Chapter 6
A Decomposition Analysis of Energy-Related CO_2 Emissions: The Top 10 Emitting Countries

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Abstract Climate change, caused by greenhouse gas (GHG) emissions, is one of the hot topics all around the world. Carbon dioxide (CO_2) emissions from fossil fuel combustion account for more than half of the total anthropogenic GHG emissions. The top 10 emitting countries accounted 65.36 % of the world carbon dioxide emissions in 2010. China was the largest emitter and generated 23.84 % of the world total. The objective of this study is to identify factors that contribute to changes in energy-related CO_2 emissions in the top 10 emitting countries for the period 1971–2010. To this aim, a decomposition analysis has been employed. Decomposition analysis is a technique used to identify the contribution of different components of a specific variable. Here, four factors, namely population, per capita income, energy intensity, and carbon intensity, are differentiated. The results show that the economic activity effect and the energy intensity effect are the two biggest contributors to CO_2 emissions for all countries with a few exceptions.

6.1 Introduction

The qualitative dimension of energy use is becoming increasingly important for sustainable development. One important question in this context and in the context of global climate change is how one can achieve the separation of greenhouse gas (GHG) emissions. Among six kinds of GHG, the largest contribution to the greenhouse effect is carbon dioxide (CO_2), and its share of greenhouse effect is about more than 50 % (IPCC 1995; He and Chen 2002).

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Table 6.1 CO_2 emission by countries (2010)

Rank	Country	CO_2 emission (Mt)	% of total
1	China	7217.1	23.84
2	USA	5368.6	17.73
3	India	1625.8	5.37
4	Russian Federation	1581.4	5.22
5	Japan	1143.1	3.78
6	Germany	761.6	2.52
7	South Korea	563.1	1.86
8	Canada	536.6	1.77
9	Islamic Republic of Iran	509.0	1.68
10	United Kingdom	483.5	1.60
	World total	30,276	100

The top 10 CO_2-emitting countries accounted for 65.36 % of the world CO_2 emissions in 2010. China and the USA were the two highest emitters and generated 23.84 and 17.73 % of the world total, respectively (Table 6.1) (IEA 2012).

Decomposition analysis is a technique used to identify the contribution of different components of a specific variable. It is an effective tool which is used in various disciplines. In economics and environmental sciences, it has been applied to investigate the main factors contributing to the CO_2 emissions and the mechanisms influencing energy consumption.

Its application to policy formulation is generally used to improve sustainability management, to reduce the economic impacts on the environment, to promote energy and technological efficiency, and to design decoupling strategies (Subhes and Arjaree 2004; Diakoulaki et al. 2006; Diakoulaki and Mandaraka 2007; McCollum and Yang 2009).

This work aims to identify the factors that contribute to the changes in CO_2 emissions in the top 10 CO_2-emitting countries for the period of 1971–2010 by the refined Laspeyres method (Steckel et al. 2011; Kumbaroğlu 2011; Andreoni and Galmarini 2012). Population, per capita income, energy intensity, and carbon intensity were the four effects that were investigated.

6.2 Materials and Methods

6.2.1 The Decomposition Analysis

The CO_2 emission can be expressed as an extended Kaya identity (Xiangzhao and Ji 2008; Girod et al. 2009; Linyun and Hongwu 2011) which is a useful tool to decompose the total carbon emission as a product of four variables as shown in Eq. (6.1).

$$(CO_2) = (P)(GDP/P)(TPES/GDP)(CO_2/TPES) \tag{6.1}$$

The right-hand side of Eq. (6.1) refers to the population (P), income per capita $G = (GDP/P)$, energy intensity of economic activity $E = (TPES/GDP)$, and carbon intensity of energy use $C = (CO_2/TPES)$.

The change of CO_2 emission between a base year (t) and a target year ($\Delta t + t$), denoted by (ΔCO_2), can be defined as a function of four variables, namely the change in the population effect, the change in the economic activity effect, the change in the energy intensity effect, and the change in the carbon intensity effect, as shown in Eq. (6.2).

$$(\Delta CO_2) = (CO_2)^{t+\Delta t} - (CO_2)^t = P_{\text{effect}} + G_{\text{effect}} + E_{\text{effect}} + C_{\text{effect}} \tag{6.2}$$

where superscripts (t) and ($\Delta t + t$) denote a base year and a target year, respectively.

According to the complete decomposition model given by refined Laspeyres method, each effect in the right-hand side of Eq. (6.2) can be computed as follows: Equation (6.3) calculates the population effect:

$$\begin{aligned} P_{\text{effect}} = {} & (\Delta P)G^tE^tC^t + \frac{1}{2}(\Delta P)[(\Delta G)E^tC^t + G^t(\Delta E)C^t + G^tE^t(\Delta C)] \\ & + \frac{1}{3}(\Delta P)[(\Delta G)(\Delta E)C^t + (\Delta G)E^t(\Delta C) + G^t(\Delta E)(\Delta C)] \\ & + \frac{1}{4}(\Delta P)(\Delta G)(\Delta E)(\Delta C) \end{aligned} \tag{6.3}$$

Equation (6.4) calculates the economic activity effect:

$$\begin{aligned} G_{\text{effect}} = {} & (\Delta G)P^tE^tC^t + \frac{1}{2}(\Delta G)[(\Delta P)E^tC^t + P^t(\Delta E)C^t + P^tE^t(\Delta C)] \\ & + \frac{1}{3}(\Delta G)[(\Delta P)(\Delta E)C^t + (\Delta P)E^t(\Delta C) + P^t(\Delta E)(\Delta C)] \\ & + \frac{1}{4}(\Delta P)(\Delta G)(\Delta E)(\Delta C) \end{aligned} \tag{6.4}$$

Equation (6.5) calculates the energy intensity effect:

$$\begin{aligned} E_{\text{effect}} = {} & (\Delta E)P^tG^tC^t + \frac{1}{2}(\Delta E)[(\Delta P)G^tC^t + P^t(\Delta G)C^t + P^tG^t(\Delta C)] \\ & + \frac{1}{3}(\Delta E)[(\Delta P)(\Delta G)C^t + (\Delta P)G^t(\Delta C) + P^t(\Delta G)(\Delta C)] \\ & + \frac{1}{4}(\Delta P)(\Delta G)(\Delta E)(\Delta C) \end{aligned} \tag{6.5}$$

Equation (6.6) calculates the carbon intensity effect:

$$\begin{aligned} C_{\text{effect}} = {} & (\Delta C)P^tG^tE^t + \frac{1}{2}(\Delta C)[(\Delta P)G^tE^t + P^t(\Delta G)E^t + P^tG^t(\Delta E)] \\ & + \frac{1}{3}(\Delta C)[(\Delta P)(\Delta G)E^t + (\Delta P)G^t(\Delta E) + P^t(\Delta G)(\Delta E)] \\ & + \frac{1}{4}(\Delta P)(\Delta G)(\Delta E)(\Delta C) \end{aligned} \tag{6.6}$$

The first parts of Eqs. (6.3–6.6) can be interpreted as the partial effect of the population, partial effect of the economic activity, partial effect of the energy intensity, and partial effect of the carbon intensity components on the change of (ΔCO_2) emissions between time step ($\Delta t + t$) and the preceding step (t). The following parts of Eqs. (6.3–6.6) capture the interactions between the remaining variables and the residual terms.

It is necessary to make clear that different factors caused the changes in CO_2 emission. The population change effect is used to control the population size. The economic activity effect reflects the economic development. Energy consumption is mainly related to some variables, such as economic structures, the efficiency of the energy systems, energy utilization technologies, energy prices, energy conservation, and energy-saving investments, which are composed of energy intensity effect. And the carbon intensity effect is used to evaluate fuel quality, fuel substitution, and the installation of abatement technologies.

Equations (6.2–6.6) present the required formulas for the decomposition analysis. A computer code in MATHEMATICA (Wolfram 2004) has been developed to do the calculations in this text.

The data used in the study for top 10 CO_2-emitting countries for the period 1971–2010 have been collected from the International Energy Agency (IEA 2012).

6.2.2 Population Growth

Figure 6.1 shows the development of population by countries in the period 1971–2010 (IEA 2012). As seen from Fig. 6.1, it should be noted that there is no analysis for Russian Federation in the period 1971–1990 because of an abruption in the data. Annual growth rate of population for Russian Federation has decreasing effect representing annual growth rate of −0.25 % in the period 1991–2010. Annual growth rate of population has increasing effect for nine countries in the period 1971–2010. Islamic Republic of Iran has the largest annual growth rate of population has increased from 29.4 million in 1971 to 74 million in 2010, representing an overall annual growth rate of 2.36 % while Germany has the lowest annual growth rate of population has increased from 78.3 million in 1971 to 81.8 million in 2010, representing an overall annual growth rate of 0.11 %.

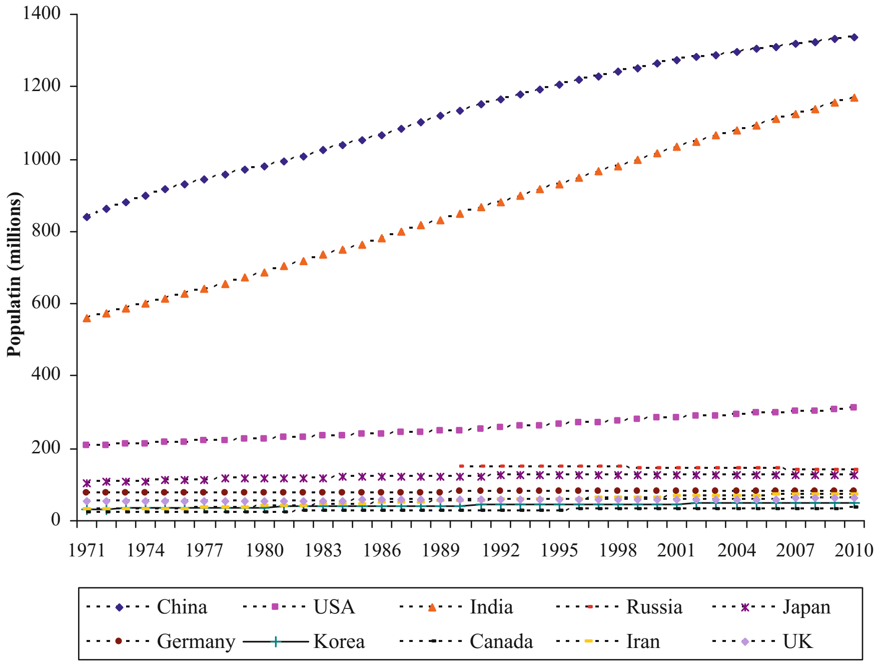

Fig. 6.1 Development of population by countries

6.2.3 Economic Growth

The development of income per capita by countries in the period 1971–2010 is presented in Fig. 6.2 (IEA 2012). Annual growth rate of income per capita has increasing effect for nine countries in the period 1971–2010 (Fig. 6.2). China has the largest annual growth rate of income per capita, which has increased from 358.65 (2005 USD/capita) in 1971 to 6816.29 (2005 USD/capita) in 2010, representing an annual growth rate of 7.55 %, while Islamic Republic of Iran has the lowest annual growth rate of income per capita, which has increased from 7662.35 (2005 USD/capita) in 1971 to 10450.32 (2005 USD/capita) in 2010, representing an annual growth rate of 0.80 %.

Annual growth rate of income per capita for Russian Federation is 0.90 % in the period 1991–2010. At the same time period, China and Japan have the largest and lowest annual growth rates of 9.21 and 0.68 %, respectively.

6.2.4 Energy Intensity

Figure 6.3 shows the development of energy intensity by countries in the period 1971–2010 (IEA 2012). As seen from Fig. 6.3, annual growth rate of energy

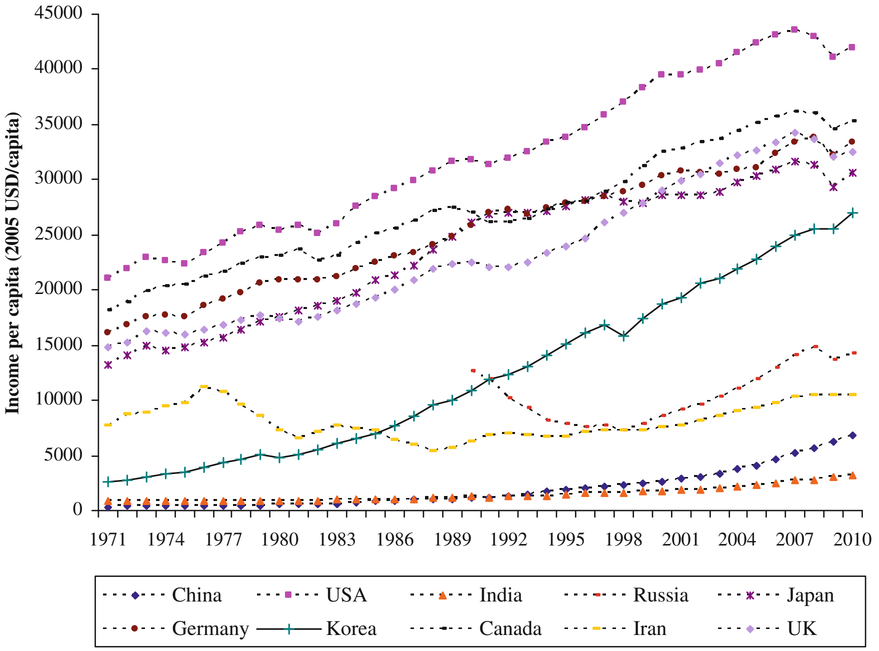

Fig. 6.2 Development of income per capita by countries

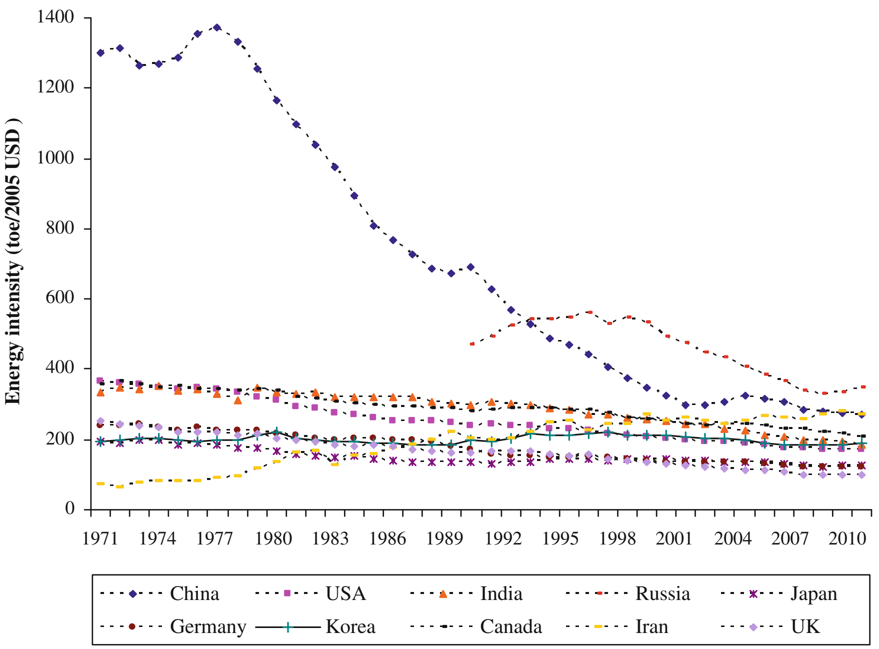

Fig. 6.3 Development of energy intensity by countries

intensity has a decreasing effect for China, the USA, India, Japan, Germany, South Korea, Canada, and the United Kingdom, while Islamic Republic of Iran has increasing effect in the period 1971–2010. China has the largest annual growth rate of energy intensity, which has decreased from 1298.49 (toe/2005 USD) in 1971 to 269.20 (toe/2005 USD) in 2010, representing an annual growth rate of −4.03 %, while Korea has the lowest annual growth rate of energy intensity, which has decreased from 196.00 (toe/2005 USD) in 1971 to 189.27 (toe/2005 USD) in 2010, representing an annual growth rate of −0.09 %.

Annual growth rate of energy intensity for Russian Federation is −1.79 % in the period 1991–2010. At the same time period, China and Korea have the largest and lowest annual growth rates of −4.46 and −0.15 %, respectively.

Annual growth rates of energy intensity for Islamic Republic of Iran are 1.55 and 3.33 % for the periods 1991–2010 and 1971–2010, respectively.

6.2.5 Carbon Intensity

The development of carbon intensity by countries in the period 1971–2010 is presented in Fig. 6.4 (IEA 2012). Annual growth rate of carbon intensity has a decreasing effect for the USA, Japan, Germany, South Korea, Canada, Islamic

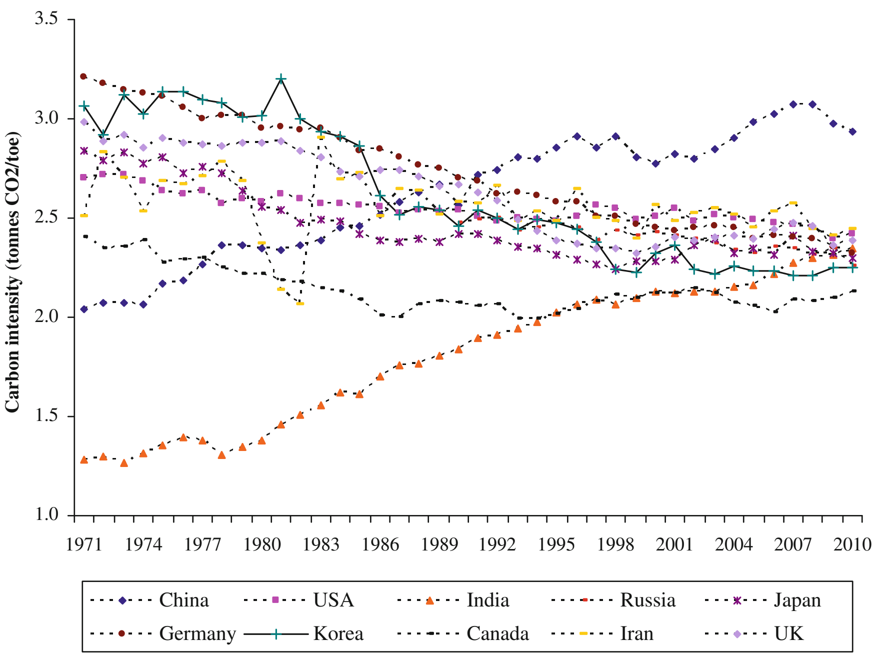

Fig. 6.4 Development of carbon intensity by countries

Republic of Iran, and the United Kingdom, while annual growth rate of carbon intensity has increasing effect for China and India in the period 1971–2010 (see Fig. 6.4). China has the largest annual growth rate of carbon intensity, which has increased from 2.04 (tones of CO_2/toe) in 1971 to 2.94 (tones of CO_2/toe) in 2010, representing an annual growth rate of 0.93 %, while Germany has the highest annual growth rate of carbon intensity, which has decreased from 3.21 (tones of CO_2/toe) in 1971 to 2.33 (tones of CO_2/toe) in 2010, representing an annual growth rate of −0.82 %.

Annual growth rate of carbon intensity for Russian Federation has decreasing effect (−0.52 %) in the period 1991–2010. At the same time period, annual growth rate of carbon intensity for China has increasing effect (0.42 %), while annual growth rate of carbon intensity for Germany has decreasing effect (−0.762 %).

6.3 Results and Discussion

The results of the decomposition analysis of CO_2 emission related to the energy consumption of the top 10 emitting countries for the period 1971–2010 divided into five-year time intervals are presented in Table 6.2. The central columns report the decomposition in the four explanatory variables (P_{effect}, G_{effect}, E_{effect}, C_{effect}).

Table 6.2 Decomposition of CO_2 emission by countries (Mt)

Time period	P_{effect}	G_{effect}	E_{effect}	C_{effect}	ΔCO_2
China					
1971–1975	78.9	122.1	−6.4	56.2	250.8
1976–1980	66.2	346.2	−190.8	90.9	312.4
1981–1985	108.2	610.2	−484.4	79.5	313.5
1986–1990	125.0	465.7	−218.8	33.5	405.4
1991–1995	124.2	1191.4	−788.1	133.6	661.0
1996–2000	113.9	886.8	−969.7	−154.5	−123.5
2001–2005	99.6	1435.9	222.9	220.7	1979.1
2006–2010	133.2	2506.6	−845.1	−180.5	1614.2
USA					
1971–1975	169.6	280.7	−274.0	−106.8	69.5
1976–1980	200.4	396.0	−496.2	−66.8	33.5
1981–1985	166.2	447.4	−563.7	−100.2	−50.2
1986–1990	181.8	404.1	−219.5	−19.7	346.7
1991–1995	251.4	383.6	−294.2	−37.2	303.7
1996–2000	253.6	713.6	−565.3	−7.4	394.4
2001–2005	213.5	400.3	−393.4	−53.9	166.5
2006–2010	199.7	−149.0	−247.5	−119.5	−316.3

(continued)

Table 6.2 (continued)

Time period	P_{effect}	G_{effect}	E_{effect}	C_{effect}	ΔCO_2
India					
1971–1975	20.0	7.9	0.1	13.1	41.0
1976–1980	24.6	12.5	−9.2	−2.7	25.2
1981–1985	30.7	39.0	−10.1	36.9	96.5
1986–1990	42.6	81.9	−31.8	40.1	132.8
1991–1995	51.1	114.6	−58.5	45.9	153.1
1996–2000	61.1	127.2	−61.6	27.7	154.4
2001–2005	62.9	244.7	−147.7	20.8	180.7
2006–2010	77.3	372.8	−163.1	82.5	369.5
Russian Federation					
1991–1995	−6.4	−784.8	209.4	−12.2	−594.0
1996–2000	−14.6	193.3	−205.1	−14.6	−40.9
2001–2005	−29.6	408.0	−317.1	−53.2	8.2
2006–2010	−7.8	152.2	−73.3	−69.4	1.6
Japan					
1971–1975	50.66	91.5	−36.07	−8.59	97.5
1976–1980	31.57	123.91	−102.22	−57.76	−4.5
1981–1985	27.58	118.87	−82.12	−42.83	21.5
1986–1990	15.04	193.91	−34.98	13.33	187.3
1991–1995	13.34	27.84	82.22	−48.5	74.9
1996–2000	9.28	16.07	1.86	−6.42	20.8
2001–2005	4.69	70.47	−52.69	28.43	50.9
2006–2010	−3.68	−13.22	−36.22	−8.78	−61.9
Germany					
1971–1975	5.0	82.0	−60.1	−30.0	−3.1
1976–1980	0.0	122.6	−64.8	−34.3	23.4
1981–1985	−9.1	72.8	−28.3	−43.1	−7.7
1986–1990	21.3	116.5	−153.3	−51.2	−66.6
1991–1995	18.9	25.9	−65.3	−36.5	−57
1996–2000	3.2	69.6	−100.8	−43.4	−71.5
2001–2005	2.0	10.2	−32.4	−14.0	−34.3
2006–2010	−6.7	27.8	−52.5	−27.8	−59.3
South Korea					
1971–1975	4.5	18.5	0.3	1.5	24.7
1976–1980	6.5	21.6	15.0	−4.1	39.0
1981–1985	7.5	43.7	−11.8	−15.5	23.9
1986–1990	7.9	65.4	7.7	−11.3	69.6
1991–1995	12.4	74.5	25.8	−8.4	104.3

(continued)

Table 6.2 (continued)

Time period	P_{effect}	G_{effect}	E_{effect}	C_{effect}	ΔCO_2
Canada					
1971–1975	17.5	50.0	−19.5	−10.3	37.8
1976–1980	17.1	36.8	−5.1	−13.3	35.4
1981–1985	16.1	25.1	−30.0	−19.1	−8.0
1986–1990	24.6	24.2	−23.9	14.1	39.0
1991–1995	20.3	27.2	−1.5	−7.5	38.5
1996–2000	18.6	76.1	−62.9	20.4	52.2
2001–2005	20.6	38.0	−7.8	−17.5	33.3
2006–2010	24.3	−7.0	−51.7	26.8	−7.5
Islamic Republic of Iran					
1971–1975	6.1	13.3	6.7	3.8	29.8)
1976–1980	11.8	−39.3	47.5	−10.7	9.3
1981–1985	17.6	4.8	4.1	28.2	54.7
1986–1990	24.7	−4.4	37.3	4.4	62.0
1991–1995	18.0	−7.2	50.6	−7.8	53.6
1996–2000	20.0	16.3	28.5	−20.8	44.0
2001–2005	18.8	69.7	−31.3	33.9	91.1
2006–2010	6.1	13.3	6.7	3.8	54.0
United Kingdom					
1971–1975	3.2	47.3	−51.4	−43.1	−44.0
1976–1980	1.1	35.8	−51.7	54.0	39.2
1981–1985	2.0	64.3	−42.8	−34.3	−10.7
1986–1990	4.9	64.0	−63.8	−15.1	−9.9
1991–1995	5.6	45.8	−42.9	−52.3	−43.7
1996–2000	6.4	88.1	−86.5	−19.2	−11.2
2001–2005	9.9	49.4	−62.7	−0.8	−4.2
2006–2010	13.3	−13.8	−39.3	−11.4	−51.2

The last column shows the cumulated changes that are calculated as the aggregation of these variables. The percentage change of the four different effects of the top 10 emitting countries for the first (1971–1975) and the last (2006–2010) time periods is also presented in Fig. 6.5 except Russian Federation. Due to lack of the data for the first (1971–1975) time period for Russian Federation, Russian Federation is not included in Fig. 6.5.

Table 6.2 shows that the economic activity effect (G_{effect}) and the energy intensity effect (E_{effect}) are the two biggest contributors to CO_2 emission for all countries with a few exceptions. The population effect (P_{effect}) for the sub-periods (1971–1975) and (1976–1980) in India, the carbon intensity effect (C_{effect}) for the sub-period (1981–1985) in Islamic Republic of Iran, and for the sub-periods (1976–1980) and (1991–1995) in the UK are the biggest contributors to CO_2 emission.

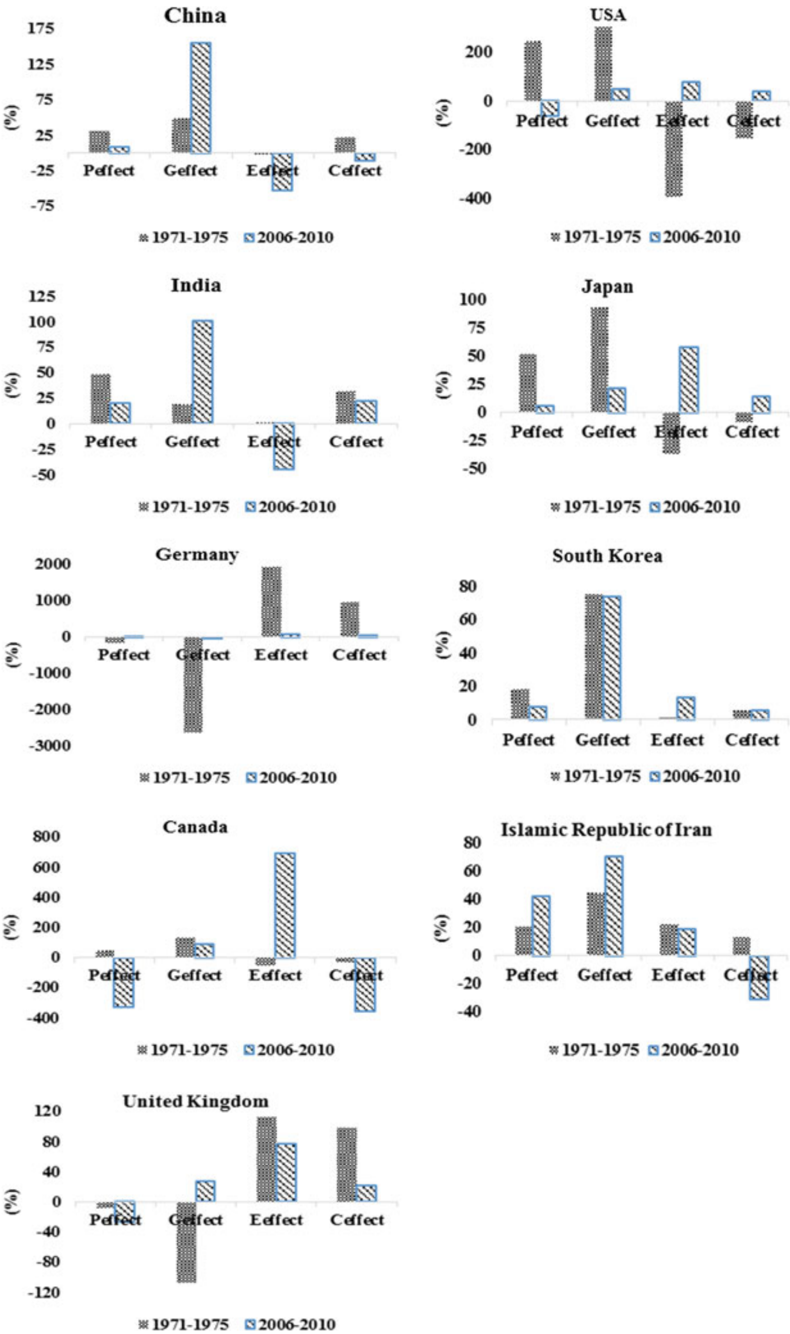

Fig. 6.5 Decomposition of CO_2 emission by countries (%)

In general, the population effect accelerated the increase in CO_2 emission for all countries in the entire sub-periods except Russian Federation. Russian Federation was the only country that the population reduced the increase in CO_2 emission for all the sub-periods. This effect also reduced the increase in CO_2 emissions in Japan and Germany for one and two sub-periods, respectively (Table 6.2).

The economic activity effect accelerated the increase in CO_2 emission for all countries in most of the sub-periods (Table 6.2). This effect reduced the increase in CO_2 emission in the developed countries such as the USA, Japan, Canada, and the United Kingdom for the sub-period 2005–2010 when the economic recession occurred.

The energy intensity effect reduced the increase in CO_2 emission for all the countries in most of the sub-periods except South Korea and Islamic Republic of Iran. This effect accelerated the increase in CO_2 emission in Islamic Republic of Iran in most of the sub-periods (Table 6.2).

The carbon intensity effect reduced the increase in CO_2 emission in the USA, Russian Federation, Japan, Germany, South Korea, Canada, and the United Kingdom, while it accelerated the increase in CO_2 emissions in China, India, and Islamic Republic of Iran (Table 6.2).

The percentage change in the economic activity effect of the top 10 emitting countries is quite different for the first (1971–1975) and the last (2006–2010) time periods except the countries South Korea, Canada, and Islamic Republic of Iran (Fig. 6.5).

The results obtained in this study are consistent with the previous studies for China (Zhang et al. 2009) and the USA (Tol et al. 2009), those of which are the top two CO_2-emitting countries.

6.4 Conclusion

The results show that the economic activity effect and the energy intensity effect are the two biggest contributors to CO_2 emissions for all the countries with a few exceptions. The economic activity caused an increase in CO_2 emission, while the energy intensity contributed a decrease in CO_2 emission.

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