Is Production or Consumption the Determiner? Sources of Turkey's CO2 Emissions between 1990-2015 and Policy Implications

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Abstract

Turkey's CO2 emissions have been steadily increasing since 1990. Determining influences of socioeconomic factors behind this increase can help identify which the sectors and what types of policies should be prioritized to go into action. This paper identifies the main contributors to CO2 emissions change within five-year intervals during 1990-2015 by adopting Structural Decomposition Analysis (SDA) method. The results show that CO2 emissions increase was driven by per capita expenditure and population factors, while emission coefficient factor had a reducing effect on emissions. As the production side factors fell pretty behind the consumption side factors, net emissions was positive and the actual determiner in CO2 emissions was found as consumption. The most contributing sectors were Electricity, Land Transportation and Mineral. Speeding up renewable energy investments and continuing energy efficiency measures, placing a carbon tax on electricity and oil consumption, promoting public transport and use

of clean fuels and vehicles, slowing down construction and raising consumer awareness to change their consumption behavior, particularly to reduce demand for high emitting products and services should be the top priority policies.

Keywords: Supply-Use Table; Structural Decomposition Analysis; CO2 emission; INDC; Turkey

Üretim mi, Tüketim mi Belirleyici? 1990-2015 yıllarında Türkiye CO2 Emisyonlarının Kaynakları ve Politika Etkileri

Özet

Türkiye'nin CO2 emisyonları 1990'dan beri istikrarlı bir şekilde artmaktadır. Bu artışın arkasındaki sosyoekonomik faktörlerin etkilerinin belirlenmesi, eyleme geçmek için hangi sektörlere ve hangi tür politikalara öncelik verilmesi gerektiğini belirlemeye yardımcı olabilir. Bu çalışma, Yapısal Ayrıştırma Analizi metodunu kullanarak 1990-2015 döneminde beş yıllık aralıklarla CO2 emisyon değişimine başlıca katkı yapan faktörleri tanımlamaktadır. Sonuçlar, CO2 emisyon artışının kişi başına harcama ve nüfus faktörlerinden kaynaklandığını, emisyon katsayısı faktörünün ise emisyonu azaltıcı bir etkiye sahip olduğunu göstermektedir. Üretim tarafı faktörleri tüketim tarafı faktörlerinin oldukça gerisinde kaldığı için net emisyon pozitif olmuş ve CO2 emisyonundaki asıl belirleyici tüketim olarak bulunmuştur. En çok katkıda bulunan sektörler Elektrik, Kara Taşımacılığı ve Mineral olmuştur. Yenilenebilir enerji yatırımlarını hızlandırmak ve enerji verimliliği önlemlerini sürdürmek, elektrik ve petrol tüketimine karbon vergisi koymak, toplu taşımayı ve

temiz yakıt ve araç kullanımını teşvik etmek, inşaatı yavaşlatmak ve tüketim davranışlarını değiştirmek, özellikle de yüksek emisyonlu ürün ve hizmetlere olan talebi azaltmak için tüketici bilincini artırmak en öncelikli politikalar olmalıdır.

Anahtar Kelimeler: Arz-Kullanım Tablosu; Yapısal Ayrıştırma Analizi; CO2 emisyonu; INDC; Türkiye

1. Introduction

Climate change is a global risk that continues to evade political resolution. The World Development Report-2010 states that solution necessitates a transformation requiring to act now, together, and differently (Bierbaum, Fay, and Ross-Larson, 2009). Turkey, as a developing country, had 2.9% share in total greenhouse gas (GHG) emissions by Annex-1 Parties to the United Nations of Climate Change Convention (UNFCCC) in 2016 (UNFCCC, 2020) and its historical contribution to atmospheric accumulation of GHG emissions is extremely low, 0.7% (Republic of Turkey, 2015). Between 1990 and 2015, CO2 emissions increased 2.15 times (CO2 emissions (kt)- World Bank, 2020a) while GDP increased 2.98 times (GDP (constant 2010 US$)- World Bank, 2020a). In 2015 population was 1.46 times that of population in 1990 (Population, total- World Bank, 2020a). The continuous increase in Turkey's CO2 emissions (120% in 1990-2015) is perturbative, especially in contrast to reductions that have been seen in the EU (-21%), USA (3%), and average of High Income (HI) (8%) countries since 2006. Nevertheless, the upward trend of CO2 emissions in Turkey (an Upper Middle Income Country (UMI) (World Bank, 2020b)) is also more aggressive than UMI countries average (88%), but not as much as those seen in China (253%) and India (149%) (see Figure 1 panel a). CO_2 emission per capita was 4.5 ton (0.0045 Gg) per capita in 2014 which was still less than the USA, China, and most of the EU countries (CO_2 emissions (metric tons per capita)- World Bank, 2020a).

After the Kyoto Protocol it took ten years to reach a new climate agreement, and the negotiations have eventually culminated in the Paris Agreement. The main objective of the Agreement is to keep the global temperature below 1.5 or 2 degrees Celsius above pre-industrial levels, recognizing that is the limit of safety to protect the planet against droughts, heatwaves, floods, and sea level rises (UNFCCC, 2016). Its power is in banding together the developed and developing countries, and forcing them to submit Intended Nationally Determined Contributions (INDCs).

In its INDC, Turkey intended an emissions reduction target that is 21% lower than the business as usual scenario by 2030 (Republic of Turkey, 2015). Turkey signed the agreement in 2016 but did not ratify it yet. Implementation period started in 2020 and will end in 2030. Turkey also states that it is responsible for only 0.7% of the accumulated global emissions, and it should continue its development. Emphasizing eligibility to developmental assistance, special circumstances that placed it in a different situation than the other Parties in Annex 1, and its national circumstances and capabilities, Turkey stated its intention as to contribute to the collective efforts to combat climate change. Turkish INDC document comprised only mitigation issue, included all types of GHGs, comprised absorptivity of Land Use and Land Use Change (LULUCF), and set a target taking a business as usual scenario as base.

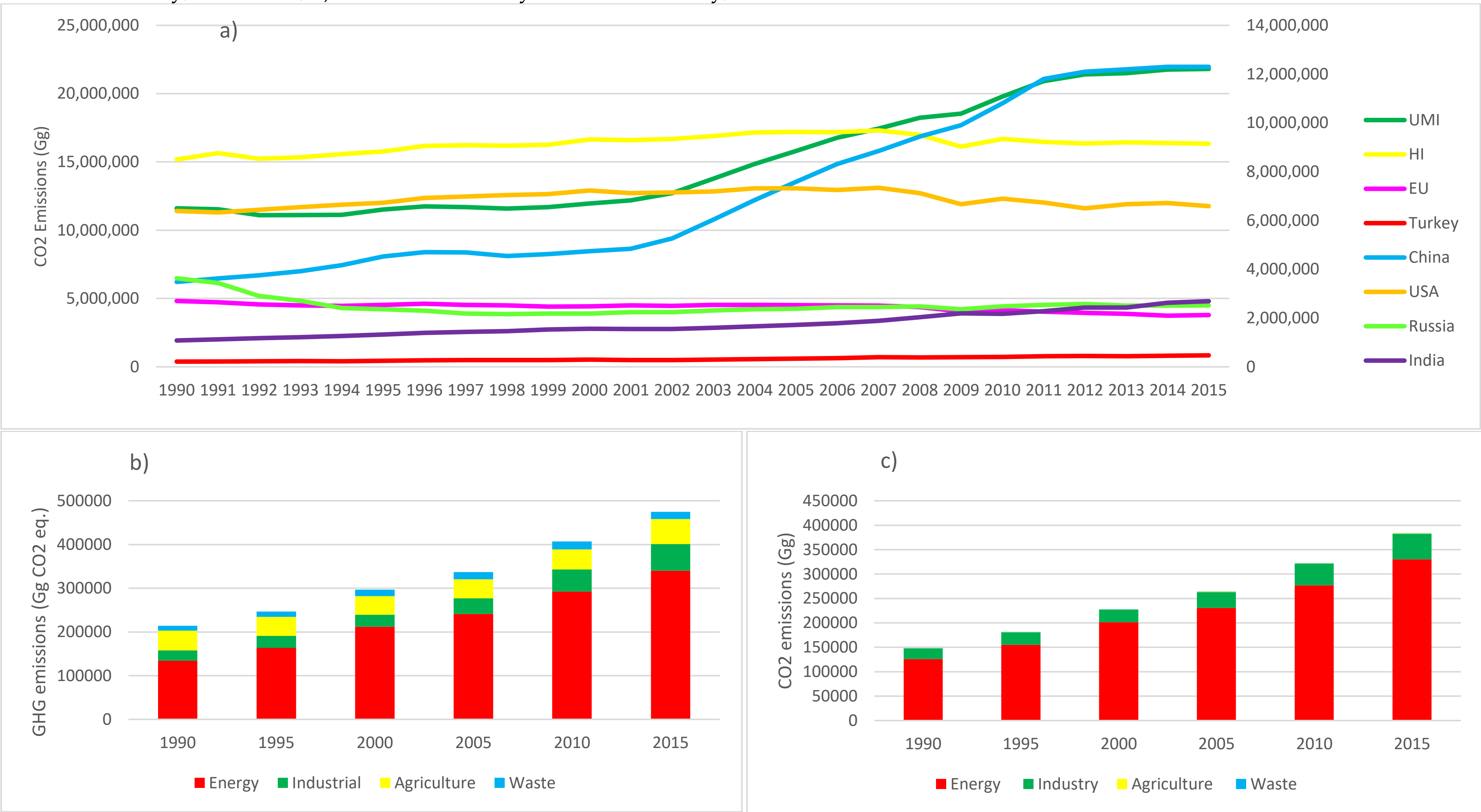
The actions planned in the energy sector are fully utilizing the country's limited energy resources (utilizing all coal reserves and all hydroelectric potential), constructing nuclear power plants, increasing renewable energy supply, and increasing efficiency in electricity transmission and distribution. The actions in the energy sector in the INDC document were not only the most numerous but also the only measurable goals, such that Alkan, Oğuş-Binatlı, and Değer (2018) were able to generate only three shocks from the INDC, and all of them were from the energy sector. The goals in transportation sector can be summarized as promoting public transport, and use of alternative fuels and clean vehicles, and increasing shares of railway and waterway transport modes. Some of these goals were repetitive and did not have quantitative targets or clear deadlines. Constructing energy-efficient buildings in the buildings and urbanization sector; land consolidation, efficient fertilizer use, rehabilitation of grazing lands, and implementing modern agricultural activities in the agriculture sector; and promoting recycling, increasing number of managed landfill sites, and using waste as an alternative fuel in the waste sector were the remaining stereotyped, unmeasurable and unexamined solutions in the INDC. Furthermore, the 21%-mitigation target is shown to be implausible by Alkan, Oğuş-Binatlı and Değer (2018), Karapinar, Dudu, Geyik, and Yakut (2019), Acar et al. (2016), and Kat et al. (2018).

After submitting its INDC, Turkey prepared its Joint First and Second Biennial Report[1] and Sixth National Communication[2] in 2016, its Third Biennial Report and Seventh National Communication in 2018, and Fourth Biennial Report in 2020. Turkey continues to publish emissions, carbon sinks and capture, precipitation, temperature, and sea surface temperature statistics annually. Between 2015 and 2020, Turkey has not prepared any new national document with a sole focus on combating climate change, and only mentions climate change in its development plans and strategy documents.

GHG emissions of Turkey in 2015 primarily originated from the energy sector (71.58%); followed by industrial processes (12.78%), the agriculture sector (12.08%), and the waste sector (3.56%)

(Turkish Statistical Institute (TSI), 2017) (see Figure 1 panel b). When only CO2 gas emissions are considered, 86.14% was from energy sector and 13.65% was from industry sector, and agriculture and waste sectors did not contribute significant amounts to total CO2 emissions (TSI, 2017) (see Figure 1 panel c). Total CO2 emissions increased at a rate of %159 in the 1990-2015 period. The energy sector grew more than this rate, by 163%. As referred in National Inventory Reports, the energy sector includes emissions from combustion of fossil fuels, fugitive emissions from fossil fuels' transportation and storage. Industry sector CO2 emissions grew by 139% in the same 25-year period. The GHG emissions from industrial processes and product use are released during manufacturing processes, and the gases released from fuel combustion which is done for supplying energy to manufacturing processes are counted in energy sector. The mineral industry contributed 62.1%, the metal industry contributed 19.42%, product uses as ODS substitutes contributed 7.91%, and the chemical industry contributed 6.87% of the total GHG emissions from industrial processes and product use sector in 2015 (TSI, 2017). The most contributing has always been the energy sector with a high growth rate, however increase in the industry sector was more significant especially after 2000s.

Figure 1 a) CO_2 Emissions of Turkey, USA, EU, China, UMI and HI Countries (Production-Based Accounting-PBA), b) GHG Emissions by sectors in Turkey, 1990-2015, c) CO_2 Emissions by Sectors in Turkey, 1990-2015[3]



Source: a) National CBA report 1970-2015 (The Eora Global Supply Chain Database, 2019a), and Country and Lending Groups-by income (World Bank, 2020b), b-c) National Greenhouse Gas Inventory Report 1990-2015 (Turkish Statistical Institute, 2017)

The motivation in this study is to determine the factors behind the continuously increasing CO2 emissions in Turkey, particularly to understand whether production or consumption side factors are determinative. This study analyzed 1990-2015 period in 5 year-intervals by employing Structural Decomposition Analysis (SDA) method and identified five driving factors to get the most from the data: emissions coefficient, technology, final demand mix, per capita expenditure, and population. Single-region IO tables were taken from the Eora database in the form of Supply-Use Tables (SUTs) (59 sectors), and CO2 emissions were added as a satellite account.

In the rest of this paper, section 2 is reviewing the related literature, section 3 is describing the data sources and the methodology, section 4 is presenting the results and carrying out a discussion and section 5 is addressing conclusion and policy suggestions.

2. Literature Review

Decomposition methods are frequently used to identify the drivers of energy or environment related magnitudes such as energy consumption, pollutant emissions, CO2 emissions which help more efficient policy making[4]. Findings of most recent decomposition studies at the global level showed that income is the primary driver of carbon emissions increases and population is the second driver increasing emissions while progress in technology and energy intensity[5] acted to curb emissions (Arto and Dietzenbacher (2014), Chang et al. (2019), Dong et al. (2019), Xia et al. (2020)). About contribution of another generally studied factor, carbon intensity, Xia et al. (2020) found that its contribution remained very small starting in 2000s and gradually became negative up to 2017 which is in contrast to the positive contribution found in Chang et al. (2019). Dong et al. (2019) decomposed CO2 emissions of High Income (HI), Upper Middle Income (UMI), Lower Middle Income (LMI) and Lower Income (LI) country groups (World Bank, 2020b) from 1980 through 2015 with LMDI method. In both HI and UMI countries, while income was the most contributing factor, energy intensity was the main offsetting factor. Population ranked second in contribution to emissions growth in both country groups, but emission coefficient was another significant factor resulting in increase in UMI countries' emissions. China, USA, EU, India and Russia are the top most contributing countries with %61.58 of global emissions rate in 2015 (The Eora Global Supply Chain Database, 2019b) and are listed in HI or UMI countries except India (LMI). China's CO2 emissions increases were driven by economic development and population (Zheng et al. 2020), but since 2012, the beginning of the new normal economy, emissions showed a plateauing trajectory which was driven by improvements in energy intensity (Zheng et al. 2019). As an HI country and ranked second in global emissions, USA's emissions decrease by energy intensity and carbon intensity improvements, while income and population continued to increase emissions (Pompermayer Sesso et al. (2020), Henriques and Borowiecki (2017), Xia et al. (2020)). EU which mostly comprises of HI countries realizes emissions reductions since 2000s by improvements in energy intensity, but income and population factors have still increasing effect on its emissions (Pompermayer Sesso et al. (2020), Henriques and Borowiecki (2017), Perrier, Guivarch, Boucher (2019), Xia et al. (2020)). In India and Russia, the other two most contributing countries, energy intensity was the primary mitigating factor, and while income acted to increase emissions in Russia, income and population together were resulting increase in India's emissions (Xia et al. (2020)).

The recent decomposition studies for Turkey were made for different sectors, different years, and different length of time. A recent study by Isik, Sarica, and Ari (2020) employed Logarithmic Mean Divisia Index (LMDI) method to reveal the factors on CO2 emissions from transportation sector between 2000 and 2017, and found that economic growth is the principal driver, followed by population and emission intensity. Kim et al. (2020) used LMDI method to analyze electricity generation sector in 36 OECD countries in the periods 1995–2008 and 2008–2017, and showed that while European countries have significantly reduced carbon emissions from GDP growth through various policy efforts such as electricity intensity (demand), closing down of thermal generation (supply), and change in energy mix (supply), but non-European countries including Turkey could not have accomplished to reduce emissions from GDP growth. The study projected that GDP increased Turkey's CO2 emissions at a rate of 98% of net emissions increase, but efficiency in electricity generation which is on the supply side decreased emissions at 12% of net emission. Akbostancı, Tunç, and Türüt-Aşık (2018) made two decomposition analyses with LMDI method, one for GDP sectors (agriculture, forestry and fishery, manufacturing industries and construction, public electricity and heat production, transport and residential sectors) in 1990-2013 and one for manufacturing and construction sectors. They concluded that economic activity and energy intensity were the principal drivers of CO2 emissions in GDP sectors, and manufacturing industries and construction and public electricity and heat production dominated the emissions change; and among the manufacturing industries and construction subsectors, the non-metallic minerals sector has the highest contribution to emissions followed by the chemicals sector. A more recent study by Karakaya, Bostan, Özçağ, (2019) studied energy-related CO2 emissions trends in 1990-2016 by using Kaya Identity and LMDI methods, and the results indicated that economic growth and population effects are the main driving forces in increases in carbon emissions, while other technology-based driving factors' impacts are rather minimal in reducing the emissions. Köne and Büke (2019) used the Kaya Identitiy decomposition analysis on the historical (1971-2014) and projected (2015-2060) CO2 emissions from fossil fuel combustion in Turkey and found that growth and population were the main drivers in the past but their effect will be greatly reduced in the future.

Three main features of this paper distinguish it from previous decomposition analyses conducted for Turkey. First, our study uses input output tables which comprise the whole economic system and make it possible to take into account both direct and indirect demand effects (demand change in one sector indirectly leads to changes in demand of others). As production and consumption structures can be shifted and thus affect emissions, evaluating mitigation performance of past policies and making new policies can be made through the national supply change. Our study particularly investigates whether production or consumption side factors dominate and this is the main contribution of the paper. Other decomposition studies on Turkey considered one or a few sectors and did not make a distinction between consumption and production and. Second, all prior decomposition studies analyzing Turkey's emissions employ LMDI (or other IDA methods), but our analysis will be the only study using the SDA method which provides a richer picture. Third, data used in this study comprises CO2 emissions for past 25 years with the most recent IO tables extending to 2015. Such a comprehensive analysis is expected to provide a better understanding of CO2 emissions change for policy makers in Turkey.

3. Data and method

3.1. Data sources

Data of this study (IO tables, CO2 emissions, and population) was obtained from the Eora database (The Eora Global Supply Chain Database, 2019b). Turkey's IO tables are provided in SUT format for years 1970-2015. These SUTs consist 61 sectors; 59 sectors are the same with the sectors in the 2002 IO table published by

Turkish Statistical Institute, and two other sectors are Re-export, and Financial Intermediary Services, Indirectly Measured (FISIM). As these two sectors caused unreasonable large deviations when SDA was applied, both were deleted from SUTs, and the analysis was made on the remaining 59 sectors.

An ordinary SUT structure and Turkey's SUT structure in the Eora database are shown in Table 1, and differently, Turkey's SUT includes import and export accounts. In Turkey's SUT, imports were provided in the industry accounts from 189 countries separately, and exports were provided in the commodity accounts to the same 189 countries. There was a Rest of World (ROW) country group aggregating imports from and exports to other countries for whom data was not separately provided. However, the ROW had import values both in the commodity accounts and in the industry accounts, and export values both in the industry accounts and in the commodity accounts. For the compliance with the import and export structure of the 189 individual countries, we added the import values from the ROW in the commodity accounts to the import values in the industry accounts; and the export values to the ROW in the industry accounts to the export values in the commodity accounts. Then, we summed up exports to all individual countries and to the ROW into one column and defined as total export, and summed up imports from all individual countries and from the ROW into one row, and defined as total import. We used import and export to balance the SUT tables. At last, we deflated the tables that are provided with the current-year prices ('000 USD) to 2010 year by using USD GDP deflator (USA-GDP deflator (base year varies by country)- World Bank, 2020a).

Table 1 An ordinary SUT structure and Turkey SUT structure in the Eora database[6]

a) Ordinary SUT

	Industry	Commodity	Final demand	Total
Industry		V		x
Commodity	U		e	q
Value added	v'			
Total	x'	q'		

b) Eora Turkey SUT

	Industry	Commodity	Final demand	Country A	Country B	...	ROW	Total
Industry		V					E_ROW1	x
Commodity	U		e	E			E_ROW2	q
Value added	v'							
Country A	M		M_fin.			Nan	Nan	
Country B								
...								
ROW	M_ROW1	M_ROW2				Nan	Nan	
Total	x'	q'						

The Eora database consists CO2 emissions inventories from two data providers: EDGAR and CDIAC. We use the EDGAR CO2 emissions since these are more in line with the official statistics. EDGAR CO2 emissions are provided in Gigagram (Gg) units.

3.2. Structural Decomposition Analysis

Structural Decomposition Analysis (SDA) is a decomposition method that reveals the roles that different economic sectors play in the growth of GHG emissions. SDA method has two alternative modes of decomposition: additive and multiplicative. The additive decomposes the change in one variable as a summation of changes in the components of that variable. Following an overwhelming majority of SDA studies (Su and Ang, 2012), we use the additive SDA in this paper.

There are various decomposition techniques for the additive SDA; namely ad hoc, the logarithmic mean Divisia index (LMDI-I and LMDI-II), the Dietzenbacher and Los (D&L), the Shapley/Sun (S/S), and the mean rate of change index (MRCI) techniques. Su and Ang (2012) grouped 43 SDA studies conducted in the 1999-2010 period into four categories according to the techniques they used, ad hoc, D&L, LMDI, and others, and the number of studies using D&L, LMDI, ad hoc, and others were 23, 5, 11, and 4, respectively.

We used the D&L technique as it has a vast theoretical and empirical literature that eases application of the technique and increases comparability of the results.

SDA method is derived from the IO multiplier equation below:

$$x = (I - A)^{-1} f \quad (1)$$

where x is nx1 and denotes the industry output of n sectors of the economy, $(I\text{-}A)^{-1}$ term is the Leontief inverse, L, which is nxn, and f, nx1, is a column vector of final demands. A denotes an nxn technical coefficients matrix, and I is an nxn identity matrix.

Change in CO2 emissions (pollutant) is calculated as:

$$e = \hat{E} L f \quad (2)$$

where E is an nxn diagonal matrix defining CO2 emissions released to environment by producing 1.00 monetary unit output by sector, and e is an nx1 column vector of emissions by each sector.

Equation (3) denotes CO2 emissions released by each sector and we decompose final demand into three components that measure final demand structure (f_d), per capita expenditure (f_e) and population (f_p):

$$e = \hat{E}Lf = \hat{E}Lf_d f_e f_p \quad (3)$$

$$f_d = f(\iota' f)^{-1}$$

$$f_e = \iota' f P^{-1}$$

$$f_p = P$$

f_d is an nx1 vector whose elements are $f_i / \sum f_i$, f_e is a number whose elements are $\sum f_i / P$, and f_p equals to P, population, which is a number.

The change in CO2 emissions in additive SDA, using these five factors changes can be written as follows:

$$\Delta e = \Delta E + \Delta L + \Delta f_d + \Delta f_e + \Delta f_p \quad (4)$$

We use the average polar decomposition technique of Dietzenbacher and Los to decompose changes in emissions as below:

$$
\begin{aligned}
\Delta e = \frac{1}{2}(\Delta E)\left[L^0 f_d^0 f_e^0 f_p^0 + L^1 f_d^1 f_e^1 f_p^1\right] \\
+ \frac{1}{2}\left[E^0 \Delta L f_d^1 f_e^1 f_p^1 + E^1 \Delta L f_d^0 f_e^0 f_p^0\right] \\
+ \frac{1}{2}\left[E^0 L^0 \Delta f_d f_e^1 f_p^1 + E^1 L^1 \Delta f_d f_e^0 f_p^0\right] \\
+ \frac{1}{2}\left[E^0 L^0 f_d^0 \Delta f_e f_p^1 + E^1 L^1 f_d^1 \Delta f_e f_p^0\right] \\
+ \frac{1}{2}[E^0 L^0 f_d^0 f_e^0 + E^1 L^1 f_d^1 f_e^1]\Delta f_p \quad (5)
\end{aligned}
$$

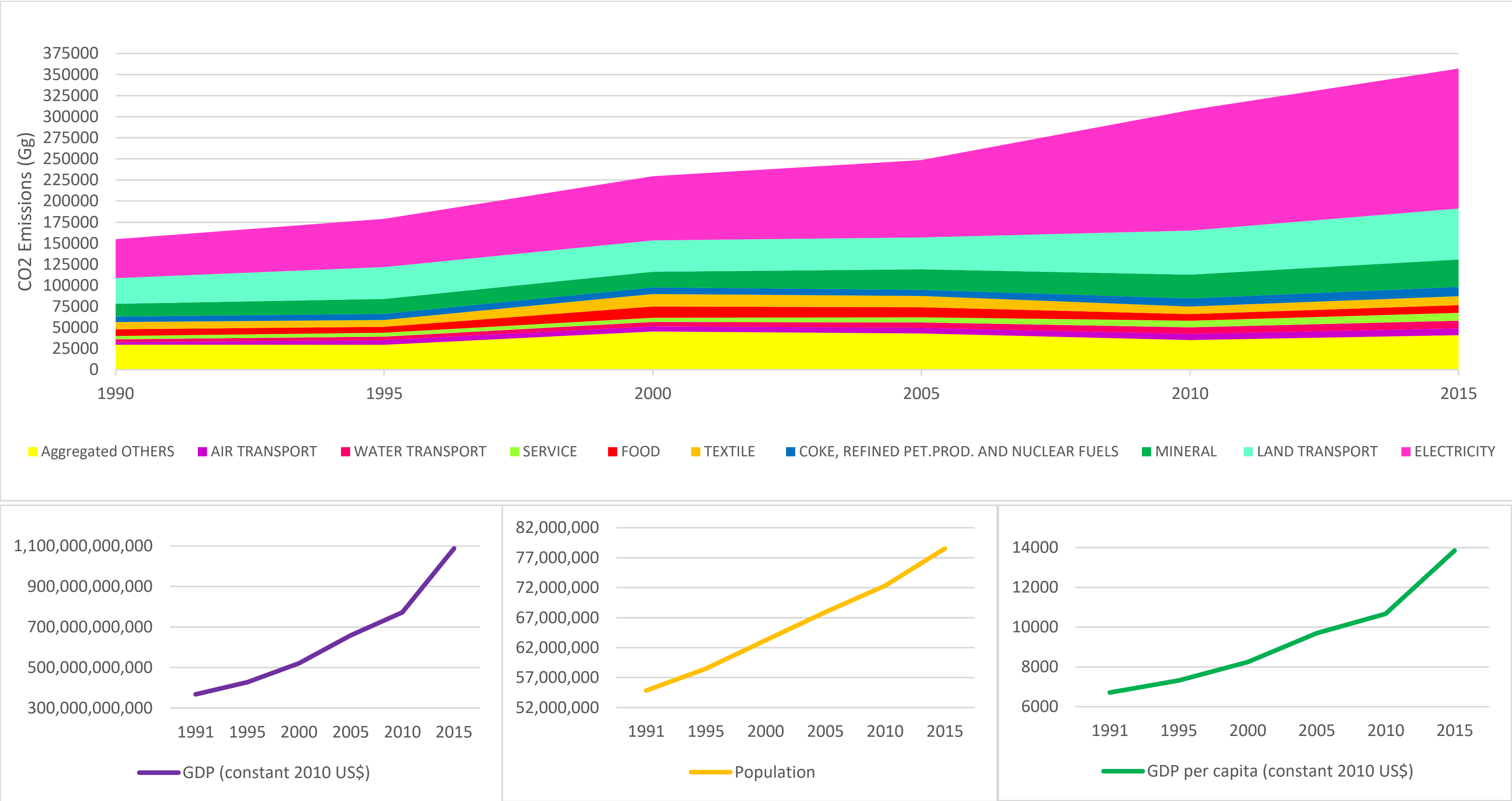
It should be noted that our data is in SUT format, it is not IO. Multiplier equation should be transformed to be applied to SUT formatted tables. L matrix and f vector are required to be computed from the SUT table and this is not a trivial transformation. The steps of the transformation is given in Appendix B.

4. Results and Discussion

4.1. Analysis of CO2 emissions

Figure 2 shows trends of the highest nine CO2 emitting sectors (according to 2015 emissions), and GDP, population, and GDP per capita values in the 25-year period. In general, emissions increases were higher in 1995-2000, 2005-2010, and 2010-2015 periods. When GDP values are reviewed for the same period, it seems that growth rates were high between 2000-2010, and reached an even higher rate between 2010-2015. Population growth was stable during these 25 years. As for GDP per capita, it grew high in 2000-2005, and recorded a much higher growth rate in 2010-2015. It seems that emissions increase does not have exactly the same course with population, GDP, or GDP per capita. Looking into sectors one by one, energy takes the first place again, it has been in an increasing trend since 1990, but its contribution has increased even more especially since 2005. Land transportation made a significant contribution in 2005-2015, and it recorded 17% of total emissions. Mineral sector has always ranked the 3rd and it has been in an upward trend after 2005. Food and Textile sectors ranked the 4th and 5th in contribution to CO2 emissions in 1990-1995, showed an increasing trend until 2005, but Coke, Refined Petroleum Products and Nuclear Fuels replaced them and became the 4th largest contributor after then. Although Service sector's contribution is small, only 3% in 2010-2015, it draws attention as it has an increasing trend after 2005. Water Transportation and Air Transportation have always increased their contributions but they remained the 8th and 9th sectors in contribution to emissions. Extraction of Petroleum and Natural Gas is a high emitting sector due to its fugitive CO_2 emissions, but as its contribution to total emissions remained relatively low in Turkey, it is not given separately in Figure 2. Metal, Chemistry, and Rubber and Plastic sectors are other high CO_2 emitting sectors due to emissions from fuel combustion and manufacturing processes in production, but again due to relatively low contributions, they are given in the Aggregated Others sector in Figure 2.

Figure 2 CO_2 emissions by sector, GDP, Population, and GDP per capita in 1991-2015[7]

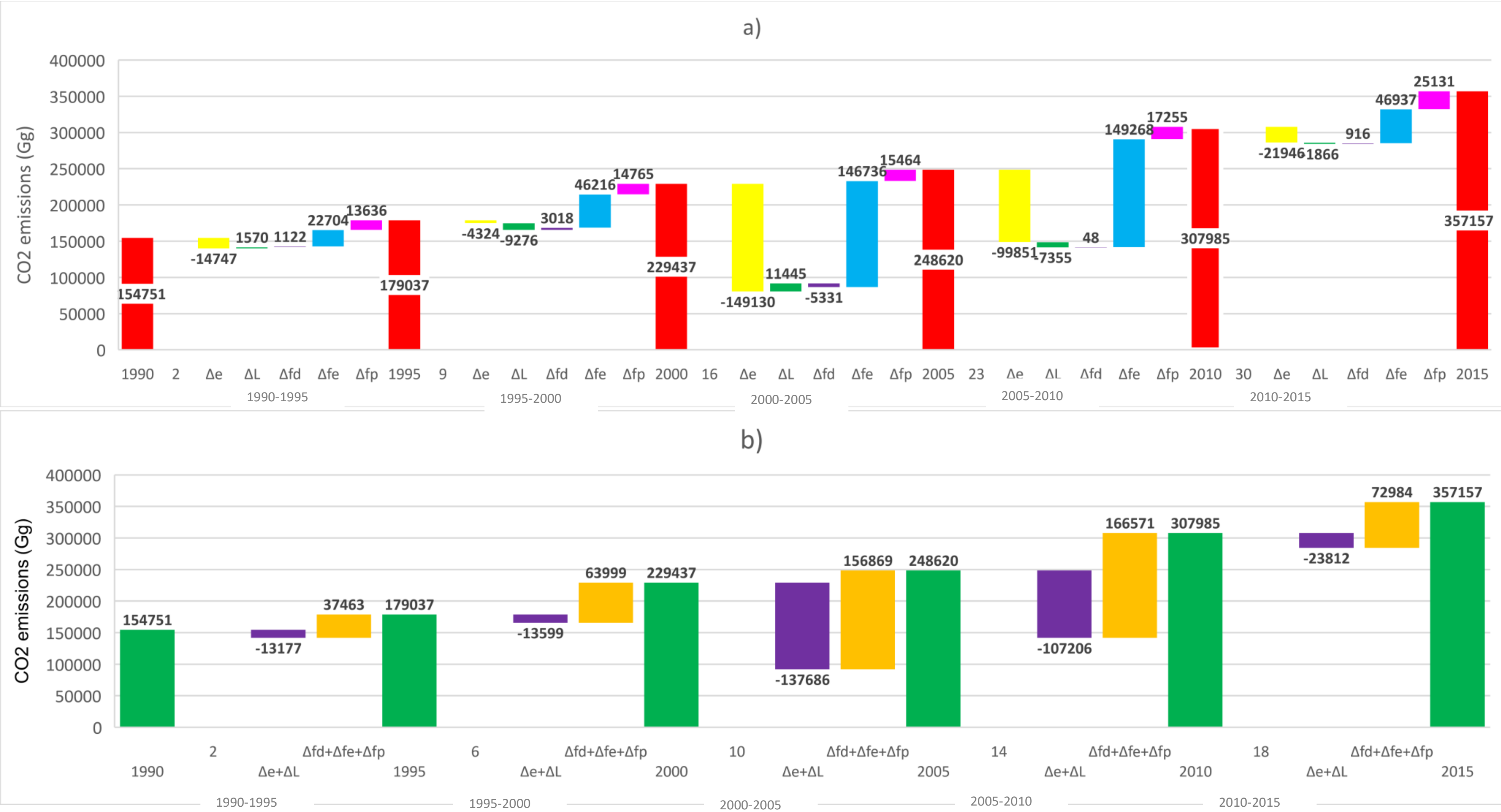


Source: a) Compiled from the Eora global supply chain database (The Eora Global Supply Chain Database, 2019b), b-c-d) GDP(constant 2010 US$), Population, total, GDP per capita (constant 2010 US$) World Bank 2020a.

4.2. Drivers of CO2 Emissions Change

The findings of the decomposition analysis provide insights into the causes of increase in Turkish CO2 emissions in the period 1990-2015 in five-year intervals. Influences of 5 different factors, namely emission coefficient, technology, final demand structure, per capita expenditure, and population were computed. The decomposition results are shown in Figure 3.

Figure 3 Decomposition results a) by each factor: e, L, f_d, f_e, f_p b) production side factors (e+L) and consumption side factors (f_d+f_e+f_p)



Source: Authors' calculation. (e: emission coefficient, L: technology, f_d: final demand structure, f_e: per capita expenditure, f_p: population)

When 25-year emissions increase is considered, both emission coefficient and technology were the curbing factors. Reduction in emission coefficients (Δe) avoided 289,998 Gg CO2 emissions alone (-143.28% of net CO2 emissions change). Technological development (ΔL) provided 5,483 Gg CO2 emissions reduction (-2.71%). Final demand structure effect was so small, but provided 226 Gg CO2 emissions reduction (-0.11%). These reductions were offset and reversed by the changes in per capita expenditure (Δf_e) (411,862 Gg CO2, +203.48%), and population (Δf_P) (86,250 Gg CO2, +42.61%), and net CO2 emissions increase was 202,406 Gg in 25-year period. Per capita expenditure was the most influencing factor resulting an actual increase in emissions, and population was the second driver of emissions growth. The reductions driven by emission coefficients and technology can be interpreted as Turkey made some progress in switching to a less carbon intensive production system.

Increasing effect of final demand to overall CO2 emissions change shows that the real determinant is the consumption side of the economy. The contribution of consumption is 1.69 times greater than the contribution of production. Per capita expenditure turned out to be the primary increasing factor, and increasing effect of population was significative as expected due to continuous increase in population.

The first part of equation (5) gives CO2 emissions change due to change in emission coefficient (e). The results in the Δe column shows a decisive trajectory, changes in emission coefficient have always decreased emissions even though the magnitudes of its effect have changed from one period to the other.

Emission coefficients can also refer to carbon intensity of the economy. Environmental awareness and sensitivity to environmental problems in Turkey, partly due to the EU accession process, has reached the highest level in the 2000s. Turkey started EU accession negotiations in 2005 and started to introduce new legislature to harmonize its legal system with that of the EU. Environmental regulations were passed largely due to this impetus. Between 2003 and 2005 2 new laws, 5 new regulations, 1 communiqué and 3 circulars related to environmental protection came into force[8]. In the next 5-year interval 22 new regulations, 14 circulars and 12 communiqués were introduced and the Environment Chapter, Chapter 27, was also opened for negotiations in 2009. But, the influence of EU accession process decreased in 2010s due to a variety of facts; cooperation on migration, the rule of law, and independence of judiciary. There is still an on-going dialog on opened but not closed 16 Chapters out of 35.

ΔL shows the effects of production technology on emissions change. The changes in technology usually resulted in decrease in emissions, except the periods 1990-1995 and 2000-2005. Decreasing effect of production technology in emissions change must be due to continuous development in production technology.

Despite attending some of the first international climate change meetings even before establishment of the UNFCCC, Turkey's politics can be defined as a perfect inaction in 1990-2000 period. This stance was altered marginally in 2001, with the removal of Turkey's name from Annex 2 in which it had been listed due to being an OECD country and the acceptance of its special circumstances among other parties in Annex 1. Turkey acceded to the UNFCCC twelve years after its establishment, in 2004. And Turkey did not sign the Kyoto Protocol in 2005, so did not have an emissions reduction target. These delays refrained Turkey from increasing its institutional capacity for climate change in these early stages.

Turkey submitted its first national GHG emissions inventory to the UNFCCC in 2006 and prepared its first National Communication on Climate Change in 2007. Turkey published its first climate change documents between 2010-2012[9]. Boosting energy efficiency projects and renewable energy investments were the outstanding targets in these documents. In addition to these documents, solely energy focused papers[10] were also prepared not only for environmental protection but also to reduce energy dependency rightfully recognized as a threat to economic and political volatility for Turkey.

Energy intensity levels continuously decreased since 1990 (0.09), and reached 0.07 tonne of oil equivalent (toe) / thousand 2010 USD in 2015 (Total primary energy supply by GDP (PPP)- IEA, 2019). Renewable energy supply was 9.7 million tonnes of oil equivalent (Mtoe) in 1990, 10.1 Mtoe in 2000, and 15.9 Mtoe in 2015 (Biofuels and waste: 3.2 Mtoe, Hydro: 5.8 Mtoe, Wind-Solar-Geothermal: 6.9 Mtoe) (Total primary energy supply by source-IEA, 2019). But, the share of renewables in total energy supply remained the same, around 12% of total primary energy supply, due to hugely increased energy demand. Turkey intends to reach a total capacity of 61 GW (45.95 Mtoe maximum annual power production) by 2023 (Biofuels and waste: 1 GW (0.75 Mtoe), Hydro: 34 GW (25.61 Mtoe), Geothermal: 1 GW (0.75 Mtoe), Solar: 5 GW (3.77 Mtoe), Wind: 20 GW (15.06 Mtoe)) [Republic of Turkey, 2017]. Negative contributions of technological changes in three 5-year periods (1995-2000, 2005-2010, 2010-2015) should be related to the success in energy efficiency projects but cannot be related to increase in renewable energy supply as use of fossil fuel resources offset it. Among fossil fuel resources, coal which has a very high CO2 emission, started to increase its share steeply after 2005, oil decreased its share continuously after 1995, and natural gas started to increase its share after 1995 and its use almost doubled since 2005. If coal supply could have been changed with renewable energy since 1990, negative contribution of technology factor might have been greater.

The final demand structure effect, Δf_d, is the third factor analyzed and its influence on emissions was the smallest.

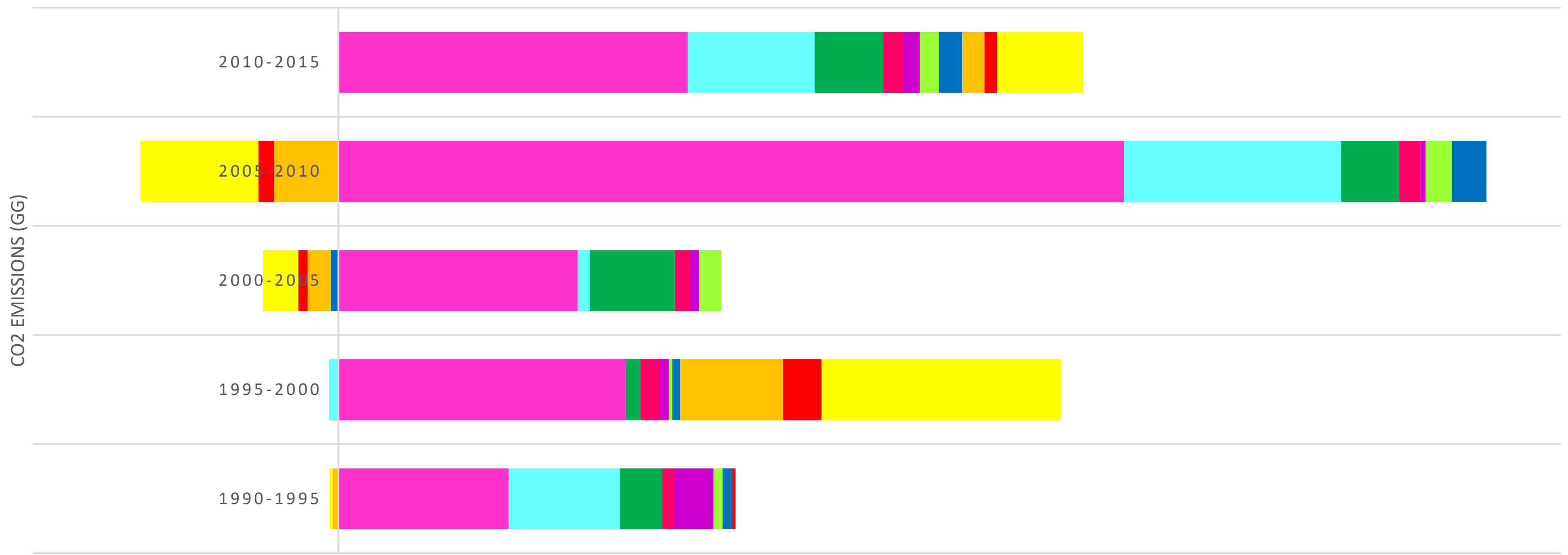
Per capita expenditure acted to increase to emissions in all periods. Especially after 2000s, the effect was great. The Turkish economy witnessed a deep economic crisis in 2001 and had to undertake many financial and economic reforms under the watchful eye of the IMF. It was also a period, when moderate political Islam was believed to be able solve the terrorism threats the fundamentalist Muslims posed. The new Turkish government, elected after and under the shadow of the 2001 economic crisis, was well-positioned to play an influential role towards this goal. The EU accession negotiations started in this climate and the years leading up to as well as the subsequent years were a time of positive expectations for Turkey and by the Turkish society. The international economic environment was also favorable with a weak dollar and a strong Turkish lira and Turkey easily borrowed from abroad. The effect of the 2008 global financial crisis on Turkey was relatively minor. After a negative growth rate of 5 percent in 2009, Turkey re-embarked on a path of growth. These economic conditions fueled domestic consumption and led to a rapid increase in per capita expenditure.

In all of the periods, the change in population, Δf_P, increased CO2 emissions increase and it followed a continuously increasing path. As the population of Turkey was increasing during these years, positive contribution of population is expected.

The results of 59 sectors were aggregated into 23 sectors by the authors according to their contributions to growth, export, employment, and emissions, and according to their energy dependence. The sectoral mapping is included in Appendix A.

Figure 4 presents the decomposition results for sectors.

Figure 4 Sectors' contributions to CO2 emissions[11]



	1990-1995	1995-2000	2000-2005	2005-2010	2010-2015
ELECTRICITY	11145	18801	15649	51389	22850
LAND TRANSPORT	7261	-602	800	14230	8316
MINERAL	2779	957	5558	3779	4488
WATER TRANSPORT	756	1248	1014	1418	1252
AIR TRANSPORT	2617	611	571	337	1130
SERVICE	580	225	1461	1714	1259
COKE, REFINED PET. PROD. AND NUCLEAR FUELS	618	524	-500	2259	1523
TEXTILE	-379	6734	-1515	-4214	1450
METAL	230	2500	-613	-1032	836
Aggregated OTHERS	-195	15668	-2292	-7708	5628

Source: Authors' calculation

Electricity, Land Transportation, and Mineral are the most important sectors that explain CO_2 emissions increase. It is noteworthy that Electricity recorded more than half of the total CO_2 emissions increase, especially in the 2005-2010 period as seen in Table 2. Turkey's population is growing and the standard of living is improving with time and technology. Since electricity consumption is an indicator of development and growth, some positive contribution over the time period under analysis is to be expected. Turkey's environmental protection policies should be considered in their infancy for most of the 25-year period although important measures for energy efficiency were taken. Nevertheless, the large contribution of electricity in the 2005-2010 period is discouraging. We argue that this is largely due to the increased capacity of coal-fired power plants. Electricity production from coal-fired power plants increased by 27 percent in this period compared to a 13 percent increase in the preceding period (Electricity generation by source- IEA, 2019). In the following period, 2010-2015, electricity from coal-fired power plants increased by 38 percent (IEA, 2019) but Turkey signed the Kyoto Protocol in 2009 and as part of the harmonization process with the EU, two important regulations regarding air quality passed around the same time. More care about environmental pollution was thus given when capacity was increased in the subsequent 5-year interval. However, the increase in coal-fired electricity production in 2015-2018 has reached 49 percent (IEA, 2019) so the electricity generation sector has likely continued to be a major contributor to CO2 emissions after 2015.

Land transport sector was the second in contribution to CO2 emissions increase with a 14.82% rate. Car ownership in Turkey has risen sharply in the 25 years analyzed. Annual new motor vehicle registrations were below 200,000 at the beginning of the period but had reached almost 750,000 by 2015. In 1997, LPG (autogas) which is considered to be cleaner than gasoline and diesel started to be used in automobiles. Today, Turkey is the first in Europe and second in the world as far as the number of automobiles with LPG are concerned. This was one factor that kept emissions due to increased car ownership in check initially because by 1997 annual new motor vehicle registrations had reached 300,000. In the period from 2000-2005 the effect of the 2001 economic crisis was significant and new motor vehicle registrations had dropped to 70,000 in 2002. During 2005 and 2010 period, the change in emissions due to land transportation is quite large. New motor vehicle registrations during this period is 1.9 million, close to 400,000 per annum on average. In 2013 and 2014, tax incentives were given to retire automobiles that were older than 20 years which resulted in retiring 400,000 older vehicles from traffic. Even though new automobile registrations continued to rise and had reached an annual average of 631,000, the increase in emissions was almost half as much as the previous period. About half the motor vehicles on the road are automobiles and the average number of road motor vehicles in Turkey has increased from around 5 million in the 1990-1995 period to 18 million by the 2010-2015 period.

The increases in Mineral sector's emissions (2.17 times of 1990 levels in 2015) and Metal sector's emissions (1.46 times of 1990 levels in 2015) are principally due to growth in emissions associated with cement production and iron and steel production, and emissions from producing these goods increased because of the industrial growth and the increased demand for construction materials. Mineral industry produces cement, lime, glass, ceramic, and non-metallurgical magnesia products, and cement production emits 86.5% of CO2 emissions of total Mineral sector emissions. Calcination process and fuel combustion for heating are the processes that CO2 is emitted.

Water Transport was the fourth, and Air Transport was the fifth in contribution to CO2 emissions. Air Transport, whose emission coefficient is well above even Land Transport, recorded an increase of 1229% in passenger transport and 920% in freight transport in 1990-2015 period, and increased its growth rate especially after 2000s. Coke, Refined Petroleum, and Nuclear Fuels sector grew in 2005-2015 years and its contribution to emissions increased as well. Raw materials are processed in this sector, and refinery processing of petroleum is prevailing. Fuels, heating oils, lubricating oils, asphalt, and petrochemical materials are the products of this sector, and its products are used by energy and transportation sectors.

5. Conclusion and Policy Implications

In this study, CO_2 emissions in five year intervals between 1990 and 2015 were decomposed into 5 factors; emission coefficient, technology, final demand structure, per capita expenditure, and population, by employing the SDA method. The results indicated that the key driving force responsible for promoting CO_2 emissions in Turkey from 1990 through 2015 was per capita expenditure, especially after 2000s, while emission coefficient was the most significant factor in inhibiting emissions. Population was significant and had a restraining effect on emissions increase as well.

These results are quite similar to the results of recent decomposition studies conducted for the whole world, for UMI countries and for Turkey. As the results shows, CO_2 emissions increased due to consumption activities and consumption is the main determinant of emissions. Mitigating effect of production factors fell pretty behind the increasing effect of consumption factors.

The actions in Turkey's INDC included only a few measures on consumption, such as promoting public transport, constructing energy efficient buildings, promoting recycling. However, this study shows that consumption activities present the greatest potential for improvements.

Electricity, Land Transportation, Mineral, Air Transportation, Coke, Refined Petroleum and Nuclear Fuels and Metal sectors were found the most contributing sectors to CO2 emissions increase and electricity dominated with recording more than half of net emission. When energy actions in the INDC were considered, utilization of all coal reserves seems inadmissible, instead, Turkey should prioritize speeding up renewable energy investments and continuing energy efficiency measures which are actions listed in the INDC already. Carbon taxation in electricity and oil consumption can decrease personal demand for these products and as a consumer-oriented policy, it can seriously contribute to the measures taken on the production side. Promoting public transport action in the INDC should be the top priority target in Land Transportation due to sharp rise in car ownership, and this can be only achieved in case of increasing people's access to public transportation. Use of clean fuels and vehicles is also a good measure and needs to be highly subsidized for rapid dissemination. Directing investments from air to rail transport and water transport (where possible) will increase the share of these modes and decrease the emissions due to much lower emission coefficients.

Slowing down the construction sector can restrain emissions increase from Mineral, Metal and also from Coke, Refined Petroleum and Nuclear Fuels sectors to some extent. Making acquisition an energy certificate mandatory for new buildings can be a good policy for both commercial and residential buildings.

Guiding consumers to change their consumption behavior through measures such as strengthening education and public awareness is an urgent necessity for reducing demand for high emitting products and services. Consumers informed about highly emitting products can exert pressure on producers to reduce emissions during production or produce alternative products, as well. Consumers with increased knowledge about emissions can reduce consumption and disposal, change use and disposal behavior and will tend to buy more efficient products, and thus, switch to a low-carbon life style.

Stating its intention as to contribute to collective efforts to fight against climate change, Turkey needs to reconcile its development with mitigation. Following the EU example which stabilized its emissions starting in 2000s and reduced since 2006 and China example which accomplished plateauing its emissions in the recent decade, Turkey can shift to a low-carbon development paradigm. But, existing economic problems that are deepening due to Covid

19 pandemic indicates a lower capability to decarbonize its economy. At this point, Turkey's efforts to be eligible for financial support gains importance but it does not seem possible due to weaknesses in its INDC and lack of serious action since 2015. First, Turkey should revise its emissions target by determining an actual year as reference year (e.g. USA, EU, India, Russia) or by stating a peak time for emissions (e.g. China) to increase admissibility of the target. Revising and prioritizing the actions, including emissions mitigation potentials of these actions, and adding implementation plans will be to Turkey's benefit. Second, actions on emissions mitigation should not be postponed any longer, existing investment plans should be revised by taking emissions into account, and low and even zero cost actions should be started immediately.

Two aspects related to the topic deserve investigation. First, instead of decomposing only CO2 emissions, all GHGs can be included. As sectoral GHG emissions provided in the Eora database did not match actual emissions well, but CO2 emissions were very consistent with actual CO2 emissions, this gas was selected for our study. Second, analyzing import and export emissions trends and the factors behind these emissions will increase our knowledge on this subject. Such an analysis requires different methodological choices than adopted in our study.

Notes

1 Annex 1 Parties submit their Biennial Reports (BRs) to the UNFCCC Secretariat every 2 years, and the Fourth BR should be submitted by 1 January 2020.

2 Annex 1 Parties submit their National Communications (NCs) to the UNFCCC Secretariat every four years and the Seventh NC should be submitted by 1 January 2018.

3 Figure 1 panel a) UMI, HI, EU, China, USA graphs use values on left y axis; Turkey, Russia, India graphs use values on right y axis; panel (c) Agriculture and Waste sectors CO2 emissions bars cannot be seen because of their relatively low emissions.

4 Methods for understanding driving forces behind an aggregate indicator are decomposition analysis and econometric techniques. Decomposition analysis provides better understanding of systems and dominates this literature. It distributes a change in an indicator into its components. The main decomposition methods are index decomposition analysis (IDA) and structural decomposition analysis (SDA). IDA relates a change on an aggregate to activity level (of an industry), SDA relates to input output model (whole economic system). IDA is flexible in formulation but covers only the direct effects. SDA is more data intensive and observes direct and indirect demand effects which defines that demand change in one sector indirectly lets changes in demand of others. Production-theoretical approach (PDA) is another decomposition method based on production theory, which is named as such and proposed for energy or environment related decompositions in Zhou and Ang (2008). Data requirements are even lower than IDA. Zhou and Ang (2008) provide a comparison between PDA, IDA and SDA. Econometric studies can also be used to identify the drivers based on the IPAT identity of Ehrlich and Holdren (1971) and its subsequent modifications, especially, STIRPAT. However, by construction these models are also aggregate in nature and cannot provide the rich sectoral detail SDA analysis can.

5 Energy intensity is a factor generally used in studies employing IDAs and defines energy consumption per GDP.

6 U: Use matrix (input matrix) purchases of commodities by industries (nxn); V: Make matrix (output matrix) output of commodities that are produced by industries (nxn); x: total industry output (nx1); q: total commodity output (nx1); e: commodity final demand (nx1); E: export from commodity accounts to "one" country (nx1); E_ROW1: export from industry accounts to rest of world (ROW) (nx1); E_ROW2: export from commodity accounts to ROW (nx1); M: import to industry accounts from "one" country (1xn); M_fin.: import to final demand accounts from "one" country (1x1); M_ROW1: import to industry accounts from ROW (1xn); M_ROW2: import to commodity accounts from ROW (1xn); for detailed information about these matrices and vectors check Appendix B

7 The first nine sectors with highest emissions were included separately and the remaining fourteen sectors were aggregated and titled "Aggregated Others". CO2 emissions from 23 sectors are given in Appendix C.

8 For laws go to https://cygm.csb.gov.tr/kanunlar-i-438; for regulations go to https://cygm.csb.gov.tr/yonetmelikler-i-440; for circulars go to https://cygm.csb.gov.tr/tebligler-i-441; for communiqués go to https://cygm.csb.gov.tr/genelgeler-i-442

9 For National Strategy for Climate Change (NCCS) (2010-2020), National Climate Change Adaptation Strategy and Action Plan, National Climate Change Action Plan (NCCAP) go to http://www.dsi.gov.tr/docs/iklim-degisikligi/

10 For The Energy Efficiency Law No. 5627 go to https://www.resmigazete.gov.tr/eskiler/2007/05/20070502-2.htm; for National Renewable Energy Action Plan (NREAP) 2017-2023 go to https://www.resmigazete.gov.tr/eskiler/2018/01/20180102M1-1-1.pdf; Energy Efficiency Strategy Paper 2012-2023 and National Energy Efficiency Action Plan (NEEAP) 2017-2023 go to http://www.yegm.gov.tr;

for Electric Energy Market and Security of Supply Strategy Paper go to https://www.eigm.gov.tr

11 The first nine sectors contributing to CO2 emissions increase were given separately and the remaining fourteen were aggregated and titled “Aggregated Others”. Decomposition results for 23 sectors are given in Appendix C.

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Is Production or Consumption the Determiner? Sources of Turkey's CO2 Emissions between 1991-2015 and Policy Implications

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Appendix A

Sectors in SUTs	**Aggregated sectors**
Products of agriculture, hunting and related services	
Products of forestry, logging and related services	AGRICULTURE
Fish and other fishing products; services incidental of fishing	
Coal and lignite; peat	MINING OF COAL
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	EXTRACTION OF PETROLEUM AND NATURAL GAS
Uranium and thorium ores	
Metal ores	MINING
Other mining and quarrying products	
Food products and beverages	FOOD
Tobacco products	
Textiles	
Wearing apparel; furs	TEXTILE
Leather and leather products	
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	
Pulp, paper and paper products	OTHER MANUFACTURING
Printed matter and recorded media	
Furniture; other manufactured goods n.e.c.	

Coke, refined petroleum products and nuclear fuels	COKE, REFINED PETROLEUM PRODUCTS AND NUCLEAR FUELS
Chemicals, chemical products and man-made fibres	CHEMISTRY
Rubber and plastic products	RUBBER AND PLASTIC
Other non-metallic mineral products	MINERAL
Basic metals Fabricated metal products, except machinery and equipment	METAL
Machinery and equipment n.e.c. Office machinery and computers Electrical machinery and apparatus n.e.c. Radio, television and communication equipment and apparatus Medical, precision and optical instruments, watches and clocks	MACHINERY AND EQUIPMENT
Motor vehicles, trailers and semi-trailers Other transport equipment	AUTOMOTIVE
Secondary raw materials	RECYCLING
Electrical energy, gas, steam and hot water	ELECTRICITY
Collected and purified water, distribution services of water Public administration and defence services; compulsory social security services Education services Health and social work services	PUBLIC SERVICE
Construction work	CONSTRUCTION
Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel Wholesale trade and commission trade services, except of motor vehicles and motorcycles Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	SERVICE

Hotel and restaurant services	
Supporting and auxiliary transport services; travel agency services	
Post and telecommunication services	
Financial intermediation services, except insurance and pension funding services	
Insurance and pension funding services, except compulsory social security services	
Services auxiliary to financial intermediation	
Real estate services	
Renting services of machinery and equipment without operator and of personal and household goods	
Computer and related services	
Research and development services	
Other business services	
Membership organisation services n.e.c.	
Recreational, cultural and sporting services	
Other services	
Private households with employed persons	
Land transport; transport via pipeline services	LAND TRANSPORT
Water transport services	WATER TRANSPORT
Air transport services	AIR TRANSPORT
Sewage and refuse disposal services, sanitation and similar services	WASTE

Appendix B

Constructing IO Multiplier Equation from SUT Table Format

Our data is in the form of SUT, and Leontief inverse matrix, L, and final demand vector, f, are not the same with the ordinary IO multiplier equation and should be extracted from the SUT table. SUT is in a commodity-industry format which allows accounting for the fact that an industry may produce more than one commodity (product). This is a major reason for the implementation of the commodity-industry accounting system - the explicit consideration of non-characteristic production, such as secondary products and by-products. SUT accounts lead to input–output models that have more complicated structures than ordinary IO accounts. The basic observation is that “industries use commodities to make commodities”. The Eora database SUT for Turkey denotes commodities and industries with i and j, and assumes the number of commodities and the number of industries is the same, and denoted by n.

In the SUT, technology matrix (A) and final demand vector (f) in the ordinary IO multiplier equation (equation (1)) are computed in a different way. In the SUT, the interindustry transactions matrix, Z, is initially replaced by the Use matrix (nxn), $\mathrm{U} = [\mathrm{u_{ij}}]$, where u_{ij} is the value of purchases of commodity i by industry j. Thus the “industries use commodities” part of “industries use commodities to make commodities” is quantified in U. (U is sometimes called the absorption or input matrix.) In conjunction with total industry output of sector j, x_j, the parallel to ordinary technical coefficients, a_{ij}, would appear to be:

$$\mathrm{b_{ij}} = \frac{\mathrm{u_{ij}}}{\mathrm{x_j}}$$

or

$$\mathrm{B} = \mathrm{U}\hat{\mathrm{x}}^{-1} \qquad (\mathrm{B.1})$$

in which column j represents the value of inputs of each commodity per dollar worth of industry j’s output. The dimensions of B are therefore commodities-by-industries.

The make matrix showing how industries make commodities is termed the Make matrix, usually denoted V (nxn) (it is also called the output matrix). An element of V, v_{ij}, shows the value of the output of commodity j that is produced by industry i. (Thus, the dimensions of V are industries-by-commodities.)

In the ordinary input–output model, only total industry output (x) is calculated but in the commodity–industry framework, both total industry output (x) and total commodity output (q) (nx1) are accounted for. From the data in the Make matrix, total output of any industry is found by summing over all commodities produced by that industry. These totals are the row sums of V,

$$\mathrm{x_j} = \mathrm{v_{j1}} + \cdots + \mathrm{v_{jn}} \qquad (\mathrm{B.2})$$

or

$$x = V\iota \qquad (B.3)$$

where, ι is used to represent a column vector of 1's with a dimension of n and creates a column vector whose elements are the row sums of V. when transpose of ι (ι ') is used, it represents a row vector of 1's, and pre-multiplication of a matrix by ι ' creates a row vector whose elements are the column sums of the matrix. Similarly, total output of any commodity can be found by summing over all industries that produce the commodity. These totals are the column sums of V (or the row sums of V'),

$$q_j = v_{1j} + \cdots + v_{nj} \quad \text{and} \quad q' = \iota' V \qquad (B.4)$$

or

$$q = (V')\iota \qquad (B.5)$$

Alternatively,

$$q_j = u_{j1} + \cdots + u_{jn} + e_j \qquad (B.6)$$

or

$$q = U\,\iota + e \qquad (B.7)$$

where e represents the final demand vector (nx1) in SUT tables.

In conjunction with the Leontief inverse (total requirements) matrix, industry outputs necessary to sustain the final demand are determined. The commodity–industry approach uses (B.7) and (B.1), and from (B.1), $U = B\hat{x}$, and substituting into (B.7) gives:

$$q = Bx + e \qquad (B.8)$$

The problem is that, one cannot generate a total requirements matrix, because (B.8) contains commodity output (q) on the left-hand side and industry output (x) on the right-hand side. One solution to this problem in (B.8) is to find an expression transforming industry outputs, x, to commodity outputs, q, or, alternatively, to transform commodity outputs (and commodity final demand, e) into industry terms.

When transforming a SUT to an IO, there are two approaches to solve the non-characteristic production problem that refers to an industry may produce more than one commodity. *Commodity technology* assumes that "a given commodity should have the same input structure in all of the industries that produce it". However, in SDA analysis, the approach must be the *industry technology* assuming that "a given commodity can have differing input structures if it is produced by more than one industry". Thus, this study follows the latter solution to obtain total requirements matrix and technology matrix, and does not include commodity technology solution at all. The data needed for such transformations are to be found in the Make matrix, whose row sums are industry outputs and whose column sums are commodity outputs.

Industry Source of Commodity Outputs Define $d_{ij} = v_{ij}/q_j$ (each element in column j of V is divided by the jth column sum, qj), so that dij denotes the fraction of total commodity j output that was produced by industry i. Forming a matrix of these commodity output proportions:

$$D = V\hat{q}^{-1} \qquad (B.9)$$

Using (B.9),

$$D = V(\hat{q})^{-1} \;\; \rightarrow \;\; D\hat{q} = V \;\; \rightarrow \;\; D\hat{q}\,\iota = V\,\iota$$

and from (B.3)

$$Dq = x \qquad (B.10)$$

so

$$q = D^{-1}x \qquad (B.11)$$

provided that D (nxn) is square and nonsingular.

A compact statement of the results in (B.8) and (B.10) is: from (B.10), x – Dq = 0, and from (B.8), again, −Bx + q = e. This pair of relationships in x and q can be represented in partitioned matrix form as

$$\begin{bmatrix} I & -D \\ -B & I \end{bmatrix} \begin{bmatrix} x \\ q \end{bmatrix} = \begin{bmatrix} 0 \\ e \end{bmatrix}$$

One solution to the dilemma posed by the presence of both x and q in (B.8) is provided by (B.10). Substitute Dq for x in (B.8),

$$q = B(Dq) + e = (BD)q + e$$

from which

$$q = (I - BD)^{-1}e \qquad (B.12)$$

The inverse on the right-hand side, which is called a commodity-by-commodity total requirements matrix, connects commodity final demand to commodity output. It thus plays the role of $(I–A)^{-1}$ in the ordinary input-output model. It is to be noted that the "parallel" to the A matrix (direct input requirements) in the ordinary model appears now to be BD [and not simply B alone, as seemed initially the case when B was defined in (B.1)].

Using (B.12), and since Dq = x,

$$x = [D(I - BD)^{-1}]e \qquad (B.13)$$

The bracketed matrix on the right connects commodity final demand to industry output. It is an industry-by-commodity total requirements matrix.

There are alternative possible expressions for total requirements matrices. For example, premultiplying both sides of (B.8) by D gives, since Dq = x,

$$x = DBx + De$$

and

$$x = [(I - DB)^{-1}D]e \qquad (B.14)$$

so the bracketed expression on the right-hand side is also an industry-by-commodity total requirements matrix.

Results for total requirements matrices, (B.12) and (B.13), are collected together in Table B.1 Since in each case the exogenous force driving the model is final demand for commodities, these are called commodity-demand driven models.

Table B.1: Total requirements matrices, commodity-demand driven models

	industry technology
commodity-by-commodity	$(I - B D)^{-1}$
industry-by-commodity	$[D (I - B D)^{-1}]$

These total requirements matrices have exactly the same structure as the Leontief inverse in the original input–output model – namely, the inverse of a matrix containing technical coefficients subtracted from an identity matrix.

It is also possible to derive total requirements matrices for industry-demand driven models, replacing “e” by an equivalent expression involving “f” in appropriate equations. For industry technology models, in which Dq = x, the assumption can be made that the same commodity-to-industry transformation is valid for final demands, that is, De = f . For example, from (B.14), since De = f , $x = (I - DB)^{-1} f$ and, using $q = D^{-1} x$, we have $q = D^{-1} (I-DB)^{-1} f$. The latter is the only industry technology result that requires D^{-1}. These are collected together in Table B.2. The commodity-by-industry result (second row) is included in Table B.2 primarily for completeness – they are of little practical use. The industry-by-industry case (first row) is useful principally for SDA analysis.

Table B.2: Total requirements matrices, industry-demand driven models

	industry technology
industry-by-industry	$(I - D B)^{-1}$
commodity-by-industry	$[D^{-1} (I - D B)^{-1}]$

As a result, we should change technology matrix (A) and final demand vector (f) in the ordinary IO multiplier equation (5) with $(I - D B)^{-1}$ and D e, respectively. So the IO multiplier equation for SUT table becomes:

$$x = (I - DB)^{-1}D\ e \qquad (B.15)$$

In our SDA formula (equation (3)), that gives the change in CO2 emissions, L matrix can be obtained by calculating $(I - DB)^{-1}$ from the SUT table, and final demand vector, f, which is decomposed to f_d, f_e, f_p can be obtained by calculating D e from the SUT table.

Appendix C

Table C.1: CO2 Emissions of Turkey, USA, EU, China, Upper-Middle and High Income Countries (Production-Based Accounting-PBA) (Data of Figure 1 panel a)

	1990	1991	1992	1993	1994	1995	1996
UMI	11609157	11533416	11102093	11107388	11120233	11520509	11738535
HI	15183349	15641306	15234695	15351704	15579172	15759028	16176244
Turkey	214000	221000	227000	235000	229000	244000	262000
EU	4819910	4721890	4567190	4488490	4465130	4529660	4617560
China	3480000	3620000	3750000	3920000	4170000	4520000	4700000
USA	6390000	6330000	6440000	6550000	6650000	6730000	6920000
Russia	3630000	3440000	2900000	2710000	2410000	2360000	2300000
India	1080000	1130000	1180000	1210000	1260000	1320000	1390000

	1997	1998	1999	2000	2001	2002	2003
UMI	11691107	11592144	11697654	11952856	12190910	12709888	13781924
HI	16224981	16192368	16264806	16647424	16599612	16677150	16897606
Turkey	274000	276000	274000	295000	275000	281000	301000
EU	4539320	4499560	4414440	4423400	4488550	4463350	4533060
China	4690000	4540000	4620000	4740000	4840000	5260000	6030000
USA	6980000	7040000	7080000	7230000	7120000	7150000	7190000
Russia	2180000	2160000	2180000	2180000	2240000	2240000	2310000
India	1430000	1460000	1530000	1560000	1550000	1550000	1600000

	2004	2005	2006	2007	2008	2009	2010
UMI	14841730	15799242	16777511	17433470	18234167	18538594	19780716

HI	17161423	17186829	17178152	17307574	16991315	16126994	16681399
Turkey	313000	334000	359000	390000	389000	396000	401000
EU	4541010	4508460	4505220	4471820	4369680	4051250	4145550
China	6830000	7580000	8320000	8850000	9440000	9910000	10800000
USA	7320000	7320000	7250000	7340000	7120000	6670000	6890000
Russia	2360000	2380000	2450000	2450000	2480000	2360000	2480000
India	1660000	1720000	1790000	1890000	2030000	2190000	2170000

	2011	**2012**	**2013**	**2014**	**2015**
UMI	20909244	21411635	21503399	21759034	21809652
HI	16479948	16342783	16444891	16379138	16328260
Turkey	431000	445000	438000	451000	470000
EU	4036220	3954670	3873580	3743080	3790640
China	11800000	12100000	12200000	12300000	12300000
USA	6740000	6500000	6670000	6720000	6590000
Russia	2540000	2580000	2510000	2510000	2520000
India	2280000	2430000	2430000	2630000	2690000

Table C.2: GHG Emissions by sectors in Turkey, 1990-2015 (Data of Figure 1 panel b)

	Energy	Industrial	Agriculture	Waste
1990	134400	23700	44800	11100
1995	163500	27300	43400	12400
2000	211700	27800	42500	14500
2005	241000	35900	43300	16900
2010	292100	51000	45800	18200
2015	340000	60700	57400	16900

Table C.3: CO2 Emissions by Sectors in Turkey, 1990-2015 (Data of Figure 1 panel c)

	1990	1995	2000	2005	2010	2015
Energy	125801	155299	201534	230776	276856	330280
Industry	21907	25667	25544	32544	44550	52336
Agriculture	460	426	617	613	645	811
Waste	27	27	23	8	6	1
Total	148195	181419	227719	263941	322057	383427

Table C.4: CO2 emissions from 23 sectors, 1991-2015

	1990	**1995**	**2000**	**2005**	**2010**	**2015**
Electricity	46135	57280	76081	91730	143119	165,969
Land transport	30400	37661	37059	37859	52089	60,405
Mineral	15039	17818	18775	24333	28112	32,600
Coke, petroleum, nuclear	6641	7259	7783	7283	9542	11,066
Textile	8454	8075	14809	13293	9079	10,529
Food	8056	7160	13392	11830	7991	9,267
Service	3903	4483	4708	6170	7883	9,142
Water transport	3408	4164	5413	6426	7845	9,097
Air transport	2938	5556	6167	6739	7076	8,205
Construction	5670	5255	7970	7433	5386	6,246
Metal	4151	4381	6881	6268	5236	6,072
Machinery and Equipment	3651	3722	6663	6087	4406	5,109
Chemistry	4180	4303	5909	5676	4285	4,969
Other manufacturing	2870	2858	5246	4824	3488	4,045
Mining of coal	3218	2734	2772	2652	3057	3,545
Agriculture	1880	1781	2109	2514	2845	3,300
Automotive	1758	1918	3867	3498	2520	2,923
Public service	876	979	904	1536	2186	2,535
Rubber and plastic	1100	1154	2149	1941	1390	1,612
Mining	256	236	403	374	289	335

Extraction of petroleum and natural gas	86	198	319	62	60	69
Waste	35	26	12	39	53	61
Recycling	46	35	45	53	47	55

Table C.5: Sectors' contributions to CO2 emissions

	1990-1995	1995-2000	2000-2005	2005-2010	2010-2015	Total
Electricity	11145	18801	15649	51389	22850	**119834**
Land transport	7261	-602	800	14230	8316	**30005**
Mineral	2779	957	5558	3779	4488	**17561**
Water transport	756	1248	1014	1418	1252	**5689**
Air transport	2617	611	571	337	1130	**5267**
Service	580	225	1461	1714	1259	**5239**
Coke, petroleum, nuclear	618	524	-500	2259	1523	**4424**
Textile	-379	6734	-1515	-4214	1450	**2075**
Metal	230	2500	-613	-1032	836	**1921**
Public service	103	-74	632	650	349	**1660**
Machinery and equipment	71	2941	-576	-1682	703	**1458**
Agriculture	-99	328	405	331	454	**1420**
Food	-896	6233	-1562	-3839	1276	**1211**
Other manufacturing	-12	2388	-422	-1336	557	**1175**
Automotive	160	1949	-369	-978	402	**1165**
Chemistry	124	1606	-234	-1391	684	**789**
Construction	-415	2715	-537	-2046	860	**577**
Rubber and plastic	54	994	-208	-551	222	**512**
Mining of coal	-484	38	-120	405	488	**327**
Mining	-20	167	-29	-85	46	**79**
Waste	-9	-14	27	14	8	**26**
Recycling	-12	10	7	-5	8	**9**
Extraction of petroleum and natural gas	113	120	-256	-3	10	**-16**