Environment Protection Engineering

Vol. 42 2016 No. 3

DOI: 10.5277/epe160307

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THE IMPACT OF CHANGING ENERGY MIX OF TURKEY ON CO_2 EMISSION INTENSITIES

A decomposition analysis of energy-related carbon dioxide emission intensities in Turkey from 1971 to 2010 has been presented. The refined Laspeyres method is used in the calculation to identify fossil fuel carbon effect, fossil fuel share effect and energy intensity effect that accelerate or reduce the increase in carbon dioxide emission intensities. The results show that the fossil fuel share effect and the energy intensity effect are the two biggest contributors to CO_2 emission. The case analysis also shows that fossil fuel carbon effects play important roles in the decrease of CO_2 emission intensities especially from 1988 to 2010.

1. INTRODUCTION

The qualitative dimension of energy use is becoming increasingly important for sustainable development [1, 2]. Among six kinds of greenhouse gases, the largest contribution to the greenhouse effect has carbon dioxide (CO_2). CO_2 emissions related to energy use results from fossil fuel combustion.

Generally, CO_2 emission intensities are decomposed into the product of the index of CO_2 emissions per total primary energy supply (TPES) and energy intensity that is defined as TPES to gross domestic product (GDP) [3–7]. In the above decomposition, the change in the index of CO_2 emissions per TPES reflects the effect of change in energy mix on CO_2 emission intensities. The change in energy intensity reflects the effect of change in energy efficiency on CO_2 emission intensities. However, this decomposition seems too general. There are two ways to have an effect on the index of CO_2 emissions per TPES by means of a change in the fossil fuel mix that determines the

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structure of CO_2 emissions, and a change in the share of fossil fuel in total primary energy supply that is used to determine the level of CO_2 emission intensities [8, 9].

The effects of changing the above two aspects on CO_2 emission intensities have been analyzed by the refined Laspeyres method [10–12]. For a case analysis, CO_2 emission intensities in Turkey from 1971 to 2010 have been analyzed.

2. MATERIALS AND METHODS

Decomposition analysis. The CO_2/GDP emission intensity can be expressed as an extended Kaya identity [13–15], which is a useful tool to decompose total carbon emission intensity as a product of three effects:

$$\frac{\mathrm{CO_2}}{\mathrm{GDP}} = \frac{\mathrm{CO_2}}{\mathrm{FFS}} \frac{\mathrm{FFS}}{\mathrm{TPES}} \frac{\mathrm{TPES}}{\mathrm{GDP}} \tag{1}$$

The right hand side of the Eq. (1) refers to CO_2 emissions per fossil fuel, FC = (CO_2/FFS), the share of fossil fuel in TPES FS = (FFS/TPES), and energy intensity of economic activity EI = (TPES/GDP).

The change of (CO_2/GDP) emission intensity between a base year t and a target year $\Delta t + t$, denoted by Δ(CO_2/GDP), can be decomposed to three effects namely, the changes in the fossil fuel carbon effect, the changes in the fossil fuel share effect, the changes in the energy intensity effect and in additive form:

$$\frac{\Delta\mathrm{CO_2}}{\mathrm{GDP}} = \left(\frac{\mathrm{CO_2}}{\mathrm{GDP}}\right)^{t+\Delta t} - \left(\frac{\mathrm{CO_2}}{\mathrm{GDP}}\right)^{t} = \mathrm{FC_{effect}} + \mathrm{FS_{effect}} + \mathrm{EI_{effect}} \tag{2}$$

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

According to the complete decomposition model given by the refined Laspeyres method each, effect in the right hand side of Eq. (2) can be computed as follows.

- the fossil fuel carbon effect:

$$\mathrm{FC_{effect}} = (\Delta FC)(\mathrm{FS})^t(\mathrm{EI})^t + \frac{1}{2}(\Delta\mathrm{FC})\left[(\Delta\mathrm{FS})(\mathrm{EI})^t + (\Delta\mathrm{EI})(\mathrm{FS})^t\right] + \frac{1}{3}(\Delta\mathrm{FC})(\Delta\mathrm{FS})(\Delta\mathrm{EI}) \tag{3}$$

- the fossil fuel share effect:

$$\mathrm{FS}_{\mathrm{effect}} = (\Delta\mathrm{FS})(\mathrm{FC})^t(\mathrm{EI})^t + \frac{1}{2}(\Delta\mathrm{FS})\left[(\Delta\mathrm{FC})(\mathrm{EI})^t + (\Delta\mathrm{EI})(\mathrm{FC})^t\right] + \frac{1}{3}(\Delta\mathrm{FC})(\Delta\mathrm{FS})(\Delta\mathrm{EI}) \quad (4)$$

- the energy intensity effect:

$$\mathrm{EI}_{\mathrm{effect}} = (\Delta\mathrm{EI})(\mathrm{FC})^t(\mathrm{FS})^t + \frac{1}{2}(\Delta\mathrm{EI})\left[(\Delta\mathrm{FC})(\mathrm{FS})^t + (\Delta\mathrm{FS})(\mathrm{FC})^t\right] + \frac{1}{3}(\Delta\mathrm{FC})(\Delta\mathrm{FS})(\Delta\mathrm{EI}) \quad (5)$$

The former terms of Eqs. (3)–(5) refer to the partial effects of the fossil fuel carbon, fossil fuel share and energy intensity on the change of $\Delta\mathrm{CO_2}/\mathrm{GDP}$ emissions between time-step $\Delta t + t$ and the preceding step *t*. The following parts of Eqs. (3)–(5) refer to capture interactions between the remaining variables and form the so called residual terms. Equations (2)–(5) present the required formulas for decomposition analysis. A program in MATHEMATICA [16] has been specially developed for calculations in this paper.

Data. The data used in the study for the period 1971–2010 have been collected from the World Energy Council, Turkish National Committee [17] and International Energy Agency [18]. An overview of the data used growth trajectories is presented below.

Total primary energy supply increased considerably during 1971–2010 as shown in Fig. 1 [17]. The average annual rate of increase was 5.0% in the fossil fuels supply, 1.7% in the non-fossil fuels supply, 4.3% in the total primary energy supply. The highest increase energy use occurred in fossil fuels supply. The share of fossil fuels in TPES increased from 69.8% in 1971 to 89.4% in 2010. The rapid growth of fossil fuels resulted from the accelerated natural gas supply, which started with 0.67 Mtoe in 1987, reached 6.31 Mtoe in 1995 and increased to 34.91 Mtoe in 2010. The average annual rate of increase from 1987 to 2010 was 7.4% in the natural gas consumption [17].

CO_2 emissions of Turkey from fuel combustion for the period 1971 to 2010 are presented in Fig. 2 [18]. Total CO_2 emission for 1971 and 2010 increased from 41.40 million t to 265.9 million t, respectively. Total CO_2 emission growth rate for the period under study was about 4.8%. The average annual rate of increase was 4.0% for coal, 1.1% for oil and 15.5% for natural gas for the period 1988–2010. The highest increase of CO_2 emission occurred in natural gas.

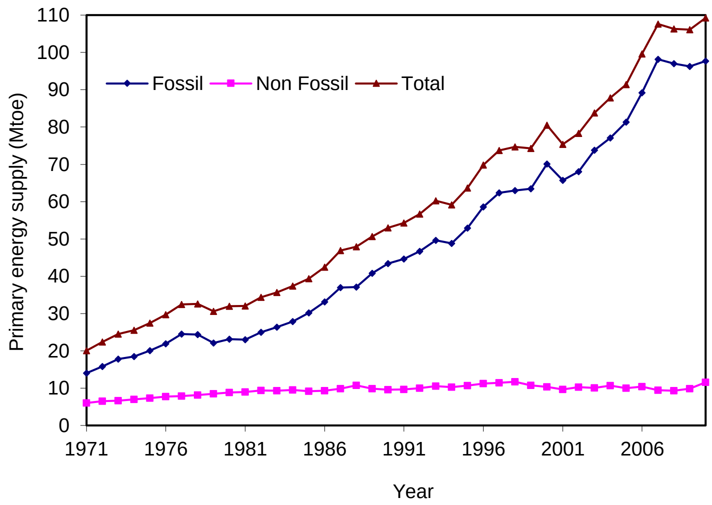

Fig. 1. Total primary energy supply by fuel [17]

As shown in Fig. 2, in 1988 the CO_2 emission was 45.3% for coal, 52.5% for oil, 2.2% for natural gas, while the CO_2 emission in 2010 was 45.0% for coal, 27.4% for oil, 27.6% for natural gas.

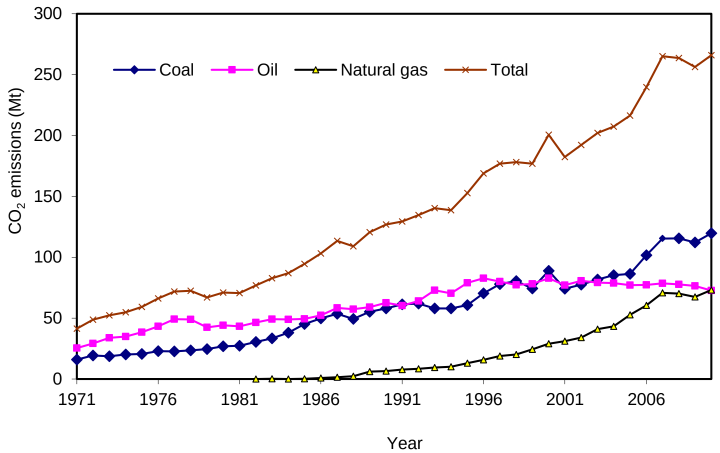

Fig. 2. CO_2 emissions by fuel [18]

In order to obtain an insight into the Turkish economy, in Fig. 3 the development of GDP over the period 1971–2010 [18] has been presented. The GDP in Turkey for 1971 and 2010 increased from 186.0 billion US$ at 2005 prices (billion 2005 US$) using purchasing power parities (PPPs) to 912.8 billion US$ at 2005 PPP. The annual growth rate of GDP was about 4.1%. However Turkish economy was hit by four years of contraction. The economic growths were decreased the years 1979, 1980, 1994, 1999, 2001, 2009.

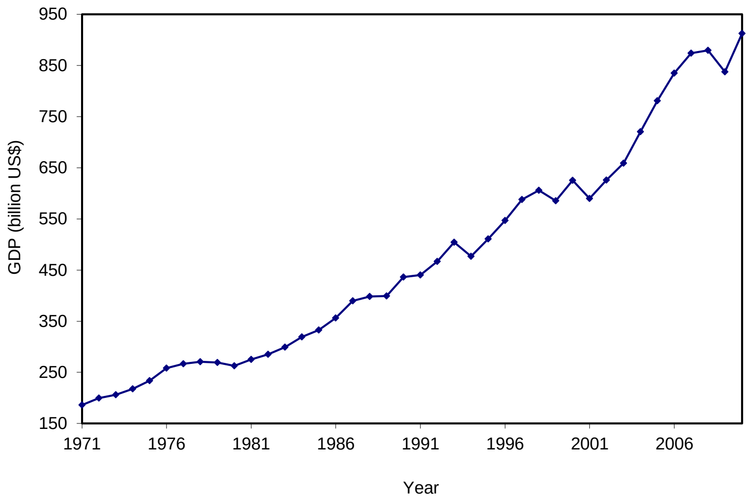

Fig. 3. GDP of Turkey [18]

3. RESULTS AND DISCUSSION

The results of the decomposition analysis of CO_2 emission intensities related to the energy consumption of Turkey for the period 1971–2010 have been presented in Table 1. The central columns report the decomposition in the three explanatory variables FC_{effect}, FS_{effect}, EI_{effect}. The last column shows the cumulated changes that are calculated as the aggregation of the FC_{effect}, FS_{effect}, EI_{effect} variables. The values in the parenthesis denote percentage of the total change, where the cumulated change is the 100% variation and the variations performed by the three different effects are calculated as percentage variation compared to the total variation of the cumulated change. As seen from Table 1, the decomposition indicates that a general conclusion on the formation of CO_2 emission intensities in the Turkey from 1971 to 2010 cannot be obtained.

Table 1 shows that the FS_{effect} and EI_{effect} were the two biggest contributors to CO_2 emission intensities. The fossil fuel carbon effect FC_{effect} accelerated in CO_2 emission intensities from 1971 to 1987 with a few exceptions while this effect was reduced to increase in CO_2 emission intensities from 1988 to 2010.

The increase of FS_{effect} and EI_{effect} accelerated in CO_2 emission intensities in the whole period from 1971 to 2010. Finally, CO_2 emission intensities increased from 0.020735 (Mt/billion 2005 US$) in 1971 to 0.068682 (Mt/billion 2005 US$) in 2010.

Table 1

Decomposition of CO_2 emission intensity [Mt/billion 2005 US$]

Years	FC_{effect}	FS_{effect}	EI_{effect}	$\frac{\Delta CO_2}{GDP}$
1971–1972	0.008830 (42.59)	0.003106 (14.98)	0.008798 (42.43)	0.020735 (100)
1971–1973	–0.001169 (–3.74)	0.009743 (31.19)	0.022667 (72.56)	0.031241 (100)
1971–1974	0.000845 (2.88)	0.009085 (31.01)	0.019370 (66.11)	0.029300 (100)
1971–1975	–0.000362 (–1.17)	0.011214 (36.29)	0.020047 (64.88)	0.030899 (100)
1971–1976	0.005322 (15.60)	0.013498 (39.57)	0.015288 (44.82)	0.034108 (100)
1971–1977	–0.002153 (–4.63)	0.019402 (41.74)	0.029230 (62.89)	0.046478 (100)
1971–1978	0.001769 (3.92)	0.016985 (37.63)	0.026383 (58.45)	0.045137 (100)
1971–1979	0.006050 (22.79)	0.008009 (30.17)	0.012490 (47.05)	0.026549 (100)
1971–1980	0.009095 (19.16)	0.008810 (18.56)	0.029564 (62.28)	0.047469 (100)
1971–1981	0.009181 (26.85)	0.006978 (20.41)	0.018038 (52.75)	0.034196 (100)
1971–1982	0.010169 (21.47)	0.009993 (21.10)	0.027203 (57.43)	0.047365 (100)
1971–1983	0.014926 (27.78)	0.014035 (26.12)	0.024764 (46.09)	0.053725 (100)
1971–1984	0.013495 (26.98)	0.016277 (32.55)	0.020239 (40.47)	0.050011 (100)
1971–1985	0.015053 (24.40)	0.023462 (38.04)	0.023165 (37.56)	0.061680 (100)
1971–1986	0.013178 (19.72)	0.028400 (42.50)	0.025249 (37.78)	0.066827 (100)
1971–1987	0.009834 (14.36)	0.031234 (45.61)	0.027410 (40.03)	0.068479 (100)
1971–1988	–0.001642 (–3.23)	0.025821 (50.75)	0.026704 (52.48)	0.050883 (100)
1971–1989	–0.000135 (–0.17)	0.037250 (46.96)	0.042210 (53.21)	0.079325 (100)
1971–1990	–0.002412 (–3.53)	0.040673 (59.52)	0.030077 (44.01)	0.068337 (100)
1971–1991	–0.004753 (–6.68)	0.041866 (58.84)	0.034037 (47.84)	0.071149 (100)
1971–1992	–0.006176 (–9.39)	0.041996 (63.83)	0.029971 (45.55)	0.065792 (100)

Years	FC_{effect}	FS_{effect}	EI_{effect}	$\frac{\Delta CO_2}{GDP}$
1971–1993	–0.010988 (–19.68)	0.041407 (74.15)	0.025423 (45.53)	0.055841 (100)
1971–1994	–0.009954 (–14.57)	0.042818 (62.67)	0.035462 (51.90)	0.068326 (100)
1971–1995	–0.006233 (–8.18)	0.045268 (59.40)	0.037179 (48.78)	0.076215 (100)
1971–1996	–0.006543 (–7.58)	0.048507 (56.16)	0.044412 (51.42)	0.086376 (100)
1971–1997	–0.010409 (–13.29)	0.049628 (63.39)	0.039073 (49.91)	0.078293 (100)
1971–1998	–0.011189 (–15.72)	0.048308 (67.88)	0.034049 (47.84)	0.071168 (100)
1971–1999	–0.015159 (–19.08)	0.052643 (66.26)	0.041964 (52.82)	0.079448 (100)
1971–2000	–0.008598 (–8.76)	0.059426 (60.55)	0.047319 (48.21)	0.098147 (100)
1971–2001	–0.016435 (–18.96)	0.058467 (67.43)	0.044671 (51.52)	0.086702 (100)
1971–2002	–0.011646 (–13.78)	0.057367 (67.89)	0.038782 (45.89)	0.084503 (100)
1971–2003	–0.019798 (–23.53)	0.060803 (72.27)	0.043125 (51.26)	0.084131 (100)
1971–2004	–0.024043 (–37.01)	0.058224 (89.62)	0.030788 (47.39)	0.064970 (100)
1971–2005	–0.026172 (–48.16)	0.060567 (111.45)	0.019950 (36.71)	0.054345 (100)
1971–2006	–0.024101 (–37.42)	0.063114 (98.00)	0.025392 (39.43)	0.064405 (100)
1971–2007	–0.023628 (–29.32)	0.069785 (86.61)	0.034417 (42.71)	0.080574 (100)
1971–2008	–0.021727 (–28.25)	0.069291 (90.09)	0.029353 (38.16)	0.076917 (100)
1971–2009	–0.027372 (–32.78)	0.068649 (82.22)	0.042216 (50.56)	0.083493 (100)
1971–2010	–0.020887 (–30.41)	0.063122 (91.90)	0.026447 (38.51)	0.068682 (100)

If the same amount of fossil fuel is used but a decrease in CO_2 emissions is desired, the only method is to change the fossil fuel mix and use low emission fuels. Accordingly, the fossil fuel mix in Turkey has changed in order to decrease CO_2 emissions. Coal is the fuel with the highest CO_2 emissions and natural gas is the fuel with the lowest CO_2 emissions from amongst coal, oil and natural gas. The period from 1988 to 2010 is chosen for observation. The share of CO_2 emissions from oil combustion in total CO_2 emissions has decreased in Turkey from 52.5% in 1988 to 27.4% in 2010. The share of

CO_2 emissions from natural gas combustion in the total CO_2 emissions has increased from 2.2% in 1988 to 27.6% in 2010. The share of CO_2 emissions in total CO_2 emissions from coal combustion were approximately in the same level between 1988 and 2010. The share was 45.3% in 1988, 45.0% in 2010 (Fig. 2). The change in the structure of the CO_2 emissions implies that the fuel mix in Turkey has lowered CO_2 emissions and decreased the index of fossil fuel carbon.

The share of the utilization of non-fossil fuels in TPES decreased from 30.167% in 1971 to 10.62% in 2010. In other words, the share of the utilization of fossil fuels in TPES increased considerably for the period 1971–2010 (Fig. 1). This is an important explanation for why the fossil fuel share effect played a positive role in increasing CO_2 emission intensities in Turkey.

There was a debate about which factor is more important for the formation of CO_2 emission intensities. Mielnik and Goldemberg [19] stated that the carbonization index $(CO_2/TPES)$ plays more important role, while Ang [20] pointed to the energy intensity. This study supports Mielnik's and Goldemberg's viewpoint. 61.5% of the increase in CO_2 emission in Turkey from 1971 to 2010 was attributed to the carbonization index and 38.5% – to the energy intensity effect.

The importance of such factors as carbonization index and energy intensity in formation of CO_2 emission intensities strongly depends on the energy policy of the countries. Therefore the debate about which of the factors is more important for the formation of CO_2 emission will be continued in the future.

4. CONCLUSIONS

The case analysis of CO_2 emission intensities in Turkey from 1971 to 2010 shows that fossil fuel share effect and energy intensity effect play important roles in the increase of CO_2 emission. However, the decrease in the share of the utilization of non-fossil fuels in TPES caused the fossil fuel share effect from 1971 to 2010 negative in decreasing CO_2 emission intensities. Finally, the fossil fuel share effect from 1988 to 2010 had a positive impact on the decrease of CO_2 emission.

This study shows that it is an important task for Turkey not only to increase the use of non-fossil fuels but to also to increase the share of the utilization of non-fossil fuels in TPES.

As a result of this study, several policies for Turkey might be suggested to increase the share of the utilization of non-fossil fuels in TPES. Turkey should continue to promote the use of cleaner fuels in all sectors. In this context, the large potential of renewables should be effectively utilized. The promotion of renewable energy investments should be continued.

Existing taxes should be reformed to internalise external (social) costs within energy prices.

The economic and political measures should be taken to reduce CO_2 emissions in fossil fuel use.

The people should be motivated on environmental issues, rational use of energy in order to decrease CO_2 emissions. They should be educated on the greenhouse gas emissions and their effects.

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