Research Article

Decomposition analysis of carbon dioxide emissions in Pakistan

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Abstract

Energy related CO_2 emissions are important factors responsible for greenhouse effect. Unprecedented increase in anthropogenic gas emissions in the recent decades have led to climatic changes. This study was aimed to decompose the changes in CO_2 emissions in Pakistan for the time periods of 1990–2017. The log mean Divisia index was employed to find out changes in CO_2 emissions into five factors such as activity effect, structural effect, intensity effect, fuel-mix effect, and emissions factor effect. The analysis confirmed an upward trend of overall emissions of the country during the specified time period (1990–2017). Results of activity effect, structural effect and intensity effect were identified as the three major factors responsible for changes in overall CO_2 emissions in the country. Among all effects, the activity effect was investigated as largest contributor to overall changes in CO_2 emissions level. The structural effect is positively affecting CO_2 emissions indicating a transition of economic activity towards more energy intensive sectors. However, intensity effect has negative relationship with emissions, which is a sign of energy efficiency gains. Energy mix of the country comprises of fossil fuel in excess of 80%. The findings suggest that policy makers should encourage the diversification of energy and output mix towards more energy efficient sub sectors of the economy.

Keywords Energy · CO_2 emissions · Decomposition analysis · LMDI · Pakistan

1 Introduction

Climate change is a contemporary global issue of utmost importance, caused primarily by excessive energy use and other anthropogenic activities [3]. The accumulation of greenhouse gases (GHG) especially carbon dioxide (CO_2) is rising rapidly. On one hand, there are some supply side factors that contribute to accumulated emission like industrialization and economic growth [34]. On the other hand, changes in land use induced by economic activity further curtail the absorption capacity of ecosystem [23]. More specifically, forests are gradually converted into crop areas implying that lesser amounts of GHG will be assimilated [10]. Among various GHG, the share of CO_2 is highest in setting up greenhouse effect [13, 15, 31].

The Kyoto Protocol is the first international treaty that extended the United Nations Framework Convention on Climate Change (UNFCCC) in February 2005. In retrospect, it aspired countries to reduce emissions with specific reduction responsibilities in order to slow down the climate change [33]. The GHG emissions are negative externalities causing external costs and the under-developed countries are more vulnerable to these external costs because they cannot take adaptive measures [38]. Pakistan is a typical example of a victim country that contributes only 0.8% in global greenhouse gases and is ranked 135th among all the countries in terms of its contribution towards emissions [2]. But the country is facing disproportionately large consequences of climatic change and is among the top 10 most vulnerable countries on the basis of long-term Climate Risk Index [16]. An estimated annual cost of environmental problems in Pakistan amounts to 6% of its GDP equivalent to PKR.365 billion [15].

Past literature on environmental economics focuses on identifying the relationship between economic growth and environmental degradation by developing

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environmental Kuznets curve [6, 14, 20, 32]. In order to identify the nature of environmental problems, the most widely used approach is the decomposition analysis of total emissions [36]. Various decomposition methods are used for analysis in order to find out the predefined factors responsible for changes in overall emissions levels. Most of the earlier studies decompose the emissions level using structural decomposition techniques in the developed countries. However, some recent studies perform decomposition analyses of CO_2 emissions focusing on the developing countries [27, 33]. Literature revealed that the index decomposition analysis such as arithmetic mean Divisia index (AMDI) and log mean Divisia index (LMDI) give converging decomposition results when zero values in data set are replaced by a sufficiently small number [1, 18]. But LMDI method is considered as robust and consistent in aggregation [3, 12].

The present study focuses on addressing the following questions.

- Whether increase in CO_2 emission is inevitable as a result of economic growth?
- Can energy consumption be disassociated from economic activity by achieving energy efficiency?
- Will structural change in the economy from traditional to modern sectors affects emissions levels?

To what extent this study helped to find the answers to these questions is a question mark??? Therefore, this study is based to find the factors responsible for changes in overall CO_2 emissions in Pakistan.

2 Survey of relevant literature

Energy consumption is essential for economic growth and has been increasing rapidly since past few decades. There is vast literature that identifies causal relationship between energy consumption and economic activity with mixed results. Some studies find that causality runs from energy consumption to economic growth, which implies that energy conservation may be harmful for economic growth.

The growth-energy literature generally ignores environmental concerns associated with risaing energy consumption, although energy consumption is the main contributor to CO_2 emissions. For developing countries, the structural effect turns out to be significant and the residual term also turns significant and results show biasness [21]. Most of the recent studies are conducted using LMDI technique to decompose the changes in CO_2 emissions as well as to decompose final energy consumption of the economy (Table 1).

3 Methodology

The study decomposes CO_2 emissions in Pakistan for the period 1990–2017 using LMDI method. The analysis focuses on different fuel types that are used for energy purposes in main sectors of the economy including agriculture, industry and services. Different effects were calculated including activity effect, structural effect, intensity effect, fuel mix effect and emissions factor effect that contribute to changes in overall emissions.

3.1 LMDI method

To decompose changes in CO_2 emissions in Pakistan, LMDI method was adopted according to standard method developed by Ang and Choi [4]. The period-wise analyses cover following three time periods as given below.

1. 1990–2000: 1990 as base period and 2000 as current period.
2. 2000–2017: 2000 as base period and 2017 as current period.
3. 1990–2017: 1990 as base period and 2017 as current period.

Analysis for the whole time period of 1990–2017 is to see the overall trends of changes in CO_2 emissions as well as trends of different sectors. The CO_2 emissions are decomposed into five effects given on the right hand side. LMDI method is the weighted sum of relative changes and holds some unique properties of handling negative and zero values.

The study chooses LMDI examining the changes in CO_2 emissions into following five components.

1. Activity effect.
2. Structural effect.
3. Intensity effect.
4. Fuel-mix effect.
5. Emission factor effect.

3.2 Total changes in CO_2 emissions

Total changes in CO_2 emissions are given in Eq. (1).

$$C = \sum_{ij} Q\ Q_i/Q\ E_i/Q_iE_{ij}/E_iC_{ij}/E_{ij} = \sum_{ij} QS_iI_iM_{ij}U_{ij} \quad (1)$$

where C_{ij} is the CO_2 emission of *i*th sector from fuel type *j*. *Q* is the total activity level of the economy proxied by real GDP. The share of *i*th sector in total economic activity is represented by $Si = (Qi/Q)$.

Table 1 Summary of selected studies on energy decomposition

Study	Data	Country	Methodology	Sector	Effects
Lin and Ahmad [17]	1990–2014	Pakistan	LMDI	Economic sector	Intensity effect Population effect
Mousavi et al. [21]	1995–2014	Iran	LMDI	Transportation sector	Intensity effect Population effect Activity effect
Dai and Gao [8]	1980–2010	China	LMDI	Industrial sector	Intensity effect Activity effect
Sumabat et al. [33]	2000–2010	Philippines	LMDI	Overall economy	Population effect Energy intensity
Ouyang and Lin [24]	1991–2010	China	LMDI	Industrial Sector	Activity effect Intensity effect
Moutinho et al. [22]	1999–2010	Europe	LMDI	Economic sector	Intensity effect Energy mix effect Structural effect
Cansino et al. [7]	1995–2009	Spain	LMDI	All sectors/multisector	Activity effect Structure effect Population effect
Xu et al. [37]	1995–2011	China	LMDI	Overall economy	Activity effect Population effect
Guo et al. [10]	2002–2012	China	LMDI	Transport sector	Activity effect Population effect Intensity effect
Brizga et al. [5]	1995–2009	Baltic states	Structural decomposition analysis	All sectors	Activity effect Structure effect Intensity effect
Das and Paul [9]	1993–2007	India	Input–output method	Household consumption	Activity effect Structure effect Population effect
Alves and Mouthinho [3]	1996–2009	Portugal	LMDI	Industrial sector	Emissions intensity Energy intensity
Nasab et al. [23]	2001–2006	Iran	LMDI	Transport and industrial sector	Activity effect Structural effect Energy intensity effect
Akbostanci et al. [1]	1995–2006	Turkey	LMDI	Manufacturing industry	Activity effect Energy intensity effect
Sahu and Narayanan [29]	1990–2008	India	General parametric Divisia index	Manufacturing sector	Activity effect
Tunç et al. [35]	1970–2006	Turkey	LMDI	Overall economy	Activity effect
Hatzigeorgiou et al. [11]	1990–2002	Greece	LMDI	Overall economy	Income effect Energy intensity effect

Other variables are defined as follows.

Ii = (*Ei*/*Qi*) is the intensity effect that is, energy consumption of *i*th sector per unit of output.

Mij = (*Eij*/*Ei*) is the fuel mix effect that shows how the economy uses available fuels. This effect is calculated by dividing the energy consumption of fuel type *j* of sector *i* by overall energy consumption of that sector.

Uij = (C_{ij}/*Eij*) is the CO_2 emission effect calculated as the per unit CO_2 emission by consuming a specific fuel type.

3.3 Additive Decomposition Technique

To decompose the changes in CO_2 emission level, additive decomposition technique was adopted.. The general decomposition identity is given as follows:

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} X_{1,i}, X_{2,i}, X_{3,i} \ldots X_{n,i} \quad (2)$$

Here V represents the overall change in emissions and $x_1^i, x_2^i, \ldots x_n^i$ are the different effects that explain overall changes. V is equal to the variables on the right hand side.

In additive decomposition analysis, CO_2 emission of base year is substracted from current year in order to get the overall change (V). By adding the variables on righthand side, it will be equal to the left hand side of the identity. Formula for additive decomposition analysis is given as follows:

$$\Delta V_{tot} = V_t - V_o = \Delta V_{x1} + \Delta V_{x2} + \cdots + \Delta V_{xm} \tag{3}$$

ΔV_{tot} shows the changes in overall emission level between two time periods. $\Delta V_{x1}, \Delta V_{x2}$ and so on represents the various factors that cause changes in total CO_2 emission level.

The formulas for each of five effects are presented below.

The general formulae of LMDI decomposition method for the kth term is given in Eq. (4).

$$\begin{aligned}\Delta V_{xk} &= \sum_i L(V_i^t, V_i^0)\ \ln(x_{kj}^t / x_{kj}^o) \\ &= \sum_i (V_i^t - V_i^o / \ln V_i^t - \ln V_i^o)\ \ln(xtkj / x_{kj}^o)\end{aligned} \tag{4}$$

ΔV_{xk} represents the changes in CO_2 emission level of sector x from fuel type k. Vi^t is the emission level of sector i at time t and Vi^0 is the emission level of sector i at time 0. The subscript i and k show different types of fuel as well as different types of sectors in an economy.

The general formula for additive decomposition is given as follows:

$$\Delta Ctot = C_t - C_0 = \Delta Cact + \Delta Cstr + \Delta Cint + \Delta Cfuel + \Delta Cemf \tag{5}$$

$\Delta Cact$ represents the change in CO_2 emission due to economic activity.

$\Delta Cstr$ represents the change in CO_2 emission due to structural changes.

$\Delta Cint$ represents the change in CO_2 emission due to intensity effect.

$\Delta Cfuel$ represents the change in CO_2 emission due to fuel-mix in the economy.

$\Delta Cemf$ represents the change in CO_2 emission due to emission effect.

Each effect is calculated on the right hand side of Eq. (5) using the formulas given below.

$$\Delta Cact = \sum_{ij} (C_{ij}^t - C_{ij}^o / \log C_{ij}^t - \log C_{ij}^o)\ \log(q^t / q^o) \tag{5a}$$

In Eq. (5a), C_{ij}^t is the CO_2 emission arising from fuel type j in sector i and C_{ij}^o is the emission level of same fuel type and of same sector but for time period 0.

3.4 Activity level

In order to calculate the activity level, CO_2 emissions is calculated coming from different fuel types one by one for all sectors. Then emissions of each fuel type is substracted from the emission level of time t and take logs of both C_{ij}^t and C_{ij}^o. Subtracting $\log C_{ij}^o$ from $\log C_{ij}^t$ and taking ratio of $C_{ij}^t - C_{ij}^o$ and $\log C_{ij}^t - \log C_{ij}^o$ and then multiply the whole term with log (q^t/q^o) give the activity effect.

3.5 Structure effect

Q^t is the gross domestic product of economy at time t and Q^o is the gross domestic product at time 0. By multiplying log (S_i^t/S_i^o) with $(C_{ij}^t - C_{ij}^o/\log C_{ij}^t - \log C_{ij}^0)$, structure effect is obtained.

$$\Delta Cstr = \sum_{ij} (C_{ij}^t - C_{ij}^o / \log C_{ij}^t - \log C_{ij}^0) \log(S_i^t / S_i^o) \tag{5b}$$

$$\Delta Cint = \sum_{ij} (C_{ij}^t - C_{ij}^o / \log C_{ij}^t - \log C_{ij}^0)\ \log(I_i^t / I_i^0) \tag{5c}$$

In Eq. (5c), I_i^t is the energy intensity of sector i at time t.

3.6 Intensity effect

In order to calculate the intensity effect, log (I_i^t/I_i^0) is multiplied with $(C_{ij}^t - C_{ij}^0/\log C_{ij}^t - \log C_{ij}^0)$. In many past studies, this effect contributes more to lower the overall effect because energy intensity decline as the economy move towards innovations and better technology.

3.7 Fuel mix effect

It is calculated through Eq. 5d.

$$\Delta Cmix = \sum_{ij} (C_{ij}^t - C_{ij}^o / \log C_{ij}^t - \log C_{ij}^0) \log(M_{ij}^t / M_{ij}^o) \tag{5d}$$

where M_{ij}^t is the fuel mix variable and is calculated by dividing the energy consumption of ith sector and fuel type j by energy consumption of the sector (E_{ij}/E_i). Here (E_{ij}/E_i) shows that energy, a sector i consumes how much fuel j in a given time period. In other words this shows the share of different fuels in different sector of the economy.

3.8 CO_2 emission factor

It is calculated through Eq. (5e).

U_{ij}^t in the above equation equals (C_{ij}^t/E_{ij}^t).

$$\Delta Cemf = \sum_{ij} (C_{ij}^t - C_{ij}^o / \log C_{ij}^t - \log C_{ij}^0) \log(U_{ij}^t - U_{ij}^o) \tag{5e}$$

Table 2 Carbon emission factor of different fuel types. *Source*: Inter-Governmental panel for climatic change (IPCC)

Fuel type	Carbon emission factor (C/Tj)
Gasoline	18.9
Kerosene	19.6
Gas/diesel oil	20.2
Residual fuel oil	21.1
LPG	17.2
Naphtha	20.0
Refinery gas	18.2
Coking coal	25.8
Natural gas (dry)	15.3

In this study the main variables for which data is required are final energy consumption for each sector of the economy and its output level.

Energy consumption data is collected from various issues of *Energy Yearbook* and the output data is collected from *Pakistan Economic Survey*. There are four main fuels in Pakistan including, oil, natural gas, hydroelectricity and coal. In this study, the economy is divided into three sectors such as, industry, agriculture and services sector and used the energy consumption data of different fuel types for each of the sector (Table 2). For each fuel type, consumed in these sectors, the amount of energy is calculated related to CO_2 emissions. The CO_2 emissions are calculated for each fuel type because different fuels have different pollution level. If one of the data is missing then decompose cannot be accurate. For this reason, data of each fuel type was collected for each sector and then converted it into CO_2 emission by following the standard procedure and formula presented by Intergovernmental Panel on Climate Change [13].

Step 1 Final energy consumption in tons of oil equivalent (TOE) is collected for the sectors of economy. Energy produced by electricity needs special attention. Since electricity is produced by different methods in Pakistan. The weights of oil and gas were measured in total electricity generation. After calculating the weights, it was converted to CO_2 emissions.

Step 2 Now this TOE value was converted to a common energy unit called Terra Joule (TJ) applying the conversion factor, $TJ = TOE * 41{,}868/10^6$.

Step 3 Carbon content was calculated by multiplying TJ values with carbon emission factor (CEF) for each fuel type presented in Table 1. Each fuel type contain different amount of carbon content. So the energy unit [Tera-joule (TJ)] of each fuel type was multiplied with its own carbon emissions factor value.

Step 4 Actual carbon emission is then calculated by multiplying carbon content with global default value (GDV) for fraction of carbon oxidized.

Step 5 Actual carbon emissions were converted into CO_2 emission by multiplying its values with (44/12).

Step 6 CO_2 emission for each fuel type are summed to get the sector-wise aggregate CO_2 emission.

4 Results and discussion

Data analysis shows that CO_2 emissions increase with the increase in final energy consumption. Among the five factors, the activity effect contributes more to the overall change. In the study period of 1990–2000, the largest contributor to CO_2 emissions is the activity effect followed by intensity effect (Table 3). The negative sign of intensity effect reveals that CO_2 emission's intensity decreases during the period. The structural effect was observed with low value. With increasing share of fossil fuel in final energy consumption, the fuel-mix effect turns out to be significant and the sign of the fuel-mix effect is positive (Table 3). The positive fuel mix effect can be attributed to the Power Policy 1994 that tilted the share of electricity towards thermal energy by raising thermal electricity generation from 35 to 65% [38]. The fifth emission factor is negligible in affecting the overall changes in CO_2 emissions level.

The results of decomposition analysis of CO_2 emissions for the period of 2000–2017 show a high share of activity effect than the previous decade (Table 3). This contribution may be attributed to higher cumulative growth rate in

Table 3 Results of decomposition analysis of CO_2 emissions (M.tons)

	1990–2000	2000–2017	1990–2017
ΔC_{act}	2.15	6.66	9.09
	(151.4)	(103.3)	(114.4)
ΔC_{str}	−0.10	0.84	0.56
	(−7.1)	(13.1)	(7.11)
ΔC_{int}	−1.07	−1.30	−2.62
	(−75.1)	(−20.2)	(−32.93)
ΔC_{mix}	0.44	0.24	0.91
	(30.8)	(3.8)	(11.40)
Δemf	0.000	0.000	0.000
	(0.01)	(0.01)	(0.01)
ΔC_{tot}	1.42	6.47	7.95
	(100)	(100)	(100)

The numbers in the parenthesis ( ) are percentages.; M.tons is abbreviation of Million tons this period. The structural effect has an increasing share in overall emissions change due to improvement in industrial sector during 2000–2017. The intensity effect of CO_2 emissions is diminishing which implies that energy efficiency is improving in the economy. The fuel mix effect is negative indicating a shift towards less polluting fuels (Table 3).

The results in fourth column of Table 3 suggest that activity effect is largest extent to overall changes in CO_2 emissions for the period followed by the intensity effect. The negative sign of intensity effect shows that the overall energy and CO_2 emissions intensity has been decreasing during the study period.

The fuel mix effect is the third largest contributor to the changes in emissions level with a positive sign. Fuel mix effect was sufficiently high during the 1990s, when electricity sector reforms allowed the independent power producers to join the market with plenty of investment in thermal electricity generation (Table 3). It transformed the outlook of electricity sector from Hydel to thermal dominated power generation. The structural effect has a positive sign which shows that structure of Pakistan economy is changing towards more energy intensive sectors that is industry and services.

4.1 Sector-wise decomposition of energy related CO_2 emissions

The results for activity effect found highest in industrial and services sectors. In agricultural sector, the intensity effect dominates other effects (Tables 4, 5, 6). The decomposition analysis of the present study are robust and consistent with various past studies conducted for different developing countries [28, 30]. Past studies for developing countries show fairly similar trends of decomposition analysis [19, 23, 29]. Our decomposition analysis results that the main effect explaining changes in CO_2 emissions is activity effect, structural effect, intensity effect and to some extent the fuel-mix effect.

The intensity effect cause a decline in emissions level as a result of energy use efficiency. The energy intensity of all the three sectors decline with the passage of time implying an improvement in the efficiency. This trend of energy intensity effect suggests that the economy is gradually becoming energy efficient. This improvement in energy efficiency can be attributed to technological improvements in production processes. The role of structural and fuel mix effects are fairly moderate since the

Table 4 Sector-wise decomposition of energy related CO_2 emissions (1990–2017)

Effect	Aggregate		Industry		Agriculture		Services	
	MTOE	%	MTOE	%	MTOE	%	MTOE	%
Activity effect	9.09	114.42	3.36	99.4	0.19	− 149.6	5.55	117.9
Structure effect	0.56	7.11	0.23	6.8	− 0.05	35.8	0.38	8.9
Intensity effect	− 2.62	− 32.93	− 0.81	− 24	− 0.27	206.5	− 1.54	− 32.7
Fuel mix effect	0.91	11.40	0.60	17.9	− 0.01	7.4	0.31	6.6
Total	7.95	100	3.38	100	− 0.13	100	4.70	100

Table 5 Sector-wise decomposition of energy related CO_2 emissions (1990–2000)

Effect	Aggregate		Industry		Agriculture		Services	
	MTOE	%	MTOE	%	MTOE	%	MTOE	%
Activity effect	2.15	151.4	0.73	150.7	0.07	− 58.6	1.35	127.6
Structure effect	− 0.10	− 7.1	− 0.13	− 26.9	0.007	− 5.4	0.02	2.2
Intensity effect	− 1.07	− 75.1	− 0.27	− 55.6	− 0.23	189.1	− 0.57	− 53.7
Fuel mix effect	0.44	30.8	0.15	31.8	0.03	− 25.1	0.25	23.9
Total	1.42	100	0.49	100	− 0.12	100	1.06	100

Table 6 Sector-wise decomposition of energy related CO_2 emissions (2000–2017)

Effect	Aggregate		Industry		Agriculture		Services	
	MTOE	%	MTOE	%	MTOE	%	MTOE	%
Activity effect	6.66	103.3	2.45	86.6	0.09	− 311.7	4.12	113.1
Structure effect	0.84	13.1	0.48	17.1	− 0.04	128.7	0.40	10.9
Intensity effect	− 1.30	− 20.2	− 0.43	− 15.2	− 0.04	128.7	− 0.84	− 22.9
Fuel mix effect	0.24	3.8	0.33	11.5	− 0.04	154.3	− 0.04	− 1.0
Total	6.45	100	2.83	100	− 0.03	100	3.65	100

economy is gradually moving towards energy intensive sectors and the use of hydrocarbons increased as can be evident from decreasing share of hydroelectricity in total electricity generation. The share of industrial and services sectors is increasing that are more energy intensive sectors as compare to the agricultural sector.

The Ministry of Petroleum and Natural Resources (MPNR) encourages natural gas consumption in the household and commercial sectors. It foster the household and vehicular gas consumption and Pakistan became the top user of compressed natural gas (CNG) in the world in the late 2000s. Now that Pakistan has exhausted its gas resources and perceived share of gas would decline as major investments are diverting towards coal based thermal power generation [25].

This study suggests that the emission level has an overall upward trend during the period 1990–2017. The most significant factors responsible for changes in the emissions level are the activity effect, structural effect and intensity effect. Both the activity and structure effects have a positive sign which shows that these two force the emissions level to increase.

5 Conclusion and recommendations

The decomposition analysis for the period 1990–2000 showed a rather stagnant share of economic activity in all sectors of economy. During 2000–2017, the structure effect has a relatively higher share in total change of CO_2 emissions. With increase in the share of comparatively more energy intensive sector, the structural effect also proliferates. The share of agricultural sector will further decrease with the economic growth implying that the structural effect will be positive. The fuel mix effect lowers the emissions during 2000–2017 mainly due to increasing share of natural gas in energy mix of the country.

For the most part, the reduction in both the activity and structural effects is detrimental to the economy and the cost of status quo is also very high. The findings of the study have important implications for the design of energy and environmental policies. The future policy design should concentrate on fuel mix and improving efficiency. The vehicular emissions are the main factor responsible for pollution in urban areas, hence the major factor behind decrease in the emissions is a replacement of biomass and oil with natural gas in household and transport sectors of the economy. The inefficient energy use and lack of energy conservation raise the environmental problems that lead to climatic changes. The policies may encourage diversification of the economic activity at the sub-sector level especially in the manufacturing industry. The increase trend of CO_2 emissions ensures the economic growth at the least cost of environmental degradation. On other hand it was observed that the intensity effect discourage the CO_2 emission level. It is concluded that prudent energy pricing policies can help in conservation of energy and environment through energy transition from non-renewable to renewable energy sources. It is therefore recommended that by introducing new technologies in electricity generation and the introduction of renewable energy sources such as, wind, biomass and solar energy will be helpful to decrease the carbon coefficient of electricity generation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

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