these findings, this study recommends that the policymakers in Saudi Arabia should sustain a robust ecological balance and industrial expansion while promoting healthy human life span. This will further enhance the country`s commitment towards the achievement of the SDG 3- promotion of healthy lives and well-being for all at all ages without in the phase of the industrial revolution.

Ethical consideration. Ethical approval or consent to participate not required as the study made use of no human or animal subjects. The study made use of available data on the World Development Indicators which are anonymized and aggregated, ensuring no risk of harm or exposure of identifiable information.

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