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DECOMPOSITION OF ENERGY-RELATED CO_2 EMISSION OVER 1998–2017 IN TURKEY

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Abstract

In recent decades, energy-related CO_2 emissions have been a critical priority of global environmental policy. It is a leading cause of the increase in greenhouse gas triggering global warming in the atmosphere. This study is aimed to identify the factors that contribute to changes in CO_2 emissions in Turkey from 1998-2017. Logarithmic Mean Divisia Index (LMDI) method has been used to decompose changes in CO_2 emissions for four industries (manufacturing industries, transportation, commercial & institutional, and agriculture & forestry). It is used to decompose CO_2 equivalent emissions changes in these sectors into five driving forces: economic activity, activity mix, energy intensity, energy mix, and emission factors. Analyses are conducted for four fuel types; liquid, solid, gaseous, and other fossil fuels. Analytical results indicate that economic activity and sectoral energy intensity are vital decisive factors in determining the change in CO_2 emissions. The activity effect has raised CO_2 emissions, while energy intensity has decreased. This method indicates that the impact of the energy intensity, which is a symbol of improvements in energy efficiency, could be the first key determinant for lowering GHG emissions from all sectors. Additionally, the energy mix and energy structure effect perform the second and third driving factors to reduce CO_2 emissions.

Keywords: energy, GHG emissions, driving forces, decomposition analysis, Turkey

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1. Introduction

Global warming and climate change are worldwide issues that seriously put life on Earth at risk. It threatens humanity's lives, destroys state economies, and transforms ecosystems. One million of the eight million species on the planet are at risk of being lost. Forest and oceans are being polluted and destroyed. Combating climate changes unavoidable damages economic growth in the long run unless measures are taken in the short term. The greenhouse gas emissions would result in higher heating and long-term changes in all climatic characteristics. It would increase the probability of extreme, extensive, and inevitable effects on humans and the environment (IPCC, 2015).

Therefore, people should immediately begin to engage in urgent, active, and cooperative actions based on mutual trust and understanding. Since sustainable development and combating climate change became a vital issue in the 21st century, Turkey's and other developing countries' governments should not only focus on pursuing economic efficiency but also enhance energy conservation and environmental quality. For this purpose, Turkey and other developing countries could adopt a long-term low-emissions strategy that integrates climate and energy objectives, especially Paris agreement goals. Since the EU is Turkey's most important export and import partner, energy efficiency and CO_2 emissions reduction in Turkey's high-energy consuming sectors are critical in deciding a low-carbon transition and carbon border adjustment mechanism under the European Green Deal.

In this study, reducing emissions is essential for many researchers and scientists in countries that intend to combat climate change and transition to low carbon and circular economy. Thus, it is crucial to determine the factors that affect energy-related emissions change and determine their effect on the sectors' emissions reduction. Therefore, this study's primary purpose is to suggest an alternative strategy to analyze the sources of changes in energy-related emissions and assess the sources' relative contributions to reducing emissions.

2. Short overview of the changes in GHG emissions

The changes in GHG emissions of four energy-intensive combustion sectors (manufacturing industries and construction, transport, commercial /institutional/residential and agriculture/ forestry/ fishing) from 1998 to 2017 in Turkey were analyzed by the LMDI method to achieve this purpose. In this context, the measures to be taken by Turkey in these sectors in the implementation of low carbon growth policies and reduction of energy-related emissions for combating climate change, achieving low carbon energy transition are detailed explained.

This study has analyzed these sectors based on the Logarithmic Mean Divisia Index (LMDI) method. The LMDI method developed by Ang (2005) is employed to decompose the changes in these sectors' CO_2 equivalent emissions into five leading forces for reaching GHG emissions reduction goals. It is determined to achieve a low-carbon transition for Turkey. These driving factors are; changes in economic activity (ΔC_{act}), structure effect (ΔC_{str}), sectoral energy intensity (ΔC_{int}), sectoral energy mix (ΔC_{mix}), and emission factors (ΔC_{emf}). Four fuels were used in the analyses; solid, liquid, gaseous, and other fossil fuels. Since CO_2 emissions from biomass are not be included in the total CO_2 emissions from fuel combustion, the biomass fuel type is not considered. GDP could be seen as the main driver of GHG emissions in Turkey because GDP and GHG emissions have increased in the same period. The essential and interesting main findings are; 1) Economic activity (GDP) is the crucial decisive factor behind the change in CO_2 emissions and accounts for most emissions, 2) the energy intensity, which is a symbol of improvements in energy efficiency, could be the first key determinant for lowering GHG emissions from all sectors, 3) the driving factors of energy intensity, energy mix, and energy structure have a decreasing effect. There is a rising trend in the total GHG emissions from 1998 to 2017; however, the economic recession had directly caused a reduction in the total GHG emissions in 1994, 1999, 2001, and 2008.

There is extensive literature on the study of energy consumption decomposition and CO_2 emissions. Many academic studies in this field have generally been about China. Zhang et al. (2020) analyze the decoupling elasticity in China and the ASEAN nations regarding carbon dioxide, national income (GDP), and energy usage during 1990 2014. Zhang et al. (2020) have utilized the LMDI framework relying on a fundamental economic and tech-theoretical approach to disintegrate alterations in the carbon density of the Chinese manufacturing sectors into three growth factors (potential carbon intensity, potential energy output, and industrial energy carbon output), three development-related factors (E.R). Wang et al. (2020) used the aggregate strength of nitrogen oxides (ANI) production to be temporarily and spatially decomposed from an electricity-related NOx processing context. Qian et al. (2020) examined the related decoupling between Chinese industrial SO_2 emissions from 1996–2015 and the industrial economy. Song et al. (2019) and Li et al. (2019) have focused on China's transportation sector. Fang et al. (2019) used the ST-LMDI multi-period model by establishing a single baseline region as a standard for various areas in China to decompose China's electricity consumption variations. Jiang et al. (2020) studied the non-residential energy consumption of China from 2007 to 2016 by using a Kaya identity-based method of the LMDI. As a result, the determining drivers via population growth, economic development, regional trade system, local industry system, and energy usage have decomposed. Jiang et al. (2020) used a multi-regional input-output method to measure the energy consumption embedded in the global trade of 39 nations from 1995 to 2011.

However, there is limited application of those techniques to the Turkish economy, most of them belong to 2013 and earlier, such as: Karakaya and Ozçağ (2003), Lise (2006), Ediger and Huvaz (2006), Tunç et al. (2009) and Akbostancı et al. (2011). For example, Akbostancı et al. (2011) analyzed the greenhouse gases from Turkish manufacturing covering 57 industries of Turkey from 1995 to 2001 by implementing the LMDI technique and identified variations in industrial.

Furthermore, Akbostancı et al. (2018) decomposed and analyzed the CO_2 emissions of five Turkish economy sectors between 1990 and 2013. They both found that energy intensity and economic activity are the decisive key drivers that cause a change in CO_2 emissions. Tunç et al. (2009) and Lise (2006) have utilized the LMDI technique to determine the decisive determinant of Turkey's three main sectors (agriculture, manufacturing, and services) carbon dioxide emissions of Turkey for 1970-2006 and 1980-2003. They both found that the most significant key driver in raising CO_2 emissions is economic development, whereas energy intensity brings down CO_2 emissions. Ediger and Havuz (2006) have used the LMDI method for evaluating sectoral energy usage in the Turkish market from 1980–2000. While there is a strong connection between primary energy usage and Gross Domestic Product, analyses indicate significant differences in sectoral energy consumption. Government policies seem to be the vital driving force for strengthening the Turkish economy's energy-economy relationship.

There are only three recent studies on this subject. Rüstemoğlu (2016) has identified and analyzed the factors increasing or decreasing the CO_2 emissions for Turkey and Iran over 1990-2011. The primary determinant of CO_2 emissions for both countries is economic development and population. On the other hand, Akbostanci et al. (2018) decomposed and studied CO_2 emissions of five Turkish economy sectors between 1990 to 2013, and Karakaya et al. (2019) has only concentrated on CO_2 emission patterns and decompositions, as well as the performance of decoupling CO_2 emissions and economic growth in Turkey from 1990 to 2016.

The LMDI method is generally applied to analyze carbon dioxide emissions and energy consumption changes. In recent years, it has also been used in many new fields: water sources, agricultural production, pollutant discharge, and other areas. Zhang and his colleagues have used the LMDI (approach to decompose the driving forces of production and domestic water use from 2003 to 2017).

In this study, scenario analysis and Monte Carlo simulation have examined the likely evolution trend of production and home water use (Zhang et al., 2021). The contribution of each agricultural water usage, crop planting scale, cropping pattern, irrigation capacity, and watering effectiveness factors to agricultural water use in the Heihe River basin, China, was calculated using the LMDI decomposition approach (Zhang et al., 2018). The decoupling relationship between crop output and fertilizer decrease and the cumulative contribution rate was also investigated. During 2002–2016, LMDI applied decomposing fertilizer throughout the province (Yang and Lin, 2019). Moreover, Zhang has used the Logarithmic Mean Divisia Index (LMDI) approach to attempt to uncover the essential effect factors of PM2.5 concentration in 152 Chinese cities in eastern, middle, and western China (Zhang et al., 2019).

In this study, to achieve emission reduction targets for determining to make a low-carbon transition of Turkey, we conduct a specific investigation on Turkish high-energy intensive combustion four sectors: manufacturing industries and construction sector (MC), transport sector, commercial/institutional/residential sector, and agriculture/forestry/fishing (AFF) sector for period 1998-2017 by employing LMDI-I method. Moreover, this study includes the most recent data from 1998-2017.

While the other studies' period covers an average of ten years, twenty years were examined in this research. Furthermore, the effect on emissions and the structure of these sectors examined in this article have changed significantly in recent years. As a result, there are significant differences in the distribution and increases for these four main sectors' emissions. Therefore, using the current and widely time range data regarding these four sectors is decisive and vital to achieving the Paris agreement's low carbon transition and goal. That is the importance and novelty of this study in these respects.

3. Methodology and data source

3.1. The LMDI method

In this analysis, the LMDI (Logarithmic Mean Divisia Index) method developed by Ang (2005) is used in this study to decompose the driving factors of on Turkish main four combustion sectors' CO_2 emissions from four fuel type combustion.

The structural decomposition analysis (SDA), the Laspeyres decomposition method (LDM), the logarithmic mean division index (LMDI) method, vector autoregression (VAR), and the STIRPAT model, among others, are standard methods for research on the influencing factors of energy utilization and manufacturing emissions. Scholars have decomposed the influencing variables of energy usage and carbon emissions using several approaches, laying a solid foundation for future research. However, no method is perfect. SDA has a competitive improvement in terms of representing the time-series variation of the factors. Based on an input-output model, this method can identify technological effects from ultimate demand impacts (Hoekstra et al., 2003) and concurrently analyze impacts (Wang et al., 2017). However, it necessitates more data, and the decomposition result can only be an additive form, which is inconvenient in practical analysis (Ang and Zhang, 2000). When influential variables exceed three, the LMD approach becomes too hard to use. Its high residual cannot be explained across long periods or multivariable analysis (Albrecht et al., 2002). In the STIRPAT technique, the indicator selection is more discretionary and lacks the requisite theoretical foundation. Because of the changes in indicator selection, considerable variances in the study's outcomes are possible (Shafiei and Salim, 2014). The PDA technique (DEA) combines production theory, direction distance function, and environmental data envelopment analysis are combined in the PDA technique (DEA). Only the multiplied decomposition variant is appropriate to the PDA approach, which requires solving a sophisticated linear programming optimal solution (Zhou and Ang, 2008).

Furthermore, since PDA cannot quantify the consequences of industrial structure and energy composition changes, it may lead to erroneous results (Du and Lin, 2015). On the other hand, the IDA method requires less data (Choi and Ang, 2012) and can be used for both additive and multiplicative decompositions. It can also handle zero values (Ang, 2004a; Ang and Liu, 2007). As a result, the IDA technique may successfully compensate for the SDA method's drawbacks, and it is frequently utilized in energy and environmental economics (Zhang et al., 2009; Zhang et al., 2016). The Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) are two types of IDA methods (Ang and Zhang, 2000).

Although the number of decomposition factors is limited, the LMDI approach is the most extensively utilized since it is easy, practical, and accurate. Moreover, it is a widely preferable technique for its analytical structure, ease of usage and adjustability and interpretation of results, and other attractive features (Ang, 2004a; Lin and Long, 2016). Furthermore, from an application standpoint, the LMDI approach has various advantages. First, LMDI provides perfect decomposition, which means that the results do not contain any unexplained residual terms, making result interpretation easier. Second, the multiplicative LMDI's results have the following additional property: $ln(D_{tot} = ln(D_{x1}) + ln(D_{x2}) + \ldots\ldots + ln(D_{xn})$. Finally, LMDI is reliable in terms of aggregation. Estimates of a sub-group effect can be aggregated to give the comparable effect at the group level, which is valuable in multi-level aggregation studies, such as grouping industry activities into sub-groups, countries into regions, and so on.

The LMDI method of decomposition has become a commonly utilized technique for analyzing ecological subject matter to evaluate the factors affecting many industries' carbon emissions in recent years. Since its incomparable advantages include a high analytical basis and proper application adjustment, it was applied in different countries such as China (Bu et al., 2020; Gu et al., 2015; Li, 2010; Song et al., 2018; Tian et al., 2013; Wang et al., 2005a; Wang et al., 2018; Wang et al., 2020; Xu et al., 2014; Yu et al., 2020; Zhang et al., 2009, 2013, 2016), Greece (Hatzigeorgiou et al., 2008), Tunisian (Achour and Belloumi, 2016), India (Paul and Bhattacharya, 2004), Malaysia (Chong et al., 2019), Nigeria (Emodi and Boo, 2015), Spain (Cansino et al., 2015), Mexico (González and Martínez, 2012), Philippine (Sumabat et al., 2016), Thailand (Chontanawat et al., 2019), Finland (Trotta, 2020) Bangladesh (Hasan and Chongbo, 2020) and Turkey (Akbostanci et al., 2011, 2018; Ipek Tunç et al., 2009; Karakaya et al., 2019; Lise, 2006; Rüstemoğlu, 2016). Researchers usually use five main decomposition factors; industrial activity, industrial structure, energy structure, energy intensity, and emission factor. In addition, some other researchers have added three other factors: productivity, investment intensity research & development, to analyze these factors affecting GHG emissions in many industries, especially the industrial sector (Shao et al., 2016). However, some fundamental aspects, such as technical efficiency and technological progress, cannot be addressed within the IDA framework (Du and Lin, 2015). The structure of the LMDI method is demonstrated as follows (Eq. 1):

$$C = \sum_{ij} C_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{ij} QS_i I_i M_i U_{ij} \qquad (1)$$

where: C is the total CO_2 emissions of Turkish four combustion sectors; i specifies the i-th combustion sector; j represents the jth type of fuel; C_ij is the CO_2 emissions from fuel j in the sector i, $Q(=\sum Q_i)$ is the overall economic activity level, Q_i is the activity level of sector i, $E_i(=\sum E_{ij})$ is the j type of energy usage of sector i, and the unit of this variable is Tj, E_{ij} is the consumption of fuel j in sector i. The unit of CO_2 emissions is 10^3 tons, and the energy consumed is taken as 10^9 kilojoules; $S_i(=Q_i/Q)$ represents the industrial structure; $I_i(=E_i/Q_i)$ represents the energy intensity of sector i; $M_{ij}(=E_{ij}/E_i)$ is the fuel-mix variable, and $U_{ij}(=C_{ij}/E_i)$ represents the CO_2 emissions factor of fuel j consumed in i sector.

The general identity of the decomposition index is given by Eq. (2):

$$V = \sum_i V_i = \sum_i x_{1,i} x_{2,i} \ldots\ldots x_{n,i} \qquad (2)$$

The aggregate changes from $V^0 = \sum_i x^0_{1,i} x^0_{2,i} \ldots\ldots x^0_{n,i}$ in period 0 to:

$V^T = \sum_i x^T_{1,i} x^T_{2,i} \ldots\ldots x^T_{n,i}$ in period T.

In multiplicative decomposition, we decompose the ratio (Eq. 3):

$$D_{tot} = V^T - V^0 = D_{x1} D_{x2} \ldots D_{xn} \qquad (3)$$

In additive decomposition, we decompose the difference (Eq. 4):

$$\Delta V_{tot} = V^T - V^0 = \Delta V_{x1} + \Delta V_{x2} \ldots\ldots + \Delta V_{xn} \qquad (4)$$

where subscription of tot indicates overall or sum change and the superscript T refers to period T and 0 refers to period 0.

The basic equations for the impact of the kth component on the right side of Eqs. (3) and (4) are alternatively used in the LMDI approach (Eqs. 5-6):

$$D_{xk} = \exp\left(\sum \frac{L(V_i^T, V_i^0)}{L(V^T, V^0)} \ln\left(\frac{x^T_{k,i}}{x^0_{k,i}}\right)\right) = \exp\left(\sum \frac{L(V_i^T - V_i^0)/(l\,nV_i^T - l\,nV_i^0)}{L(V_i^T - V_i^0)/(l\,nV^T - l\,nV^0)} \ln\left(\frac{x^T_{k,i}}{x^0_{k,i}}\right)\right) \qquad (5)$$

$$\Delta V_{xk} = \sum_i L(V_i^T, V_i^0)\, ln\left(\frac{x^T_{k,i}}{x^0_{k,i}}\right) = \sum_i \frac{V_i^T - V_i^0}{ln(V_i^T - V_i^0)} ln\left(\frac{x^T_{k,i}}{x^0_{k,i}}\right) \qquad (6)$$

where $L(a,b)=(a-b)/(ln\ a-ln\ b)$, where both a and b positive numbers and $a=b$ as defined in Ang (2004b).

Therefore, the changes in the CO_2 equivalent emissions of four incineration sectors in Turkey between a target year t and a base year 0, displayed by

ΔC_{tot} has been decomposed by the LMDI into the five components as illustrated:

(i) the economic activity effect (shown as ΔC_{act});

(ii) the structure effect (shown as ΔC_{str});

(iii) the sectoral energy intensity effect (shown as ΔC_{int});

(iv) the sectoral energy-mix effect (shown as ΔC_{mix}); and

(v) the emissions factor effect (denoted as ΔC_{emf}) in additive form, as shown in Eq. (7):

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{tot} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \quad (7)$$

The LMDI can be expressed as (Eqs. 8-12):

$$\Delta C_{act} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln(\frac{Q^T}{Q^0}) \quad (8)$$

$$\Delta C_{str} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln(\frac{S_i^T}{S_i^0}) \quad (9)$$

$$\Delta C_{int} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln(\frac{I_i^T}{I_i^0}) \quad (10)$$

$$\Delta C_{mix} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln(\frac{M_{ij}^T}{M_{ij}^0}) \quad (11)$$

$$\Delta C_{emf} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln(\frac{U_{ij}^T}{U_{ij}^0}) \quad (12)$$

3.2. Data source

The LMDI-based method of decomposition is used to determine the key drivers and to evaluate the contribution of these factors to change GHG emissions in Turkey's four-combustion sectors individually from 1998 through 2017 years. During the decomposition analysis application, CO_2 equilibrium emissions data sets were employed in the Turkish Greenhouse Gas Inventory 1990-2017 report and CRF (Common reporting format) tables submitted to the UNFCCC (United Nations Framework Convention On Climate Change) secretariat (TURKSTAT, 2019a). Therefore, the study's data set complies with international standards.

The national income statistics, sectoral energy consumption (*Tj*) values, total greenhouse gas emissions by sectors (CO_2 equivalent, kilotonnes), production shares of industries (%), sectoral energy intensity (tonne of oil equivalent (toe)/1000 $), sectoral energy consumption shares by source types (%) and CO_2 emission factor of four fuel types have been used for input data. The Ministry of Treasury and Finance employs GDP and economic development data. National income statistics are obtained from the Ministry of Treasury and Finance and World Bank indicators and provided in four-sector detail; manufacturing industries and construction (MC), commercial/institutional/residential (CIR), transport, and agriculture/forestry/fishing. Since there is a manufacturing industry and construction sector in CRF tables, we have to apply aggregated data of two industries (manufacturing industry and construction) to ensure consistency between the national income statistics and emission values in CRF tables. CO_2 equivalences emissions for 1998-2017 are estimated using the Intergovernmental Panel on Climate Change (IPCC) manual (IPCC, 2006). According to the manual, CO_2 equivalences can be found by the sum of CO_2 emission, CH_4 multiplied by 25, and N_2O multiplied by 298. Four fuels were analyzed: solid fuels, liquid fuels, gaseous fuels, and other fossil fuels. Since CO_2 emissions from biomass are not included in the overall CO_2 emissions from fuel combustion in IPCC calculations, biomass fuel is not considered.

Energy balance tables of the Ministry of Energy and Natural Resources were used for the Energy-related statistics for 1998-2017. There are only solid fuels, liquid fuels, and gas fuels related to energy consumption values in the balance sheet. Renewable energy resource values are not considered since they are not emission sources. The fuel *j* consumption in sector *i* values (E_{ij}) is collected from the CRF tables in the consumption section as TJ.

Commercial/institutional fuel consumption is not separated in the energy balance tables until 2015; it is given under the residential sector for the 1990-2014 period. Emissions are offered under this category in 2015 for the first time, and they are included under residential for 1990-2014 periods (TURKSTAT, 2019a). Therefore, the aggregated values of the two sectors are used.

4. Overview of necessary information related to the four industries taken in analysis

For most countries, energy systems are powered primarily by fossil fuel combustion. Generally, the energy sector is the most significant in GHG inventories and usually generating more than 90% of the CO_2 emissions and 75% of overall GHG emissions in developed countries. These values are 86.3 percent and 81 percent for Turkey's overall GHG emissions in 2017, respectively. Usually, CO_2 is responsible for 95 % of GHG emissions in the energy sector (TURKSTAT, 2019b). Stationary combustion typically accounts for around 70 percent of the energy sector's emissions. Around halves of those emissions are mainly related to combustion in power plants and refineries in the energy industries. Mobile combustion (road and other traffic) responsible for approximately one-quarter of energy emissions (IPCC, 2006).

3.1. The economic activity of Turkey

The Turkish economy has a 4.8% real yearly gross domestic product (GDP) growth rate from 1998 to 2017. In 2017, GDP increased to over $ 1.206 billion, up from $ 505 billion in 1998. In the last decade, GDP per capita has almost doubled in 2017 to $ 10.616, up from $ 4.442 in 1998. Turkey's greenhouse gas (GHG) emissions have been increased over the past decade due to strong economic and population growth, increasing income levels, and continued dependence on carbon-intensive fuel mix (TURKSTAT, 2019a). Excluding the LULUCF (Land Use, Land-Use Change and Forestry) sector, total GHG emissions were 526.3 Mt CO_2 eq. GHG in 2017. This value represents an increase of 245.6 Mt GHG, with a ratio of 87.8% on total emissions in 1998. Population growth, economic expansion, and increased energy demand are the fundamental causes of the rise in all sectors. (TURKSTAT, 2019a). GDP could be seen as the main driver of GHG emissions in Turkey. Because GDP has increased with a ratio of 138.5%, this ratio is more significant than the rising of GHG emissions in the same period. Even though there is a rising trend in the total emissions from 1998 to 2017, there were exceptional years. Such as, economic recession in 1999, 2001, and 2009 caused a 3.4%, 6.0%, 4.7% decrease in GDP. It had directly caused a reduction in the total GHG emissions in 1999, 2001, and 2008. In these years, total emissions are decreased by 2.5%, 0.9%, 6.2%, and 1.0% compared to the previous year's emissions, respectively.

The fluctuations in the emission trends are mainly due to the economic activities' directions, which can be seen through Gross Domestic Product (GDP) at market prices (constant 2010 USD), as shown in Fig. 1. Although there was no economic recession, total emissions were slightly decreased by 1.8% in 2013. This finding mainly results in a change in the share of solid fuels for electricity generation. Figure 2 indicates the sectoral portion of overall economic activity. The industrial sector had a 25-30% proportion of GDP. At 92 percent of the workforce, the manufacturing industry had the most substantial proportion and 82% share of turnover in the entire industrial sector (Republic of Turkey Ministry of Environment and Urbanization, 2018).

3.2. Sectoral CO_2 emissions in Turkey

The energy sector has the highest share among all industries, with 72.2%. The total amount of the energy sector's emissions in 2017 was predicted to be 379.9 Mt CO_2 equivalent, where industrial processes and product use is the second-largest GHG sector with 12.6%. The agricultural activities with 11.9% and the waste with 3.3% follow it. CO_2 emissions per capita were 4.5 tons in 1998, compared to 6.6 tons in 2017 (TURKSTAT, 2019b). Emissions per capita are still below the OECD (Organisation for Economic Co-operation and Development) average, but it is rising rapidly. As a result, emissions intensity declines, but not as much as the OECD average (OECD, 2019).

Table 1 shows that the combined sectoral GHG emissions of four sectors rose from 125.96 Mt in 1998 to 218.23 Mt in 2017. The increase rate in GHG is 73.3%. The contribution of industries to increase GHG is 5.0 % of the manufacturing sector, 38.5% of the commercial industry, 55.2% of the transport sector, and 1.4 % of the agriculture sector. The primary source of Turkish anthropogenic greenhouse gas emissions is the energy sector. It had the highest share with 72.2% in 2017 GHG emissions (excluding LULUCF). Energy sector emissions were measured at 380 Mt GHG in 2017, which 373.2 Mt CO_2 eq. GHG is related to fuel combustion with a share of 98.2%.
Energy industry subsectors were the main contributor, accounting for 155.0 Mt CO_2 eq. (40.8%) emissions. It is followed by transport sector with 84.7 Mt (22.3%), other sectors with 73.4 Mt (19.3%) (Commercial / institutional / Residential with 60.2 Mt (16.6%) and Agriculture/forestry/fishing with 10.2 Mt (2.7%) and manufacturing industries and construction subsector with 60.2 Mt CO_2 eq. GHG (15.8%) in the same year, as shown in Fig. 3, also holds for Fig. 4 (TURKSTAT, 2019a).

Compared to 1998, the energy sector's total emissions were increased by 93.96%. GHG emissions' sharpest increase occurred in transportation (by 158.2%) and Commercial Institutional, Residential services (119.4%). On the other hand, the emissions from Agriculture, forestry, fishing, and manufacturing industries and construction sectors increased by 14.4% and 8.5%, respectively, as shown in Fig. 5.

3.3. Primary energy use of Turkey

Turkey's total primary energy supply had to occur as 73.3 Mtoe in 1998, and this has been a severe increase in value 145.3 Mtoe in 2017. In total primary energy supply, the proportion of fossil fuels was 88.1%, and the proportion of renewables was 11.9% in 2017. Turkey's final energy consumption had risen from 57.1 Mtoe in 1998 to 111.7 Mtoe in 2017. The total energy consumption of the four main sectors is 104.0 Mtoe. In contrast, sectors total is 111.4 Mtoe with non-energy use part (7.4 Mtoe) (Republic of Turkey Ministry of Energy and Natural Resources (MENR)., Balance Sheet.).

The industrial and building sectors are the leading energy-intensive sectors. Manufacturing, industrial, and construction sectors accounted for 31.6 %; commercial, institutional, and residential sectors were 32.3%; transportation 25.5%; and agriculture, forestry, and fishing 3.8% of Turkey's final energy consumption in 2017. These values were 35.3%, 33.3%, 18.8%, and 4.9% in 1998, respectively, as shown in Fig. 6.

The highest increases in primary energy usage in the transportation sector were 164.2%. In contrast, primary energy uses from the CIR services (by), manufacturing industries and construction and agriculture, forestry, and fishing sectors increased by 89.6 %, 75.1 %, and 49.5%, respectively, during 1998 2017.

5. Results and discussion

In this study, we have applied the LMDI method to decompose the changes in the CO_2 equivalent emissions of Turkish main four fuel combustion sectors into five effects for the period 1998-2017 by using LMDI.

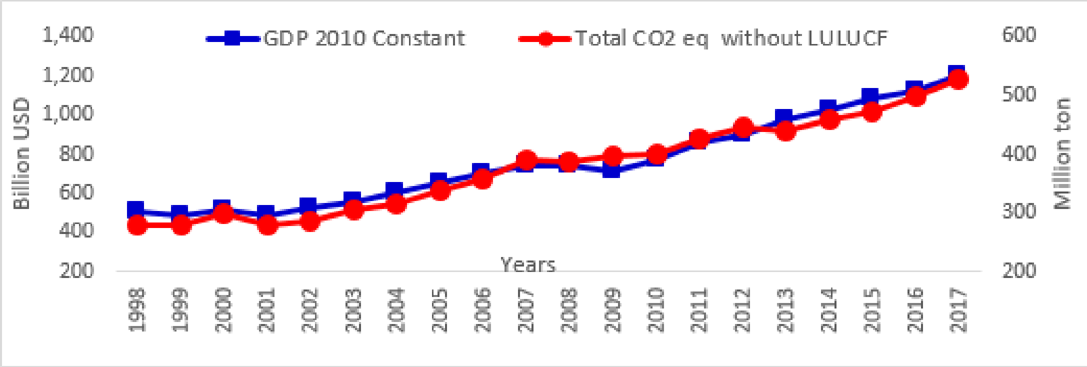

Fig. 1. Total emissions and GDP trend over the period 1998-2017

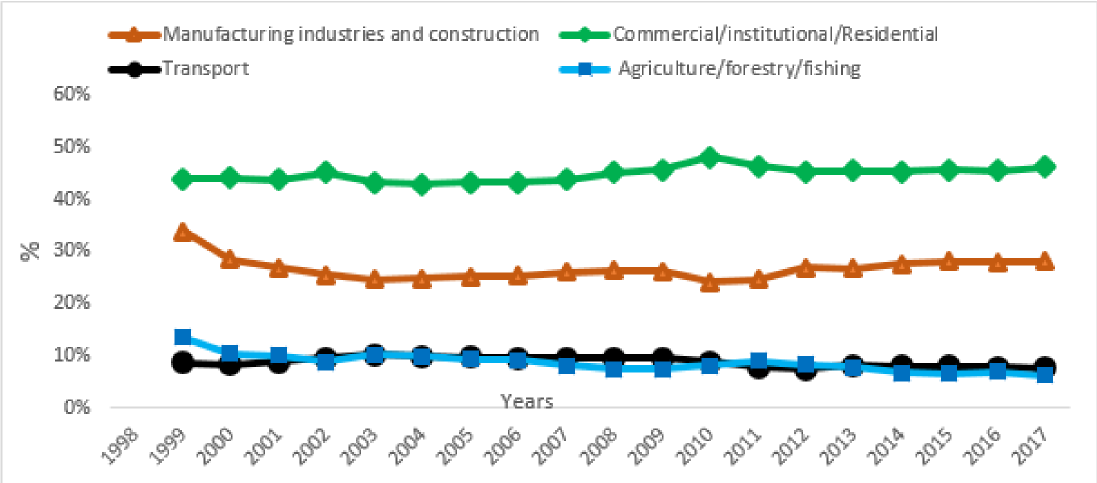

Fig. 2. The proportion of sectors in an economic activity

Table 1. Energy sector GHG emissions, kt CO_2 eq. (1998-2017)

				Fuel combustion			
Year	***Total Energy***	***Fuel combustion total***	***Energy industries***	***Sectors Total***	***Manufacturing industries and construction***	***Transport***	***Other sectors***
1998	195,864	191,119	65,164	125,956	55,470	32,782	37,704
1999	193,817	188,096	70,360	117,735	47,365	34,617	35,753
2000	216,054	209,908	77,743	132,165	57,936	36,465	37,764
2001	199,233	193,530	80,022	113,508	45,656	36,455	31,397
2002	205,832	200,415	74,138	126,276	57,112	36,234	32,930
2003	220,300	215,110	74,371	140,739	66,682	37,825	36,232
2004	226,139	221,005	75,539	145,466	63,857	42,048	39,561
2005	243,965	238,213	90,458	147,754	63,004	42,041	42,709
2006	259,959	253,874	96,129	157,744	70,084	45,424	42,236
2007	290,771	282,821	113,570	169,252	71,874	52,099	45,279
2008	287,279	278,869	118,939	159,930	47,354	48,166	64,410
2009	292,501	284,372	119,280	165,092	46,226	47,907	70,959
2010	287,047	278,821	113,324	165,497	52,332	45,392	67,773
2011	308,666	299,601	124,975	174,627	52,585	47,386	74,656
2012	320,489	311,108	125,944	185,163	61,052	62,525	61,586
2013	307,523	299,000	120,773	178,227	52,978	68,865	56,384
2014	325,767	315,551	131,474	184,076	54,438	73,559	56,079
2015	340,907	335,411	134,702	200,710	59,585	75,798	65,327
2016	359,671	351,075	143,963	207,113	60,071	81,841	65,201
2017	379,901	373,202	154,971	218,230	60,180	84,659	73,391

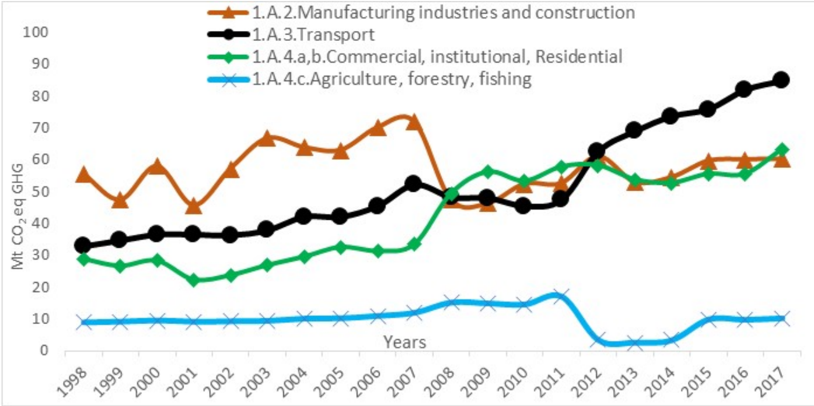

Fig. 1. Energy-related CO_2 equivalent emissions by sector over the period 1998-2017

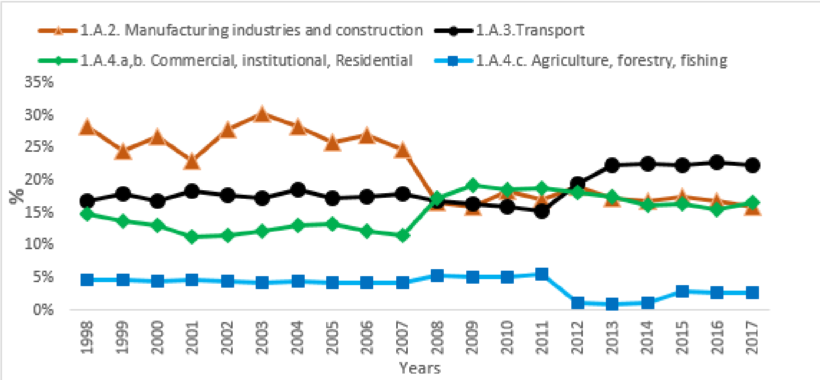

Fig. 2. The shares of energy-related sectors' emissions in Turkey over the period 1998 to 2017

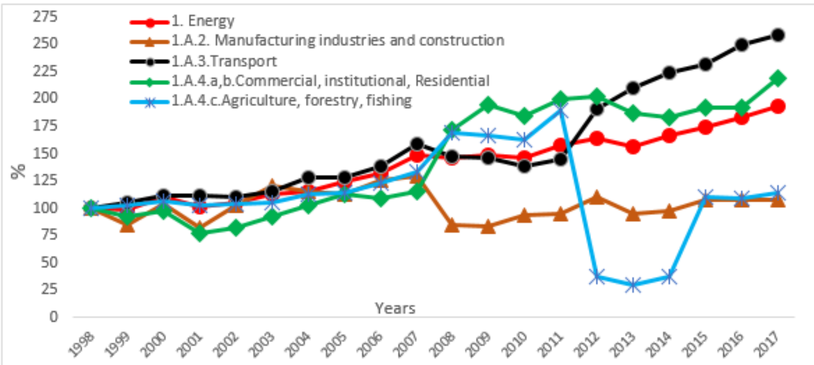

Fig. 3. The rise of shares of energy-related sectors' emissions in Turkey over the period 1998 to 2017

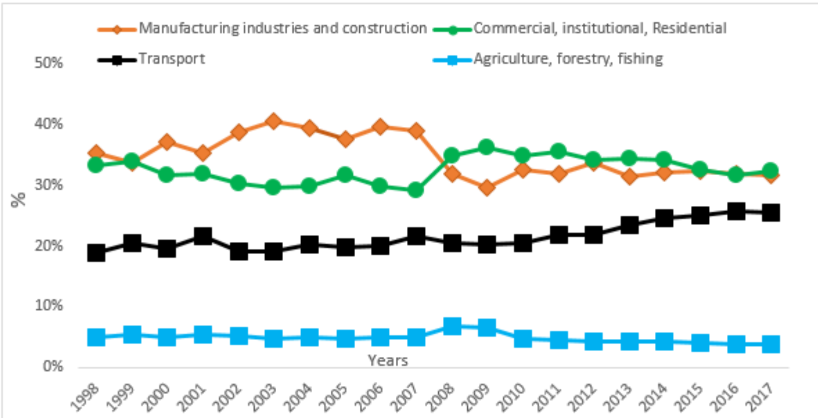

Fig. 4. The shares of energy consumption of sectors in Turkey over the period 1998-2017

The complete decomposition of CO_2 equivalent change emissions is listed in Table 2. The reduction of CO_2 emissions results from significant energy intensity improvements, followed by the energy mix and sectoral energy structure. In general, the energy intensity effect is having a reducing impact on CO_2 emissions from all sectors evaluated in this study.

However, economic activity's impact is the sole highest significant contribution to increasing CO_2 emissions of four primary incineration sectors in Turkey (Fig. 7).

5.1. Economic activity effect

GDP represents the country's economic performance and is a measure of national wealth. GDP is a generator of CO_2 emissions because energy usage and greenhouse gas are related to economic activity. As a result, GDP growth leads to increased greenhouse gas emissions. Therefore, GDP is the main driving force of increased pollution between 1998 and 2017 (GDP rose by 4.8 percent on average); however, the economic recession in 1999, 2001, and 2009 decreased by 3.4%, 6.0%, and 4.7%, contributing to a reduction in emissions.

Energy consumption decreased in all sectors except petrochemical raw materials, non-ferrous metals, and cement during the crisis.

However, due to the financial crisis in 1999 and the severe economic recession in 2001, the output effect was -10.706 in 1999 and -36.187 in 2001 (Table 4). In the 2001 crisis, energy consumption decreased in all sectors except the Fertilizer and Sugar industries. After 2001, with the economic recovery seen in the world and the Turkish economy, the output returned positive values. The output effect, which was at high levels between 2001 and 2007, decreased by 16.7 percent in 2009. The global economic crisis impacted economic contraction in our country, causing a decrease in emissions to –29,362 kt.

The consequences of economic activity affect (ΔCact) is the continual increase in emissions of CO_2 over the period 1998–2017 (except for the years of economic recession (1999, 2001, 2009) and GDP declining compared to the previous years (2014, 2015 and 2017). The cumulative effect is a rise of 169.26 Mt, reflecting the absolute value of 179.99 % of the total change in (ΔCtot). Table 4 reveals that the economic activity effect on the overall growth of CO_2 was found primarily in the manufacturing industries and construction sector and accounted for +73.8 Mt of GHG emissions. Similarly, the economic activity effect also accounts for 48.1 Mt GHG CO_2 equivalent emissions rising in the CIR sector, 35.4 Mt CO_2 equivalent emissions rising in the transport sector, and 12.1 Mt CO_2 equivalent emissions in the AFF sector period 1998–2017.

Table 2. Complete decomposition of CO_2 emissions changes, kt CO_2 eq. (1998–2017)

Years	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}	ΔC_{emf}	ΔC_{tot}
	Activity effect	***Structure effect***	***Intensity effect***	***Energy-mix effect***	***Emission factor effect***	***Total effect***
1999-1998	-10,706	-3,154	11,651	-4,633	-1,303	**-8,145**
2000-1999	8,440	-1,186	6,897	1,451	-1,079	**14,524**
2001-2000	-36,187	-109	25,841	-10,110	1,999	**-18,566**
2002-2001	19,016	766	-12,974	7,094	-1,048	**12,854**
2003-2002	37,154	-778	-23,771	1,300	638	**14,543**
2004-2003	35,260	-728	-26,147	-236	-3,343	**4,806**
2005-2004	31,152	-440	-29,004	-600	1,256	**2,364**
2006-2005	13,787	1,080	-2,921	212	-2,095	**10,062**
2007-2006	34,277	921	-22,745	-1,330	452	**11,575**
2008-2007	21,913	380	-29,741	-3,635	1,842	**-9,241**
2009-2008	-29,362	-4,194	32,320	5,834	606	**5,203**
2010-2009	28,986	-4,567	-23,216	-574	-151	**478**
2011-2010	12,445	-785	976	-2,612	-526	**9,499**
2012-2011	8,169	4,708	-4,326	1,428	595	**10,575**
2013-2012	15,673	-741	-15,065	-6,952	196	**-6,889**
2014-2013	-2,959	1,649	7,392	518	-688	**5,912**
2015-2014	-15,497	-1,323	36,179	-360	-2,231	**16,768**
2016-2015	204	-2,662	11,965	-534	-2,486	**6,486**
2017-2016	-2,500	3,107	13,021	-4,884	2,491	**11,235**
Total	**169,264**	**-8,057**	**-43,668**	**-18,621**	**-4,877**	**94,041**

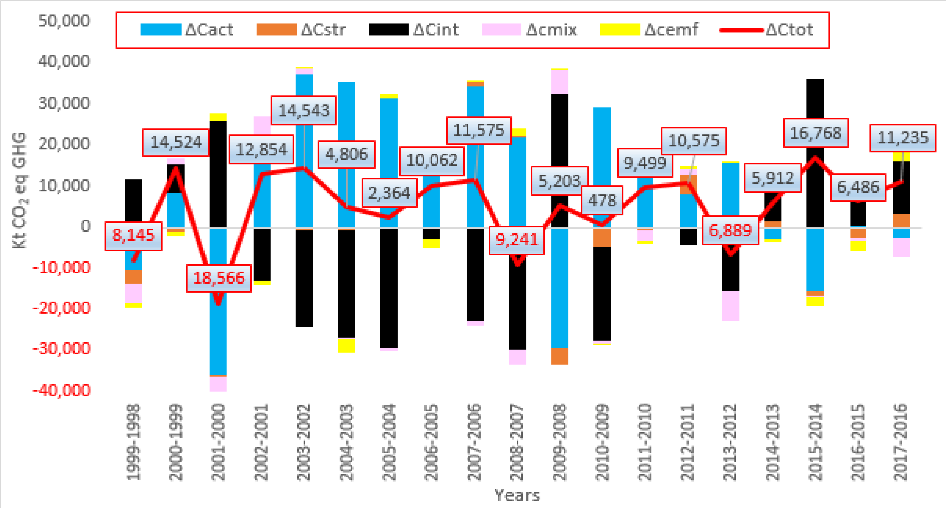

Fig. 5. The effects of driving forces on change in GHG emissions over the period 1998-2017

The weak GDP effect in the agricultural industry is related to the low share of agriculture in national income, and it is not an energy-intensive sector. While energy consumption decreased in Sugar, Cement, Fertilizer, and other industrial sectors this year, energy consumption increased in the Chemical-Petrochemical, petrochemical, raw material, and iron-steel sectors.

As for the sub-sectors of the industry, the output effect is more robust in the iron-steel, cement, and chemical-petrochemical sub-sectors, while it is weaker in the petrochemical raw materials, fertilizer, sugar, and non-ferrous metals sectors. The negative change in GDP from the previous year results in a reduction in emissions in all sectors simultaneously but at different rates (Tables 3 and 4). The difference in this ratio is that the sectors' greenhouse gas emissions are different from each other.

In this context, while GDP declined in 1999, 2001, 2009, 2014, 2015, and 2017, all industries' emissions dropped (Table 3). However, since GDP has increased relative to the prior year, emissions have climbed in the remaining years.

5.2. Sectoral structure effect

The structural effect is the factor that indicates the change in the value of each sector value within the total economic activity (GDP). It is observed that the share of emissions in the manufacturing sector decreased from 19.8 percent to 11.4 percent, and the agriculture sector decreased from 3.2 percent to 1.9 percent during the analysis phase from Fig. 8, respectively.

Table 3. Gross domestic product-by kind of economic activity (Million $) (1998–2017)

Years	*Manufacturing industries and construction*	*Commercial institutional residential (CIR)*	*Transport*	*Agriculture forestry fishing (AFF)*	*GDP*	*Change (%)*
1998	86.371	112.265	22.331	34.571	277.468	-
1999	72.091	111.780	20.969	26.575	253.622	-8.6%
2000	73.113	118.899	23.928	27.398	271.768	7.2%
2001	51.449	90.841	19.170	17.796	200.998	-26.0%
2002	58.166	102.136	24.041	24.269	236.338	17.6%
2003	77.921	134.806	31.204	31.008	313.776	32.8%
2004	101.262	173.999	38.912	37.965	402.952	28.4%
2005	126.478	216.368	47.406	46.262	499.874	24.1%
2006	143.032	239.384	52.002	44.713	547.832	9.6%
2007	179.228	305.992	64.187	50.933	677.438	23.7%
2008	203.764	355.311	74.232	58.125	776.643	14.6%
2009	155.616	311.845	56.847	52.592	646.893	-16.7%
2010	190.015	358.662	60.689	69.714	772.365	19.4%
2011	224.024	377.728	61.383	68.492	831.696	7.7%
2012	233.236	397.207	70.887	67.536	871.125	4.7%
2013	263.212	430.209	75.184	63.914	950.355	9.1%
2014	263.584	427.427	74.200	61.605	934.857	-1.6%
2015	240.501	391.676	67.779	59.500	861.879	-7.8%
2016	243.150	398.597	65.242	53.350	862.746	0.1%
2017	249.004	388.793	65.962	51.857	852.618	-1.2%

Table 4. The effect of economic activity on different sectors, kt CO_2 eq. (1998–2017)

Years	*Manufacturing industries and construction*	*Commercial institutional residential (CIR)*	*Transport*	*Agriculture forestry fishing (AFF)*	*Total*
1999-1998	-4,604	-2,264	-3,028	-810	-10,706
2000-1999	3,612	1,729	2,455	644	8,440
2001-2000	-15,498	-6,882	-10,998	-2,808	-36,187
2002-2001	8,284	3,359	5,887	1,486	19,016
2003-2002	17,487	6,534	10,493	2,641	37,154
2004-2003	16,322	6,523	9,980	2,435	35,260
2005-2004	13,663	6,243	9,061	2,184	31,152
2006-2005	6,079	2,737	4,004	967	13,787
2007-2006	15,044	6,471	10,338	2,424	34,277
2008-2007	7,971	5,258	6,847	1,836	21,913
2009-2008	-8,547	-9,304	-8,780	-2,731	-29,362
2010-2009	8,718	9,404	8,268	2,596	28,986
2011-2010	3,878	3,975	3,433	1,159	12,445
2012-2011	2,626	2,625	2,529	388	8,169
2013-2012	4,951	4,750	5,714	258	15,673
2014-2013	-883	-857	-1,170	-49	-2,959
2015-2014	-4,627	-4,312	-6,069	-489	-15,497
2016-2015	60	55	79	10	204
2017-2016	-710	-690	-983	-117	-2,500
Total	**73,826**	**35,353**	**48,061**	**12,025**	**169,264**

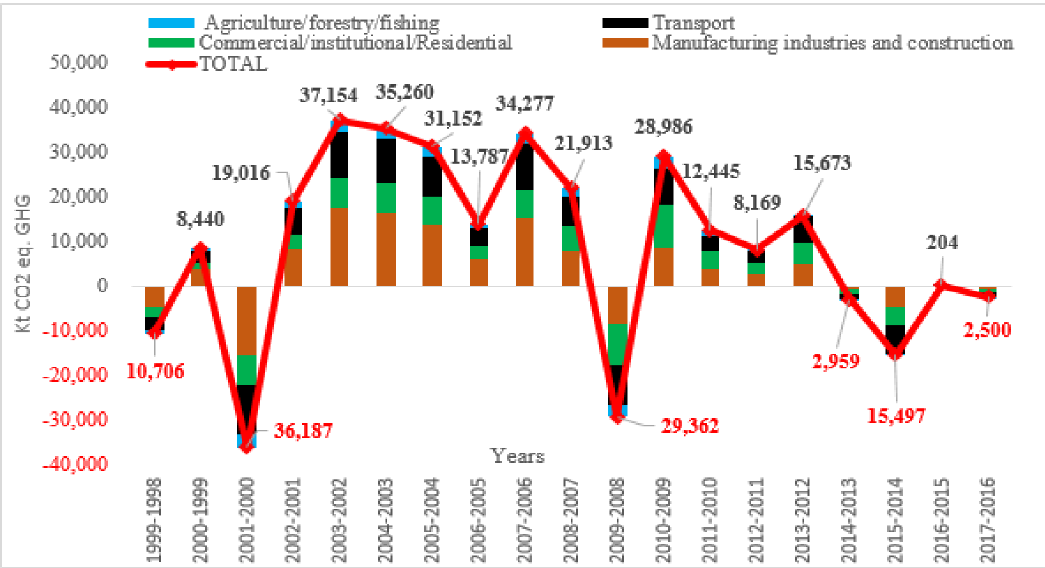

Fig. 6. The effect of economic activity on the change in GHG emissions

In contrast, the transport and commercial sectors increased from 11.7 % to 16.1 % and from 10.3% to 12.0%, respectively.

Table 5 illustrates the production shares of economic activity of sectors. Table 6 demonstrates the effect of sectoral structure (ΔCstr), which reduces the emissions of 8.06 Mt CO_2 eq., constituting 8.57% of the absolute value of total change (ΔCtot). The positive or negative values of the structural effect are related to the share of that sector in the total economic production. If the percentage of that sector in total economic production decreases, its structural impact will be a negative value, and if it increases, it will be positive. Since the share of the CIR sector (from %40.5 to % 45.6) in total production has increased over the years, it causes an increase in emissions. On the contrary, since the share of the MIC sector decreased from 31.1 to 29.3%, the share of the transport sector from 8% to 7.7%, and the share of the AFF sector from 12.3% to 6.1%, they had a reducing effect on emissions (Tables 5 and 6). Fig. 9 shows that the sectoral structure has a lower impact on the overall change of CO_2 emissions in three sectors; AFF, transport, and MC, while the positive impact only the CIR sector.

This effect accounts for the reduction of -5.7 Mt CO_2 eq. GHG emissions in AFF, -4.3 Mt CO_2 eq. GHG emissions in the transport sector, and -1.3 Mt CO_2 eq. GHG emissions in the MC sector. In contrast, it accounts for a rising of 3.8 Mt GHG emissions in the CIR sector over 1998–2017. Therefore, the negative value of the structural effect indicates that it has a reducing impact on the total energy consumption in that year. The number of years with positive values in the CIR sector (1999, 2001, 2004-2009, 2012, 2014, and 2016) is more than those with negative values (2000, 2002, 2003, 2010, 2011, 2013, and 2017). Since the absolute values are large, the structural effect for CIR sectors increases the total emissions (3,282 kt) in the relevant period. The other three main sectors, on the other hand, have negative values in absolute value since the structural effect is having a reducing impact on total emissions in the relevant period.

5.3. Sectoral energy intensity effect

Energy's intensity is measured by the amount of energy per unit output or operation needed. The use of lower Energy to generate a material decreases the intensity. The intensity effect decreases if economic output increases higher than the increase in energy input.

Table 5. The production shares of sectors (%) (1998–2017)

Years	*Manufacturing industries and construction (MIC) (%)*	*Commercial institutional residential (CIR) (%)*	*Transport (%)*	*Agriculture forestry fishing (AFF) (%)*
1998	31.1	40.5	8.0	12.5
1999	28.4	44.1	8.3	10.5
2000	26.9	43.8	8.8	10.1
2001	25.6	45.2	9.5	8.9
2002	24.6	43.2	10.2	10.3
2003	24.8	43.0	9.9	9.9
2004	25.1	43.2	9.7	9.4
2005	25.3	43.3	9.5	9.3
2006	26.1	43.7	9.5	8.2
2007	26.5	45.2	9.5	7.5
2008	26.2	45.7	9.6	7.5
2009	24.1	48.2	8.8	8.1
2010	24.6	46.4	7.9	9.0
2011	26.9	45.4	7.4	8.2
2012	26.8	45.6	8.1	7.8
2013	27.7	45.3	7.9	6.7
2014	28.2	45.7	7.9	6.6
2015	27.9	45.4	7.9	6.9
2016	28.2	46.2	7.6	6.2
2017	29.2	45.6	7.7	6.1

Table 6. The effect of sectoral structure, kt CO_2 eq. (1998–2017)

Years	*Manufacturing industries and construction (MIC)*	*Commercial institutional residential (CIR)*	*Transport*	*Agriculture forestry fishing (AFF)*	*Total*
1999-1998	-4,655	2,155	907	-1,561	-3,154
2000-1999	-2,877	-184	2,235	-360	-1,186
2001-2000	-2,556	741	2,915	-1,209	-109
2002-2001	-2,008	-929	2,343	1,360	766
2003-2002	554	-136	-839	-358	-778
2004-2003	775	132	-1,172	-465	-728
2005-2004	432	69	-761	-181	-440
2006-2005	2,083	283	40	-1,326	1,080
2007-2006	938	1,010	-89	-937	921
2008-2007	-487	491	438	-61	380
2009-2008	-4,057	2,663	-4,036	1,236	-4,194
2010-2009	1,103	-1,984	-5,218	1,531	-4,567
2011-2010	4,750	-1,193	-2,905	-1,436	-785
2012-2011	-341	225	5,331	-506	4,708
2013-2012	1,926	-395	-1,850	-421	-741
2014-2013	958	519	233	-61	1,649
2015-2014	-590	-322	-690	280	-1,323
2016-2015	595	901	-3,084	-1,074	-2,662
2017-2016	2,140	-766	1,897	-165	3,107
Total	**-1,318**	**3,282**	**-4,307**	**-5,714**	**-8,057**

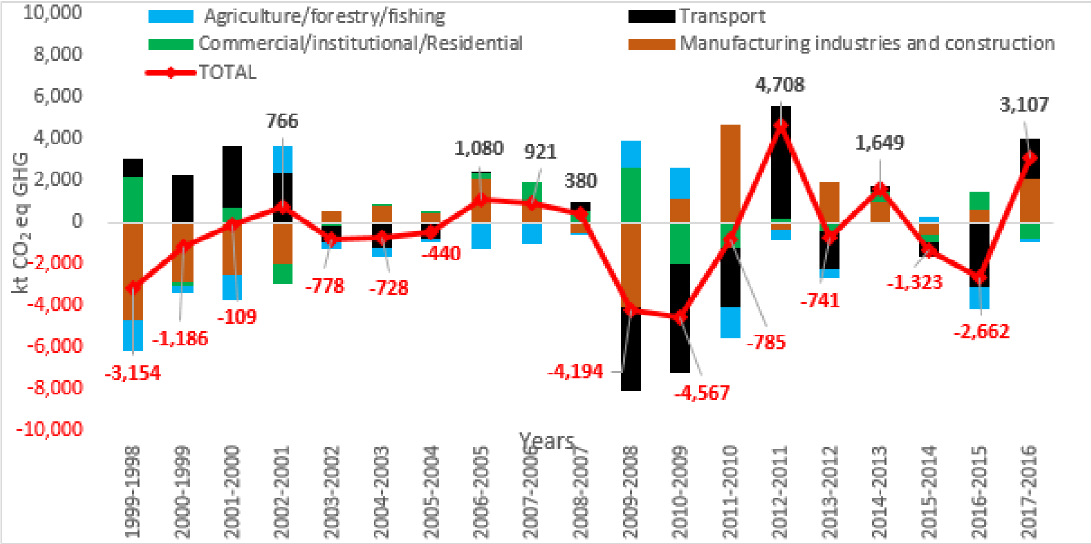

Fig. 7. The effect of sectoral structure on change in GHG emissions

Table 7. Sectoral energy intensity, 1998-2017 (toe/1000$)

Years	***Manufacturing industries and construction (MIC)***	***Commercial institutional residential (CIR)***	***Transport***	***Agriculture forestry fishing (AFF)***
1998	0.23	0.17	0.48	0.08
1999	0.26	0.17	0.54	0.11
2000	0.31	0.16	0.50	0.11
2001	0.38	0.19	0.63	0.17
2002	0.40	0.18	0.47	0.12
2003	0.34	0.14	0.40	0.10
2004	0.27	0.12	0.35	0.09
2005	0.21	0.10	0.29	0.07
2006	0.21	0.09	0.29	0.08
2007	0.17	0.08	0.27	0.08
2008	0.12	0.08	0.22	0.09
2009	0.15	0.09	0.28	0.10
2010	0.14	0.08	0.27	0.05
2011	0.12	0.08	0.30	0.06
2012	0.13	0.08	0.27	0.06
2013	0.11	0.07	0.28	0.06
2014	0.11	0.07	0.30	0.06
2015	0.13	0.08	0.37	0.07
2016	0.14	0.08	0.41	0.08
2017	0.14	0.09	0.43	0.08

Application of more efficient, effective production techniques, efficient energy management, changes in product mix within or between sub-sectors, and improvements in material and fuel input quality reduce the intensity effect. This result means that more output is produced with less energy, or more production acquired with the same amount of energy used (Du et al., 2018).

Many recent academic studies have demonstrated that energy intensity reduction is limited or even reduced the increasing energy-related GHG emissions (Akbostanci et al., 2011, 2018; Feng et al., 2018; Lin and Tan, 2017; Wang et al., 2005b; Wang and Feng, 2018; Zhang et al., 2013; Zhang et al., 2016).

Energy intensities for four combustion sectors are presented in Table 7 and Fig. 10. It is clear that while the transportation sector has the ultimate energy density, the AFF sector has a minimum from 1998-2017. Moreover, it is noticed that the energy intensity in agriculture fluctuated very much during that period. Finally, in 2017, they reached the level of 1998. Fig. 10 illustrates that the commercial sector's energy intensity has shown a decreasing trend over the period, especially between 1998 and 2014. The transport sector's energy intensity tends to decrease from 2000 to 2008, the year of the global economic crisis. Especially after the global economic crisis in 2008, the energy intensity trend in the transport sector has been reversed and started to increase so far.

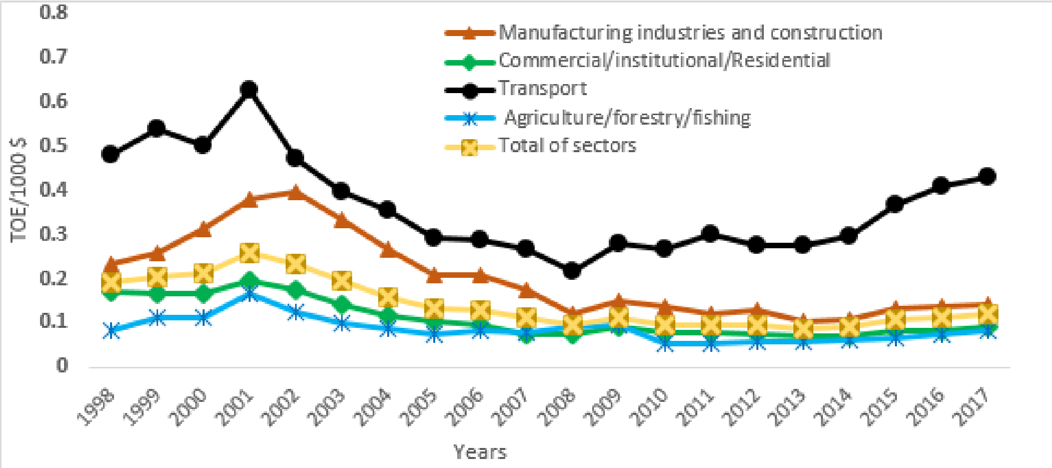

Fig. 8. Sectoral energy intensity during 1998-2017 period

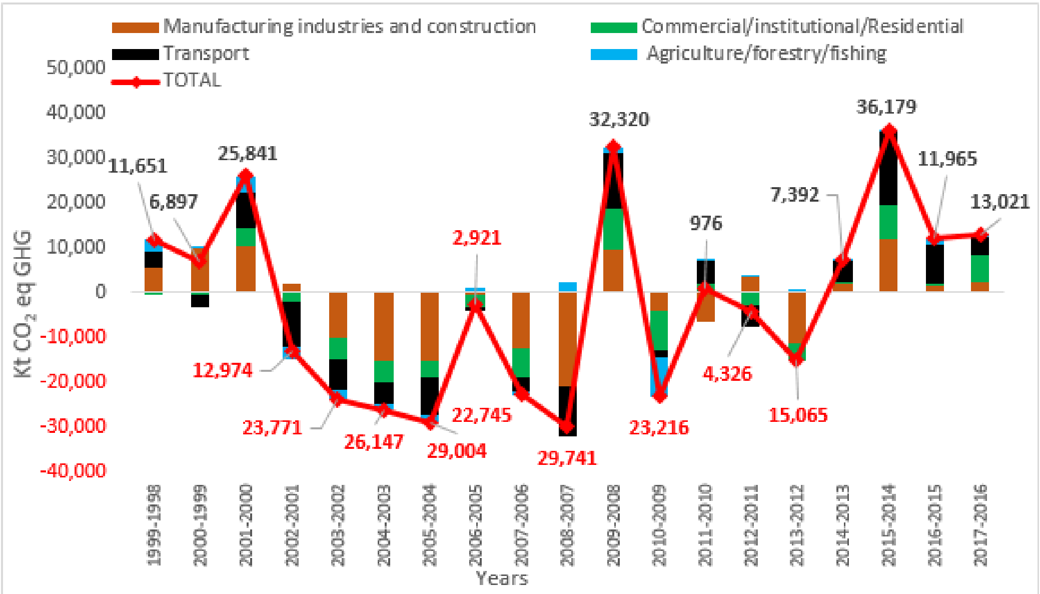

Fig. 9. The effect of sectoral energy intensity on change in GHG emissions

Our findings also indicate that the intensity effect (ΔCint) has decreased CO_2 emissions for almost years except 1999–2001 and 2014-2017. The accumulated impact of intensity effect reduces the emissions of 43.67 Mt CO_2 eq., constituting 46.43% of the total change (ΔCtot). In other words, the intensity effect plays a significant and active role in reducing CO_2 emissions. It has been particularly effective in sectors of manufacturing industries and construction (-39.30 Mt CO_2 eq) and Commercial & institutional & Residential industries (-11.48 Mt CO_2 eq). The impact of the sectoral energy intensity on changes in CO_2 equivalent emissions from 1998 to 2017 is presented in Fig. 11. It shows that even there is a slight increase in 1998-1999, it had a continuously decreasing trend in 2001-2013. The declining tendency may be due to new techniques, innovations, and new tools, followed by widespread energy-saving technologies and progress at the administration level. Unfortunately, the intensity effect has an increasing tendency from 2015 and so far.

5.4. Energy mix effect

This effect shows how industries are using available fuels and are calculated by dividing the energy consumption of a fuel type by the total energy consumption of that sector. Fig. 12 demonstrates that the impact of energy mix (ΔCmix) reduces the emission of 18.6 Mt CO_2 eq., constituting 19.80 % percent of the total change (ΔCtot). Fig. 12 also shows that the sectoral energy mix impact has a lower impact on the complete change of CO_2 emissions in three sectors, MC, transport, and AFF, while positively influencing only the CIR sector. This effect accounts for the reduction of -27.1 Mt CO_2 eq. GHG emissions in MC, -1.3 GHG emissions in transport -2.1. GHG emissions in the AFF sector account for the rising of

+11.8 Mt CO_2 eq. GHG emissions in the CIR sector over the period 1998–2017. Solid fuels were accounted for a reduction of -24.6 Mt CO_2 eq. GHG emissions and fluid fuels were accounted for a decrease of -13.9 Mt CO_2 eq. GHG emissions in the manufacturing sector. In contrast, gas and other fuels have a rising energy-mix effect on the same industry.

5.5. Emission factor effect

The emission factor effect shows the effect of the efficiency of fuels used in the sector on emissions, and Fig. 13 demonstrates that the emission factor effect (ΔCemf) reduces the CO_2 eq. emissions only in 10 years in this study. However, the emission factor's impact eases 4.9 Mt CO_2 eq., constituting 5.19% of the absolute value of the total change (ΔCtot). This effect has a minor effect on decreasing CO_2 eq. emissions in the transportation sector. The emission factor effect (ΔCemf) reduces CO_2 emissions, especially in two industries; CIR and MC. This effect accounts for the reduction of -2.8 Mt CO_2 eq. GHG emissions in CIR and -1.4 GHG emissions in the MC sector over 1998–2017.

6. Conclusions and policy recommendations

In this study, reducing emissions is essential for many researchers and scientists in countries that intend to combat climate change and transition to low carbon or green and circular economy. Thus, it is crucial to determine the key drivers that affect emissions change and determine these drivers' effect on the sectors' emissions reduction. For this purpose, a comprehensive and detailed analysis of Turkey's GHG emissions for four fuel combustion sectors covering 57% of the energy sector emissions from 1998-2017 was examined.

Their contribution to the emission increase was revealed based on the LMDI method. This method makes it possible to differentiate greenhouse gas emissions on a sectoral basis related to the main effects, such as the activity, structural, intensity, energy-mix, and emission-factor effects

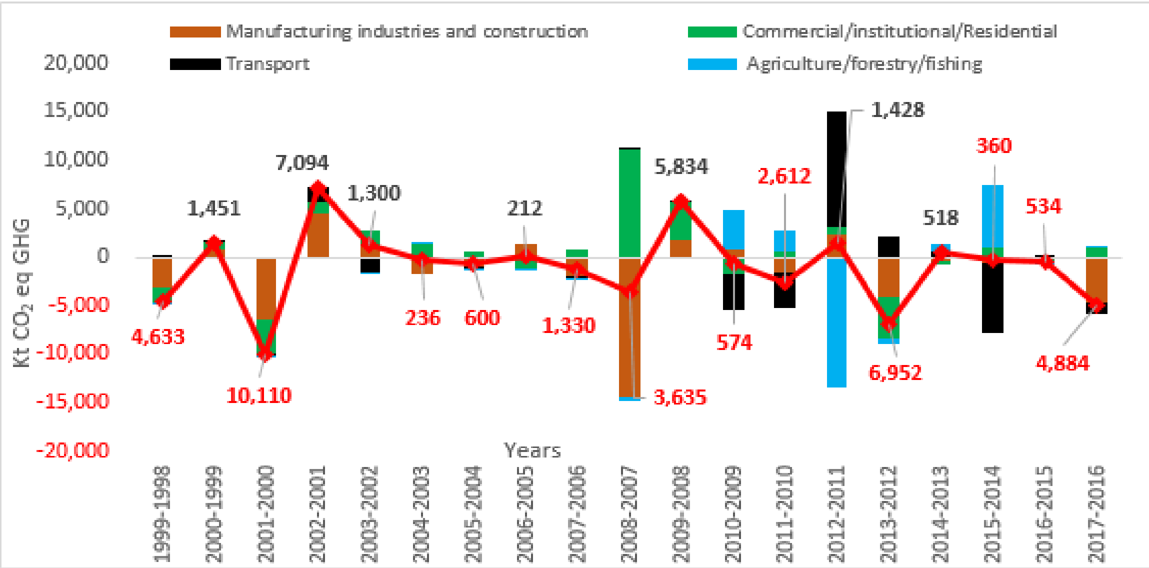

Fig. 10. The effect of energy mixes on change in GHG emissions

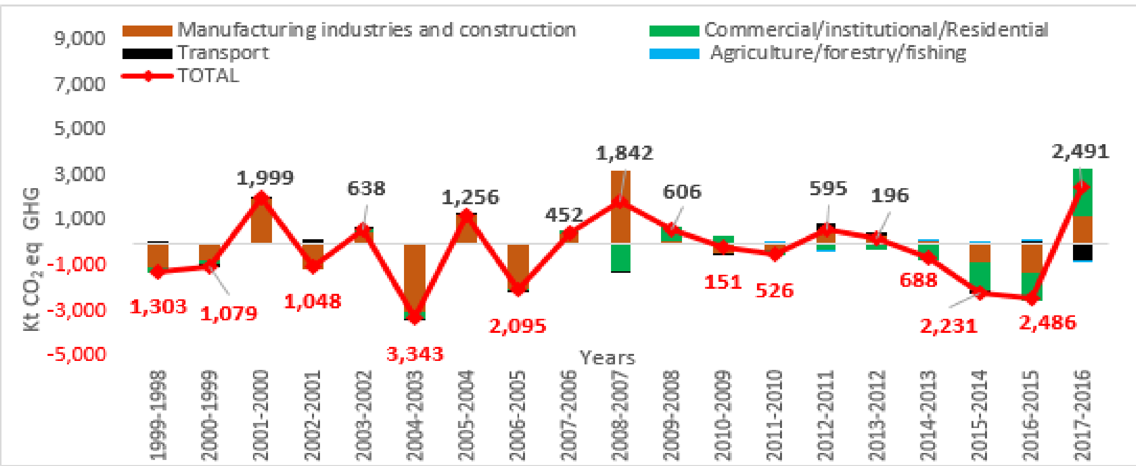

Fig. 11. The effect of emission factor on change in GHG emissions

Accordingly, in the 1998-2017 period, significant improvements in energy density led to a reduction in CO_2 emissions (43.6 Mt). It is followed by the energy mix (18.6 Mt) and sectoral energy structure (8.1 Mt). This study, therefore, calls for policies aimed at reducing the energy intensity of companies in the manufacturing industries and construction sector, Commercial/institutional/Residential industries so that Turkey can make use of industrial development without having to cause more GHG emissions. The key findings of this study could be summarized as follows:

(1) There is a definite increasing trend between GDP and GHG emissions with different ratios, 138.5%, and 87.5%, respectively. However, after 2009, Turkey's economic growth's proportional increase was higher than the proportional increase in greenhouse gas emissions and began to experience a divergence between these two variables. That is why the energy demand in Turkey has increased more than GDP growth.

(2) Turkey demands a high amount of energy since it is a developing country, has economic growth, and carries out intensive fossil fuel consumption. The empirical results indicated a general increasing tendency in the operating period of CO_2 emissions from all four fuel combustion sectors. Analysis results suggest that economic activity is the primary decisive factor causing rising in GHG emissions and sectoral energy intensity. Namely, the growing economic activity and reducing energy intensity are significant contributors to increasing and decreasing CO_2 emissions of Turkey's four fuel combustion industries. The emission-reducing effect of the energy density factor could be seen in a considerable reduction in manufacturing and commercial sectors' greenhouse gas emissions in 1998-2017 as 39.3 Mt and 11.5 Mt. CO_2 eq. GHG emissions. Energy structure and emission factor effects would have few impacts on CO_2 emission change because of the lack of adequate energy structure changes during the study period.

(3) The density effect, another analysis made in the study, is related to the energy consumption per output. As the development level of the countries increases, it is expected that the density values will decrease due to the increasing technology level and energy efficiency. The Turkish manufacturing and commercial industries' energy intensity decreased by 39.3 Mt and 11.5 Mt CO_2 eq. GHG, respectively. Unfortunately, there is no progress in the transport sector's energy intensity, and it causes 10 Mt CO_2 equivalent emissions to increase. From 2002 through 2008, there was an excellent declining energy intensity for four energy-intensive industries. After the global economic crisis in 2008, the tendency of energy intensity of manufacturing, commercial, and agricultural sectors has stayed on the same level.

(4) In contrast, the transport sector's energy intensity has reversed and increased tremendously. Even though energy intensities of only manufacturing and commercial sectors have displayed continual reduction during the 1998-2014 period, the rate of decrease has decelerated and, after 2017, slightly increased. During this time, GHG emissions reduction related to the energy intensity falling has shown that energy intensity could be reduced by improving energy use. Therefore, policymakers should investigate and try to find and solve the reasons behind these most critical problems. Moreover, Turkey could set more ambitious measurable energy efficiency objectives in the transport, agricultural, and other energy-intensive sectors (Republic of Turkey Ministry of Energy and Natural Resources (MoENR), 2018).

(5) The energy mix effect performed the second leading position in reducing CO_2 emissions and accounted for the reduction of -18.6 Mt GHG emissions. Most of this reduction is set in the manufacturing industry (reducing -27.1 Mt g emissions). Except for the CIR sector, it reduced emissions in three other industries.

(6) The structural effect has the third impact effect in CO_2 emissions and accounted for the reduction of -8.06 Mt GHG emissions. Except for the CIR sector, it had an emission reduction effect on three other industries as the energy mix effect.

Furthermore, we could also propose that Turkey and other developing countries continue their attempts to raise the share of renewable energy sources and add nuclear energy to their energy mix to reduce their reliance on energy imports. The accelerated legal regulations and increasing investment in renewable energy in Turkey's near term have an essential role in forming this situation. If renewable energy production policies are implemented in the following years, it would significantly reduce greenhouse gas emissions. They also would optimize natural resources and combat climate change under the enrichment of the national energy mix topic. Moreover, it is explained what this model does and measures to be taken on a sector basis. According to the finding obtained in this study, the above-mentioned proposed policies would positively reduce Turkey's emissions.

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