Environmental Science and Pollution Research (2019) 26:19481–19489
https://doi.org/10.1007/s11356-019-05281-0

RESEARCH ARTICLE

# Identification and analysis of driving factors of $CO_2$ emissions from economic growth in Pakistan

Zubair Akram[1] · Jean Engo[1,2] · Umair Akram[3] · Muhammad Wasif Zafar[1]

Received: 5 February 2019 / Accepted: 25 April 2019 / Published online: 10 May 2019


## Abstract

This study applied the logarithmic mean Divisia index (LMDI) model to identify and discuss the main drivers of Pakistan's $CO_2$ emissions over the period 1990–2016. The study examined the effects of five factors based on Pakistan's three main economic sectors while considering the 11 types of fuels consumed in that country. The results showed that the energy structure effect is the greatest driving force of $CO_2$ emissions in this country, followed by scale effect and economic structure effect. Energy intensity is the main contributor to reducing Pakistan's carbon emissions throughout the study period. A comparative review at the sectoral level shows that the industrial sector for which coal is the main source of energy supply is the one that contributes the most to $CO_2$ emissions in Pakistan. Alongside this sector is the tertiary sector, where the transport sub-sector imposes rules of conduct based on a growing Pakistani population. Meanwhile, deforestation would be the main cause of $CO_2$ emissions from the agricultural sector in Pakistan, as energy consumption in this sector remains very low. Improving energy efficiency through the intensification of clean energy is urgently needed if Pakistan's environmental goals are to be achieved.

**Keywords** Pakistan · Economic growth · LMDI · $CO_2$ emission · Energy intensity · Population

## Introduction

Fossil fuels, which continue to play a dominant role in today's global energy systems, have been the driving force behind the industrial revolution and the technological, social, and economic development of our planet in recent years. In 2017, global primary energy consumption increased by 2.2%, about double the growth in consumption in 2016 (1.2%) (BP 2018). Oil consumption increased from 3234 Mtoe in 1990 to 4390 Mtoe in 2016, while consumption of natural gas and coal increased from 1664 to 3035 and 2220 to 3731 Mtoe over the same period, respectively (IEA 2019). Although they have contributed to the production of goods and services necessary for the well-being of populations, the consumption of these energies has led to a high concentration of carbon dioxide ($CO_2$) in the atmosphere. Global $CO_2$ emissions increased from 19.89 $GtCO_2$ in 1990 to 32.31 $GtCO_2$ in 2016 and are expected to reach 530 and 650 ppm in 2050 and 2100, respectively (IEA 2017; Van Ypersele 2015). To this end, if we want to achieve the goal of maintaining temperatures below 2° (UNFCCC 2015), humanity must find a balance between the role of energy in social and economic development and the need to reduce dependence on fossil fuels, especially in developing countries.

Despite decades of internal political conflict that has reduced the level of its foreign investment, Pakistan is one of the energy-intensive and high-carbon developing countries. Mainly dominated by the tertiary sector (56.5%), followed by the agricultural (24.4%) and industrial (19.1%) sectors

Responsible editor: Eyup Dogan

✉ Muhammad Wasif Zafar
wasif.zafar6@yahoo.com

Zubair Akram
zubairakram91@yahoo.com

Jean Engo
jean_engo@yahoo.fr

Umair Akram
akram.umair88@pku.edu.cn

1 School of Management and Economics, Beijing Institute of Technology, South-Zhongguancun Street, Beijing 100081, People's Republic of China

2 Center for Energy and Environmental Policy Research, School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China

3 Guanghua school of Management, Peking University, Beijing 100871, People's Republic of China

(CIA 2019), Pakistan's economic growth has been relatively strong in recent years, rising from 4.45% in 1990 to 1.6 and 5.7% in 2010 and 2017, respectively. Alongside this economic growth, the population is growing at an annual rate of 2% and is currently estimated at more than 195 million inhabitants (WDI 2019). This strong economic and demographic development is accompanied by a high energy consumption whose main sources are coal (5.39%), oil (28.44%), natural gas (26.18%), Biofuel (35.26%), hydropower (3.29%), nuclear power (1.32%), and other renewable energies (0.09%). Pakistan's energy consumption increased from 42.91 Mtoe in 1990 to 95.7 Mtoe in 2016 (IEA 2019), which has contributed not only to improving Pakistan's economic and social development but also to increase its environmental pollution (i.e., $CO_2$ emissions).

In Pakistan, emissions from the energy sector are divided into two main groups, namely fuel combustion emissions and fugitive emissions. Of the total $CO_2$ emissions from fuel combustion, 52% comes from burning liquid fossil fuels, 36% from burning natural gas, and the rest from burning solid fossil fuels (Nielsen 1974). The country's total $CO_2$ emissions have increased from 55.97 to 155.27 $MtCO_2$ in 1990 and 2016, respectively (IEA 2019). These $CO_2$ emissions are increasing at an annual growth rate of 6% and are expected to reach 400 $MtCO_2$ in 2030. Based on the 2008 emissions level, Pakistan's current vision is to reduce its greenhouse gas emissions by 30% by 2025 (Shaikh and Tunio 2015). However, when we look at the current level of $CO_2$ emissions in this country compared to 2008 (130.52 $MtCO_2$), we can see that these emissions have increased by about 16%. This shows Pakistan's chances of not meeting its greenhouse gas mitigation vision, given the country's political, economic, and sociocultural indicators. Therefore, it is clear that Pakistan is looking for the solutions needed to achieve its GHG vision.

In the field of energy-related environmental pollution, many models have been used to examine the determinants of $CO_2$ emissions, including the logarithmic mean Divisia index (LMDI) model (Ang and Choi 1997), Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model (Zhou and Liu 2016), index decomposition analysis (IDA) model (Ang and Wang 2015), Kaya model (Kaya 1990), and structural decomposition analysis (SDA) model (Ang and Wang 2015). Because of its perfect decomposition, the coherence of the aggregation, the independence of the path, and its ability to manage zero values (Ang 2004; Ang and Liu 2001; Ang and Zhang 2000; Ang et al. 1998), the LMDI model is the most used among all these models. In recent years, the LMDI method has been widely used in environmental studies to identify and analyze the factors that influence $CO_2$ emissions at different scales and in different economic sectors. Moutinho et al. (2018) applied the IMDI model to break down carbon emissions into six effects in the 23 major, highly developed renewable energy countries. In this study, which covered a period of 26 years from 1985 to 2011, they found that there are different positive and negative impacts of the change in behavior of $CO_2$ emissions in Europe compared with the rest of the world. Karmellos et al. (2016) applied the LDMI to analyze $CO_2$ emissions from 28 EU countries and found that in times of economic growth, the main factor offsetting the effect of activity was the decrease in electricity intensity in most countries, while the contribution of all other factors appears later. To evaluate and analyze the factors affecting $CO_2$ emissions in the Chinese provinces during the period 2000–2014, Wang and Feng (2017) also applied the LMDI model. They concluded that economic output and the effects of demographic change were the main contributors to increased $CO_2$ emissions in China, while energy intensity played an important role in reducing these emissions. Engo (2018) applied the LMDI model in evaluating the decoupling relationship between $CO_2$ emissions and economic growth in Cameroon over the period 1990–2015. He found that the effect of population change followed by energy intensity and economic activity contributed to the increase of $CO_2$ emissions in that country, while the economic structure effect and the emission factor contributed to reducing these carbon emissions. Sumabat et al. (2016) applied the LMDI model to identify drivers of $CO_2$ emissions from the energy sector in the Philippines during the period 1991–2014. The results showed that improving the standard of living and the growth of economic activity could have a negative impact on this country's $CO_2$ emissions. Like these studies, the LMDI model has been applied in several other studies to identify the main factors that affect $CO_2$ emissions. Among these studies, we found those of Mousavi et al. (2017), Román-Collado and Morales-Carrión (2018), Cansino et al. (2015), Achour and Belloumi (2016), Roinioti and Koroneos (2017), and Engo (2019a, b).

Meanwhile, previous studies have assessed the factors affecting $CO_2$ emissions in a single sector and these studies were particularly intense in developed and emerging economies. In addition, available studies on the energy issue and their adverse environmental effects in the context of Pakistan have only examined the causal link between economic growth and energy consumption. Thus, they presented strong evidence of causality between the two factors (Danish et al. 2018; Khan et al. 2018; Mirza and Kanwal 2017; Lahiani 2018; Shahzad et al. 2017; Hassan et al. 2019). However, no study has yet been conducted to identify the main factors influencing $CO_2$ emissions in Pakistan. To this end, based on an extended Kaya identity, this study applied the logarithmic mean Divisia index model to identify and discuss the main drivers of Pakistan's $CO_2$ emissions over the period 1990–2016. The analyses were carried out in the country's three main sectors of economic activity, namely the agricultural sector, the industrial sector, and the tertiary sector. In addition, this study took into account the 11 types of fuels used in Pakistan's economic development, i.e., natural gas, lignite, fuel oil, coke oven coke, blast furnace gas, other bituminous coals, gas-diesel, other kerosene, motor gasoline, aviation gasoline, and liquified petroleum gases. Thus, this study attempts not only to break the literature gap but also to complement the previous studies in the context of Pakistan. This study provided indicators that can be used by policymakers to develop long-term carbon reduction strategies that will enable Pakistan to effectively achieve its GHG mitigation vision. In addition, the results of this study can serve as a reference for other developing countries whose political, economic, and consumption patterns are similar to those of Pakistan.

The rest of this paper is organized as follows. The "Methodology and data sources" section presents the decomposition analysis methodology used in this study. The results of the study are presented and discussed in the "Results and discussions" section, while we conclude the study in the "Conclusion and policy implications" section.

## Methodology and data sources

### Decomposition method

According to Kaya, four main factors, including population, carbon intensity, economic activity, and energy intensity, are responsible for the observed changes in a country's $CO_2$ emissions. He founded a model that consists of interconnecting these four factors in the form of a product, as expressed in Eq. 1 (Kaya 1990).

$$C = \frac{C}{E} \times \frac{E}{\mathrm{GDP}} \times \frac{\mathrm{GDP}}{P} \times P \quad (1)$$

where $C$, $E$, GDP, and $P$ designate $CO_2$ emissions, energy consumption, gross domestic product, and population, respectively. ($\mathrm{IC} = \frac{C}{E}$), ($\mathrm{IE} = \frac{E}{\mathrm{GDP}}$), ($G = \frac{\mathrm{GDP}}{P}$) denote carbon intensity per unit of energy consumption, energy intensity consumed to produce a unit of GDP, and GDP per capita. In this paper, the carbon intensity of Eq. 1 has been extended to decompose the change in Pakistan's $CO_2$ emissions into six main factors: emission factor ($F$), energy structure ($S$), energy intensity ($I$), economic structure ($Y$), economic activity ($G$), and the population ($P$). To this end, we rewrote Eq. 1 as represented in Eq. 2, and the application of the additive approach of the LMDI model between a baseline year (0) and a target year ($t$) (Ang 2005) allowed to obtain Eqs. 3 to 7.

$$C = \frac{C_i}{E_i} \times \frac{E_i}{T_{ei}} \times \frac{T_{ei}}{\mathrm{GDP}_i} \times \frac{\mathrm{GDP}_i}{\mathrm{GDP}} \times \frac{\mathrm{GDP}}{P} \times P$$
$$= F \times S \times I \times Y \times G \times P \quad (2)$$

$$\Delta C_{tot} = \Delta C_t - \Delta C_0 = \Delta C_F + \Delta C_S + \Delta C_I + \Delta C_Y + \Delta C_G + \Delta C_P \quad (3)$$

$$\Delta C_F = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{F^t}{F^0}\right) \quad (4)$$

$$\Delta C_S = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{S^t}{S^0}\right) \quad (5)$$

$$\Delta C_I = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{I^t}{I^0}\right) \quad (6)$$

$$\Delta C_Y = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{Y^t}{Y^0}\right) \quad (7)$$

$$\Delta C_G = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{G^t}{G^0}\right) \quad (8)$$

$$\Delta C_P = \mathrm{L}\left(M^t, M^0\right) \times ln\left(\frac{P^t}{P^0}\right) \quad (9)$$

where $M = F \times S \times I \times Y \times G \times P$ and $\mathrm{L}\left(M^t, M^0\right) = \frac{M^t - M^0}{lnM^t - lnM^0}$; In addition, ($C_i$), ($E_i$), ($T_{ei}$), and ($\mathrm{GDP}_i$) refer to the amount of carbon emitted by the fuel type ($i$), the quantity of fuel of type ($i$) consumed, the total quantity of all fuels consumed in a given sector, and the GDP produced by a given economic sector, respectively. ($\Delta C_F$, $\Delta C_S$, $\Delta C_I$, $\Delta C_Y$, $\Delta C_G$, and $\Delta C_P$) identify the effect of total change in $CO_2$ emissions, the emission factor, the energy structure effect, the energy intensity effect, the economic structure effect, the economic activity effect, and the population effect, respectively. Equation (3) equals to zero ($\Delta C_F = 0$) given that the emission factor of the fuel types is constant.

### Data sources

This study applied to annual data covering a period of 26 years from 1990 to 2016. These data were all collected from the databases of the World Bank and the International Energy Agency (IEA 2019; WDI 2019). Data related to population, GDP per capita, and energy consumption are estimated in million, in constant 2010 US$, and in tonnes of oil equivalent (Toe), respectively. The $CO_2$ emissions data for the different economic sectors are estimated in million tonnes of $CO_2$ ($MtCO_2$) and were determined from the following equation, where ($\gamma_i$) is the carbon emission factor per type of fuels (see Table 1) (IPCC 2006).

$$C = \sum_{i=1}^{11} C_i = \sum_{i=1}^{11} E_i \times \gamma_i \quad (10)$$

## Results and discussions

The results presented in the appendix Table 6 shows that carbon intensity has increased by 0.022 $tCO_2$, which corresponds to a growth rate of 115.38% in absolute values of Pakistan's total $CO_2$ emissions over the

**Table 1** The types of fuels consumed in Pakistan and their emission factor

| Fuel type ($E_i$) | $\gamma_i$ (kgCO2/GJ) |
|---|---|
| Other bituminous coal | 25.8 |
| Coke oven coke | 29.2 |
| Blast furnace gas | 70.8 |
| Lignite | 27.6 |
| Gas-diesel | 20.2 |
| Fuel oil | 21.1 |
| Other kerosene | 19.6 |
| Motor gasoline | 69.3 |
| Aviation gasoline | 70 |
| Liquified petroleum gases | 63.1 |
| Natural gas | 15.3 |

Source: (IPCC 2006)

period 1990–2016, as shown in Table 2. Although attributable to the strong economic and demographic growth experienced by Pakistan during this period, the results of this study suggest that it is urgent to optimize the country's energy structure. However, to better understand the reasons for this high rate of carbon growth, it is necessary to examine in detail the effects of the main factors that influenced these emissions during the study period.

## The effects of demographic change and economic activity (scale effects)

In this paper, we found that scale effects contributed to increasing Pakistan's $CO_2$ emissions by 22.25%, which is consistent with other decomposition analysis studies. Tables 2 and the Appendix Table 6 show that the total cumulative effect of the demographic factor is 0.0025 $tCO_2$, which corresponds to an 11.5% increase in total $CO_2$ emissions of Pakistan over the period 1990–2016. From a sectoral point of view, this factor has contributed to increasing the country's $CO_2$ emissions by 12.27, 7.5, and 105.55% in the industrial, tertiary, and agricultural sectors, respectively (see Tables 3, 4, and 5). This shows that the effect of population change on $CO_2$ emissions in Pakistan is greater in the agricultural and industrial sectors. However, it should be noted that the total population of Pakistan increased by 44.26%, from 107,678,614 in 1990 to 193,203,476 in 2016, which contributed to the increase in energy needs, particularly in the transport and industrial sectors. Thus, the country's economic growth was supported by high energy consumption during the study period, which also contributed to increasing the effect of economic activity on total $CO_2$ emissions by 0.0023 $tCO_2$, or 10.75%, as shown in Table 6 in the Appendix and Table 2. As in the case of the demographic factor effect, the economic activity effect contributed to increasing Pakistan's $CO_2$ emissions by 8.64, 7.49, and 63% in the industrial, tertiary, and agricultural sectors, respectively (see Tables 3, 4, and 5). This also shows that the effect of this factor is greater in the country's agricultural and industrial sectors. There are three main reasons for this situation. First, these two sectors alone employ about 70% of Pakistan's workforce (CIA 2019). Second, the intensification of agricultural activities, which currently accounts for about 25% of Pakistan's GDP, has led to deforestation and thus increased $CO_2$ emissions. Third, coal, the most polluting source of energy, still represents a large part of Pakistan's energy supply. Furthermore, Pakistan's GDP per capita has risen from 741.8 constant 2010 USD in 1990 to 1179.41 constant 2010 USD in 2016. Therefore, the Pakistani government should implement policies to optimize its economic growth path and improve its energy intensity.

## The economic structure effects

As shown in the Appendix Table 6, the total cumulative effect of the economic structure is 0.0016 $tCO_2$, which corresponds

**Table 2** The cumulative results of the decomposition of Pakistan's $CO_2$ emissions from economic growth during the period 1990–2016 in percentage

| | $\Delta C_S$ | $\Delta C_I$ | $\Delta C_Y$ | $\Delta C_G$ | $\Delta C_P$ | $\Delta C_{tot}$ |
|---|---|---|---|---|---|---|
| 1900–1995 | − 1.98 | 0.7 | − 0.22 | 1.14 | 1.62 | 1.26 |
| 1995–2000 | − 8.68 | 9.88 | 0.98 | 0.8 | 2.46 | 5.45 |
| 2000–2005 | − 291.66 | 52.43 | 2.71 | 3.38 | 2.85 | − 230.28 |
| 2005–2010 | 434.15 | − 82.05 | 3.08 | 1.87 | 1.61 | 358.67 |
| 2010–2016 | − 53.75 | 11.34 | 0.8 | 3.55 | 2.93 | − 35.11 |
| 1990–2016 | 78.06 | − 7.69 | 7.36 | 10.75 | 11.5 | 115.38 |

Source: authors' own computation

**Table 3** The cumulative results of the decomposition of Pakistan's $CO_2$ emissions in the industrial sector during the period 1990–2016 in percentage

| | $\Delta C_S$ | $\Delta C_I$ | $\Delta C_Y$ | $\Delta C_G$ | $\Delta C_P$ | $\Delta C_{tot}$ |
|---|---|---|---|---|---|---|
| 1900–1995 | 40.58 | − 3.67 | − 1.84 | 3.89 | 5.36 | 44.32 |
| 1995–2000 | − 201.61 | − 6.3 | 0.71 | 1.16 | 3.48 | − 202.54 |
| 2000–2005 | 72.69 | − 9.8 | 3.39 | 2.68 | 2.16 | 71.12 |
| 2005–2010 | − 11.92 | − 0.32 | − 1.64 | 0.49 | 0.83 | − 12.56 |
| 2010–2016 | 0.08 | − 1.08 | − 0.17 | 0.4 | 0.42 | − 0.33 |
| 1990–2016 | − 100.17 | − 21.19 | 0.43 | 8.64 | 12.27 | 142.73 |

Source: authors' own computation

**Table 4** The cumulative results of the decomposition of Pakistan's $CO_2$ emissions in the Tertiary sector during the period 1990–2016 in percentage

| | $\Delta C_S$ | $\Delta C_I$ | $\Delta C_Y$ | $\Delta C_G$ | $\Delta C_P$ | $\Delta C_{tot}$ |
|---|---|---|---|---|---|---|
| 1900–1995 | − 8.47 | 1.2 | 0.12 | 0.29 | 0.45 | − 6.39 |
| 1995–2000 | 26.67 | 9.28 | 0.69 | 0.46 | 1.46 | 38.59 |
| 2000–2005 | − 254.84 | 45.26 | 1.69 | 2.36 | 2.008 | − 203.52 |
| 2005–2010 | 363.15 | − 68.2 | 2.84 | 1.47 | 1.2 | 300.47 |
| 2010–2016 | − 44.72 | 9.61 | 0.69 | 2.88 | 2.37 | − 29.15 |
| 1990–2016 | 81.78 | − 2.83 | 6.05 | 7.49 | 7.5 | 105.66 |

Source: authors' own computation

to a 7.36% increase in absolute value of Pakistan's total $CO_2$ emissions over the period 1990–2016, as shown in Table 2. Regarding the three economic sectors considered in this study, Tables 3, 4, and 5 show that, unlike the industrial and tertiary sectors where the economic structure effect has contributed to increasing $CO_2$ emissions by 0.43 and 6.05%, this factor has reduced carbon emissions by − 3.62% in the agricultural sector during the period under review. These findings, which are in line with those of other studies, suggest structurally that the tertiary sector is the largest contributor to $CO_2$ emissions in Pakistan's economic growth. Currently, this sector alone accounts for more than 50% of Pakistan's GDP and has increased steadily throughout the study period, from 43.34% in 1990 to 52.77% in 2016. In the same vein, energy consumption has been important in this sector, given that its energy intensity has increased from 0.0034 to 0.0043 Toe per capita during the same period. Due to the increasing need for mobility of the population, energy consumption in the tertiary sector has been mainly driven by the transport sub-sector. Therefore, the Pakistani government should pay particular attention to the transport sector to reduce carbon emissions from the tertiary sector. Meanwhile, it should be noted that the share of the agricultural sector in Pakistan's GDP has remained virtually stable over the study period, while that of the industrial sector has decreased from 22 to 18% in 1990 and 2016, respectively. These poor economic conditions are mainly due to political instability, which has contributed not only to reducing the country's investment intensity but also to reducing its carbon intensity in the agricultural and industrial sectors.

**Table 5** The cumulative results of the decomposition of Pakistan's $CO_2$ emissions in the agricultural sector during the period 1990–2016 in percentage

| | $\Delta C_I$ | $\Delta C_Y$ | $\Delta C_G$ | $\Delta C_P$ | $\Delta C_{tot}$ |
|---|---|---|---|---|---|
| 1900–1995 | − 143.47 | 6.6 | 45.34 | 64.46 | − 27.05 |
| 1995–2000 | − 66.07 | 6.32 | 11.86 | 32.34 | − 15.54 |
| 2000–2005 | − 52.52 | − 17.26 | 5.28 | 8.23 | − 56.26 |
| 2005–2010 | − 2.66 | 0.7 | 0.47 | 0.47 | − 1.01 |
| 2010–2016 | − 0.17 | 0.009 | 0.02 | 0.02 | − 0.12 |
| 1990–2016 | − 264.92 | − 3.62 | 62.99 | 105.55 | 437.09 |

Source: authors' own computation

## The energy structure effects

We have noted in previous studies that the effect of energy structure on $CO_2$ emissions is unstable, which means that it can contribute to reducing carbon emissions, as it can also help to increase them. In this study, Tables 2 and the Appendix Table 6 show that the cumulative total effect of the energy structure is 0.017 $tCO_2$, which corresponds to a 78.06% increase in total $CO_2$ emissions from Pakistan over the period 1990–2016. This factor was, therefore, the main driver of Pakistan's $CO_2$ emissions during the period under study and was mainly important in the tertiary sector (81.78%), as shown in Table 4. Figure 1 shows that between 1990 and 2016, liquified petroleum gases (LPG), aviation gasoline, natural gas, and fuel oil contributed to increasing $CO_2$ emissions by 66.66, 36.3, 13.21, and 2.23%, respectively. This means that these fuels were the main factors related to the growth of $CO_2$ emissions due to the energy structure effect in Pakistan's economic development. This situation could be explained by the growing consumption of these fuels, particularly in the country's transport and commercial sectors, achieving in Pakistan over the study period. Meanwhile, Table 3 shows that the energy structure effect contributed to reducing $CO_2$ emissions in the industrial sector by − 100.17%, which can be explained by the decrease in energy consumption from sources such as other kerosene, coke oven coke, blast furnace gas, gas, and fuel oil. Figure 2 shows that during the period 1990–2016, the use of these fuels (i.e., other kerosene, coke oven coke, blast furnace gas, natural gas, and fuel oil) contributed to reducing $CO_2$ emissions in the industrial sector by − 159.76, − 12.62, − 11.5, − 7.29, and − 0.48%, respectively. Therefore, intensification of energy policies to optimize these fuels is needed to decarbonize Pakistan's industrial sector. The Government of Pakistan is expected to increase its energy efficiency through renewable energy, in order to effectively reduce its carbon intensity in the industrial and tertiary sectors.

## The energy intensity effect

Previous studies of decomposition analyses show that energy intensity is an important $CO_2$ mitigation force, which was also verified in this study, where we found that the total cumulative effect of this factor is − 0.0017 $tCO_2$ (see

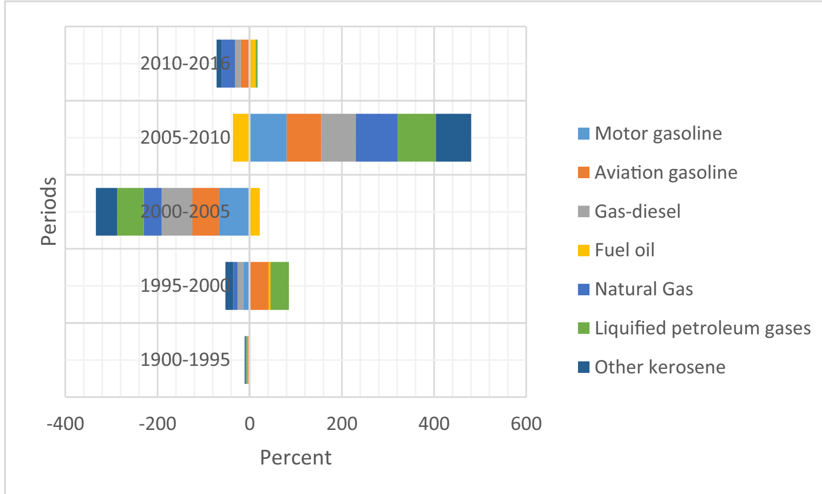


**Fig. 1** Cumulative decomposition of $CO_2$ emissions from fuel combustion in Pakistan's tertiary sector over the period 1990–2016

Appendix Table 6 ). This means that the energy intensity effect has helped to reduce Pakistan's total $CO_2$ emissions by −7.69% over the period 1990–2016, as shown in Table 2. Although having played an important role in reducing Pakistan's $CO_2$ emissions, Table 2 shows that over five periods, energy intensity reduced carbon emissions by −82.05% between 2005 and 2010, while contributing to emission growth in other periods. This suggests that the effect of energy intensity on Pakistan's $CO_2$ emissions remains less powerful. The decrease in energy intensity observed over the period 2005–2010 is mainly due to the extensive application of energy-saving technologies and the improvement of the level of management, whereas the increase in energy intensity per unit of GDP per capita may explain the negative role played by this factor in the country's economic growth over the other four periods. However, the results of this study as presented in the Appendix Table 6 indicates in detail that the effect of this factor has shifted from positive to negative, which could mean that Pakistan has used more energy-efficient technologies or switched to more energy-intensive industries year after year. At the sectoral level, Tables 3, 4, and 5 show that energy intensity also contributed to reducing $CO_2$ emissions by −21.19, −2.83, and −264.92% in the industrial, tertiary, and agricultural sectors, respectively. This shows that the effect of energy intensity in reducing $CO_2$ emissions in Pakistan is greater in the agricultural and industrial sectors, compared with the tertiary sector, which accounts for more than half of the country's GDP. Meanwhile, it should be noted that the energy intensity per unit of GDP in the agricultural sector is very low and that gas-diesel is until now the main fuel used in this sector. This is why the energy intensity effect is important in this sector, while the energy structure effect remains imaginary. Although consuming highly polluting energy sources, the proper switching of fuels used in Pakistan's industrial sector

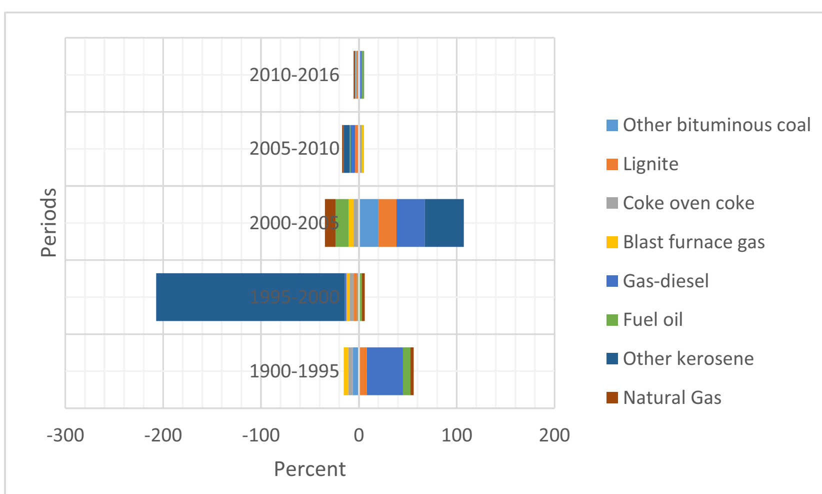


**Fig. 2** Cumulative decomposition of $CO_2$ emissions from fuel combustion in Pakistan's industrial sector over the period 1990–2016

could be the main reason for the reduction of $CO_2$ emissions due to the energy intensity effect. The reduction of carbon emissions due to the energy intensity effect of the tertiary sector is mainly due to the use of more energy-efficient technologies in the majority of Pakistan's utilities. In addition, the effect of energy intensity is smaller in Pakistan's tertiary sector, as the energy intensity per unit of GDP per capita in this sector remains very high due to the increased transportation needs.

## Conclusion and policy implications

### Conclusion

This study applied the logarithmic mean Divisia index model to identify and discuss the main drivers of Pakistan's $CO_2$ emissions over the period 1990–2016. The analysis was conducted in the three main economic sectors of the country (i.e., agricultural, industrial, and tertiary sectors), taking into account the 11 types of fuels used in Pakistan's economic development. The main results of this study can be summarized as follows.

At the end of this study's analyses, which were based on five factors, we found that the energy structure effect was the greatest force that contributed to increasing Pakistan's $CO_2$ emissions over the period 1990–2016, followed by the effects of demographic change, economic activity, and the economic structure. As in other studies and contrary to the previous four factors, the energy intensity effect was the main factor contributing to the reduction of this country's $CO_2$ emissions during the study period.

At the sectoral level, we found that total $CO_2$ emissions increased by 142.73% in absolute value in the industrial sector. The effects of demographic change, followed by the effects of economic activity and structure, contributed to the increase of carbon emissions, whereas the effects of energy structure and intensity contributed to reducing emissions in this sector. In the tertiary sector, total $CO_2$ emissions increased by 105.66% in absolute value and the energy structure effect was the main force contributing to this increase, while the energy intensity effect was the only factor that reduced carbon emissions in this sector. The total $CO_2$ emissions of the agricultural sector increased by 437.09% and the effects of energy intensity and economic structure played an important role in reducing these emissions, compared with the scale effect that contributed to increased carbon emissions.

### Policy implications

In order to develop a low-carbon economy, the Government of Pakistan should pay particular attention to the following policy recommendations:

1. In this study, we found that scale effects contributed to increasing $CO_2$ emissions. As the economy grows and standards of living improve, the Pakistani population tends to consume more energy to ensure a comfortable life and easy travel, which will put more pressure on reducing environmental pollution. Thus, a preventive information policy aimed at modifying resident behavior can be used to reduce environmental pollution.
2. The results of this study showed that the energy structure effect was the largest driving force of Pakistan's $CO_2$ emissions over the study period, suggesting that the country's energy structure needs to be optimized. Fuel switching has great potential for reducing this country's $CO_2$ emissions, particularly in the industrial sector. Currently, Pakistan's industrial sector is still heavily dependent on coal. It is, therefore, possible to reduce $CO_2$ emissions from this sector by switching from coal to fuels with lower carbon emission factors, and more particularly renewable energies. In addition, the use of more energy-efficient industrial processes, technical improvements, and energy savings are strategies that the Government of Pakistan needs to implement to reduce carbon emissions resulting from its economic growth.
3. Because of its key role in reducing the $CO_2$ emissions of the three economic sectors identified in this study, energy intensity must continue to be given special attention by the government. Therefore, Pakistan should encourage the efficient use of coal by increasing the share of washed raw coal and substituting the direct combustion of coal for electricity by developing a large size at high temperatures. It is also important to improve the efficiency of energy use, particularly in energy-intensive sectors, while encouraging imports of energy-intensive products. In addition, increasing the share of renewable energy in the country's energy mix is a very effective way that Pakistan needs to implement not only to reduce energy intensity per unit of GDP per capita but also to reduce its carbon emissions.

**Acknowledgments** The authors would like to dedicate this work to Prof. Jacques FAME NDONGO, Mrs. Nadege Abendang Zeh, Mr. Daniel Mvom, and Mrs. Jeanne Nelly Engo, for their outstanding support. Furthermore, we would like to thank the supervisor of this study, Professor Dr. Yi-Ming Wei, in China and all those who participated in the scientific evaluation of this paper, especially editors and reviewers.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

## Appendix

**Table 6** Pakistan's total $CO_2$ emission annual time series decomposition results in (tCO2)

| | $\Delta C_S$ | $\Delta C_I$ | $\Delta C_Y$ | $\Delta C_G$ | $\Delta C_P$ | $\Delta C_{tot}$ |
|---|---|---|---|---|---|---|
| 1990–1991 | 0.0001 | − 0.0002 | 2.5E-05 | 5.6E-05 | 7.3E-05 | 7.4E-05 |
| 1991–1992 | − 0.0002 | − 5.9E-07 | − 3.4E-05 | 0.0001 | 6.7E-05 | − 0.0001 |
| 1992–1993 | 0.0002 | 0.0001 | 2.5E-05 | − 2.4E-05 | 7.19E-05 | 0.0004 |
| 1993–1994 | 0.001 | − 0.0001 | − 2.3E-05 | 3.14E-05 | 7.18E-05 | 0.001 |
| 1994–1995 | − 0.001 | 0.0003 | − 4.3E-05 | 7.2E-05 | 7.8E-05 | − 0.001 |
| 1995–1996 | 0.016 | 0.0005 | 0.0001 | 9E-05 | 0.0001 | 0.01 |
| 1996–1997 | 0.001 | 2.76E-05 | − 4.1E-05 | − 7.3E-05 | 0.0001 | 0.001 |
| 1997–1998 | 0.004 | − 0.0006 | 6.9E-06 | 4E-06 | 0.0001 | 0.003 |
| 1998–1999 | 0.0006 | − 8.6E-05 | 3.3E-05 | 4.6E-05 | 8.8E-05 | 0.0007 |
| 1999–2000 | − 0.02 | 0.002 | 0.0001 | 0.0001 | 0.0001 | − 0.02 |
| 2000–2001 | − 0.007 | 0.001 | 0.0002 | − 2.3E-05 | 0.0002 | − 0.006 |
| 2001–2002 | 0.02 | − 0.004 | 6.6E-05 | 5.7E-05 | 0.0001 | 0.01 |
| 2002–2003 | 0.0009 | − 0.0002 | − 2.8E-06 | 6.02E-05 | 4.7E-05 | 0.0008 |
| 2003–2004 | 0.002 | − 0.0001 | 7.1E-05 | 0.0001 | 4.5E-05 | 0.002 |
| 2004–2005 | − 0.08 | 0.01 | 0.0002 | 0.0005 | 0.0002 | − 0.06 |
| 2005–2006 | 0.09 | − 0.01 | 0.0006 | 0.0003 | 0.0001 | 0.07 |
| 2006–2007 | − 0.002 | 0.0005 | 9.2E-06 | 4.7E-05 | 3.6E-05 | − 0.002 |
| 2007–2008 | − 0.0002 | 0.0001 | 5.9E-05 | − 9.6E-06 | 5.4E-05 | 9.7E-05 |
| 2008–2009 | 0.002 | − 0.0004 | − 4.9E-05 | 1.7E-05 | 4.8E-05 | 0.001 |
| 2009–2010 | 0.002 | − 0.0004 | 1.5E-07 | − 6.8E-06 | 2.8E-05 | 0.001 |
| 2010–2011 | − 0.007 | 0.0015 | − 6.4E-05 | 1.3E-05 | 4.5E-05 | − 0.005 |
| 2011–2012 | − 0.002 | 0.0003 | 6.3E-05 | 6.2E-05 | 9.9E-05 | − 0.002 |
| 2012–2013 | 0.011 | − 0.002 | 1.5E-05 | 5.7E-05 | 5.5E-05 | 0.009 |
| 2013–2014 | − 0.01 | 0.002 | − 1.8E-05 | 7.5E-05 | 6.3E-05 | − 0.009 |
| 2014–2015 | − 0.004 | 0.001 | 6.7E-05 | 0.0002 | 0.0001 | − 0.002 |
| 2015–2016 | 0.003 | − 0.0008 | 0.0001 | 0.0003 | 0.0002 | 0.003 |
| 1990–2016 | 0.017 | − 0.001 | 0.001 | 0.0023 | 0.0025 | 0.022 |

Source: authors' own computation

## References

Achour H, Belloumi M (2016) Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. Transp Policy 52:64–71 Available at: http://www.sciencedirect.com/science/article/pii/S0967070X16304322

Ang BW (2004) Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32(9):1131–1139 Available at: http://www.sciencedirect.com/science/article/pii/S0301421503000764

Ang BW (2005) The LMDI approach to decomposition analysis: a practical guide. Energy Policy 33(7):867–871 Available at: https://www.sciencedirect.com/science/article/pii/S0301421503003136

Ang BW, Choi K-H (1997) Decomposition of aggregate energy and gas emission intensities for industry: a refined Divisia index method. Energy J 18(3):59–73 Available at: https://www.jstor.org/stable/41322738

Ang BW, Liu FL (2001) A new energy decomposition method: perfect in decomposition and consistent in aggregation. Energy 26(6):537–548 Available at: http://www.sciencedirect.com/science/article/pii/S0360544201000226

Ang BW, Wang H (2015) Index decomposition analysis with multidimensional and multilevel energy data. Energy Econ 51(Supplement C):67–76 Available at: http://www.sciencedirect.com/science/article/pii/S0140988315001772

Ang BW, Zhang FQ (2000) A survey of index decomposition analysis in energy and environmental studies. Energy 25(12):1149–1176 Available at: http://www.sciencedirect.com/science/article/pii/S0360544200000396

Ang BW, Zhang FQ, Choi K-H (1998) Factorizing changes in energy and environmental indicators through decomposition. Energy 23(6):489–495 Available at: http://www.sciencedirect.com/science/article/pii/S0360544298000164

BP (2018) 67th edition Contents is one of the most widely respected. Stat Rev World Energy 1–56. Available at: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

Cansino JM, Sánchez-Braza A, Rodríguez-Arévalo ML (2015) Driving forces of Spain's CO2 emissions: a LMDI decomposition approach. Renew Sust Energ Rev 48:749–759 Available at: https://www.sciencedirect.com/science/article/pii/S1364032115002816

CIA (2019) The world factbook — Central Intelligence Agency. Central Intelligence Agency (US) Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/pe.html. Accessed 4 Feb 2019

Danish, Baloch MA, Suad S (2018) Modeling the impact of transport energy consumption on $CO_2$ emission in Pakistan: evidence from ARDL approach. Environ Sci Pollut Res 25(10):9461–9473

Engo J (2018) Decomposing the decoupling of CO2 emissions from economic growth in Cameroon. Environ Sci Pollut Res 25:35451–35463. https://doi.org/10.1007/s11356-018-3511-z

Engo J (2019a) Decomposition of Cameroon's $CO_2$ emissions from 2007 to 2014: an extended Kaya identity. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-05042-z

Engo J (2019b) Decoupling greenhouse gas emissions from economic growth in cameroon. Resources and Environmental Economics 1(1):16–28. https://doi.org/10.25082/REE.2019.01.003

Hassan ST, Xia E, Khan NH, Shah SMA (2019) Economic growth, natural resources, and ecological footprints: evidence from Pakistan. Environ Sci Pollut Res 26(3):2929–2938. https://doi.org/10.1007/s11356-018-3803-3

IEA (2017) $CO_2$ emissions from fuel combustion. Oecd/Iea, pp 1–155. Available at: https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf. Accessed 1 Dec 2019

IEA (2019) International Energy Agency. World energy outlook. Paris, France, p 45. Available at: https://www.iea.org/. Accessed 15 Jan 2019

IPCC (2006) Chapter 1: Guidelines, Ipcc Greenhouse, National Inventories, Gas. Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

Karmellos M, Kopidou D, Diakoulaki D (2016) A decomposition analysis of the driving factors of CO2 (carbon dioxide) emissions from the power sector in the European Union countries. Energy 94:680–692 Available at: https://www.sciencedirect.com/science/article/pii/S0360544215015406

Kaya (1990) Impact of carbon dioxide emission on GNP growth: interpretation of proposed scenarios. Paris: presentation to the Energy and Industry Subgroup, Response Strategies Working Group, IPCC. X'Pert Stress PW3208, Software for Residual stress analysis, PANalytical, The Netherlands, www.panalytical.com. Available at: http://www.wiki.nus.edu.sg

Khan NH, Ju Y, Hassan ST (2018) Modeling the impact of economic growth and terrorism on the human development index: collecting evidence from Pakistan. Environ Sci Pollut Res 25(34):34661–34673. https://doi.org/10.1007/s11356-018-3275-5

Lahiani A (2018) Revisiting the growth-carbon dioxide emissions nexus in Pakistan. Environ Sci Pollut Res 25(35):35637–35645. https://doi.org/10.1007/s11356-018-3524-7

Mirza FM, Kanwal A (2017) Energy consumption, carbon emissions and economic growth in Pakistan: dynamic causality analysis. Renew Sust Energ Rev 72:1233–1240 Available at: http://www.sciencedirect.com/science/article/pii/S136403211630689X

Mousavi B, Lopez NSA, Biona JBM, Chiu ASF, Blesl M (2017) Driving forces of Iran's CO2emissions from energy consumption: an LMDI decomposition approach. Appl Energy 206(August):804–814 Available at: https://www.sciencedirect.com/science/article/pii/S0306261917312321

Moutinho V, Madaleno M, Inglesi-Lotz R, Dogan E (2018) Factors affecting CO2 emissions in top countries on renewable energies: a LMDI decomposition application. Renew Sust Energ Rev 90:605–622 Available at: http://www.sciencedirect.com/science/article/pii/S1364032118300339

Nielsen RF (1974) Pakistan's initial national communication on climate change. Nord Psykol 26(4):336–336 Available at: https://unfccc.int/resource/docs/natc/paknc1.pdf

Roinioti A, Koroneos C (2017) The decomposition of CO2 emissions from energy use in Greece before and during the economic crisis and their decoupling from economic growth. Renew Sust Energ Rev 76:448–459 Available at: https://www.sciencedirect.com/science/article/pii/S1364032117303404

Román-Collado R, Morales-Carrión AV (2018) Towards a sustainable growth in Latin America: a multiregional spatial decomposition analysis of the driving forces behind CO 2 emissions changes. Energy Policy 115:273–280 Available at: https://www.sciencedirect.com/science/article/pii/S0301421518300193

Shahzad SJH, Kumar RR, Zakaria M, Hurr M (2017) Carbon emission, energy consumption, trade openness and financial development in Pakistan: a revisit. Renew Sust Energ Rev 70:185–192 Available at: http://www.sciencedirect.com/science/article/pii/S1364032116308401

Shaikh S, Tunio S (2015) Pakistan crafts plan to cut carbon emissions 30 pct by 2025 | Reuters. Reuters Available at: https://in.reuters.com/article/climate-change-pakistan/pakistan-crafts-plan-to-cut-carbon-emissions-30-pct-by-2025-idINKBN0OQ15K20150610

Sumabat AK, Lopez NS, Yu KD, Hao H, Li R, Geng Y, Chiu ASF (2016) Decomposition analysis of Philippine CO 2 emissions from fuel combustion and electricity generation. Appl Energy 164:795–804 Available at: https://www.sciencedirect.com/science/article/pii/S0306261915015962

UNFCCC (2015) Paris Agreement. Conference of the parties on its twenty-first session, 21932(December), p 32. Available at: http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Van Ypersele J (2015) Climate change projections for 2050 / 2100 and their potential impacts in the Middle East why the IPCC? Established by WMO and UNEP in 1988. IPCC. Available at: http://www.climate.be/users/vanyp/presentations/2015-1-26_jpvy_ramallah_palast__climasouth_climate_change_projections_for_20502100.pdf

Wang M, Feng C (2017) Decomposition of energy-related CO2 emissions in China: an empirical analysis based on provincial panel data of three sectors. Appl Energy 190(Supplement C):772–787 Available at: http://www.sciencedirect.com/science/article/pii/S0306261917300090

WDI (2019) World Development Indicators | DataBank. The World Bank. Available at: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#advancedDownloadOptions. Accessed 4 Feb 2019

Zhou Y, Liu Y (2016) Does population have a larger impact on carbon dioxide emissions than income? Evidence from a cross-regional panel analysis in China. Appl Energy 180:800–809. https://doi.org/10.1016/j.apenergy.2016.08.035